Results of Crop Improvement and Management Research for 2019/2020

Part II

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Ethiopian Institute of Agricultural Research

Results of Crop Improvement and Management Research for 2019/2020

Part II

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Foreword

Agriculture plays significant role in Ethiopia economy. The sector is a major source of food for the increasing human population, feed for the livestock resource and export earnings, among others. The country is endowed with huge crop genetic recourses that would be useful for tapping genes for genetic improvement and has long tradition of practicing crop production. Several biotic and abiotic factors constrain crop production and productivity. In addition, introduction of new pest is threatening production of a number of crops.

The agricultural development policies of Ethiopia aims at increasing the production and productivity of crops and secure the food demand of the country, produce export commodities to foreign currency earning, and the sector is also expected to produce raw materials for the growing industries. In the past decade agricultural productivity has shown an increasing trend. The productivity increment is related to the increasing use of improved technologies such as improved crop varieties and crop management practices. However, the growth has not been commensurate with the growing population and there is still considerable gap between food demand and supply. A number of factors are contributing for the discrepancy, of which access to improved technologies and lack integration of the different actors along the value chain are the major challenges to transformation in the sector.

The Ethiopian Agricultural Research Institute (EIAR) has been undertaking research on selected nationally important crops contributing for food security and high value crops for export. The institute is mandated to develop improved agricultural technologies, create demand through demonstration of the same and provide early generation seed and planting materials for seed growers. The institute is collaborating with regional research institutes and higher education institutions within the country and with international research and academic institutions.

The crop directorate is one of the sectors in the institute undertaking research projects aimed at generating appropriate technologies for the diverse agro-ecologies on field crops, horticultural crops, coffee and tea, root and tubers, medicinal and aromatic crops. The research also targeted at generating information that could be packed with the improved varieties and management practices to be delivered to end users and also used for future research and development endeavors. The institute envisions to enhance the capacity of its research programs to implement targeted research works aligned with the national agricultural development polices. The use of advanced technologies such as molecular markers and techniques that would help to fast truck the generation of improved technologies are deemed to have importance to attain better genetic gain for the economically important crops. In partnership with our collaborators efforts will also be made to address the growing demand for agricultural technologies through enhancing the capacity of the research system.

These proceedings are the result of the past three years of crop research undertaken by the various crop research programs. The compilation of the results of the completed crop research activities is aimed at documenting the technologies and information generated so that they will be accessible to users. I would like to congratulate the authors and editors for their dedication and contribution to compile the papers included in the document.

Diriba Geleti (PhD)
DDG, EIAR

Preface

Agriculture is the backbone of Ethiopian economy contributing for food self-sufficiency, foreign currency earning, supplying raw materials for the emerging agro-processing industries while conserving the ecosystem for sustainable use. In alignment the government policy to transform the agriculture sector the research system has been playing the leading role in generating improved technologies, creating demand for the technologies and supplying start up technologies for targeted beneficiaries. The Ethiopian Institute of Agricultural research has mad the major contribution and has generated 60% of the improved crop varieties and are among the widely used technologies across regions. In the past two decades agricultural productivity has shown an increasing trend by 5.8% while the global average increment was 1.4%. The increasing use of improved technologies specifically the use of improved varieties has played a pivotal role in the increasing productivity and production. In comparison to the research potential and in some case under well managed on farm condition the national average productivity is, however, lower by half. This needs additional efforts for the extension and seed system to reach out wider users and optimize the use improved packages.

The gap between demand and supply on agricultural products remains to be a challenge for the sector to feed the increasing human population and contribution for the economic growth. The crop research directorate is being undertaking research to generate technologies resilient to the changing environments while supporting the development endeavors to create access for the improved technologies. In this regard, a ten years strategy has designed to increase the genetic gain through breeding by 1.5% per annum, and double productivity of the major food security and other economically important crops. In order to achieve these targets modernization of the breeding program in a way of addressing the customer demand while implementing advanced techniques have been given more emphasis. It is thus vital to expand these efforts to have efficient system to address the eminent challenges in the agriculture sector.

This proceeding is the result of the past three years research undertakings of the national programs. In the execution of the research activities the federal and regional research canters and some of the universities have been participated. In this proceeding the major results of the completed research activities of the 2019/20 crop season were published with aim of sharing the major outputs of the research undertakings for our beneficiaries and document the research experiences for future reference in the research system. The institute has registered 36 varsities on 22 different crops for use.

The published papers have passed a two stage review by assigned senior researchers in the respective disciplines and editors who have compiled the proceeding. The papers included in this proceeding were selected based on the contributions to generate appropriate technologies for users, scientific merits and contribution for advancement of scientific research in the country. The proceeding published in two volumes and contained a total of 74 papers on field crops and horticultural crops plant, agronomy, on farm demonstration of improved technologies and post-harvest related issues. The papers organized into different sections as field crops, horticulture, root and tubers, spices and coffee and tea crops. The respective program coordinators and the team members have exerted maximum efforts in execution of the research activities and were participated in writing and reviewing the papers at program level. The authors are recognized for the implementation of the research activities and their commitment in writing the papers as per the standard set initially and incorporation of the comments given by the reviewers for the betterment of the quality of the papers. The contribution of the senior researchers across canters in reviewing the papers was immense and I would like to thank those who have been involved in the review and edition process. The final edition was done by W/o Elizabeth Baslyos and would like extend my thanks for the support and efforts to make the proceeding to the standard. I believe that the papers contained in this document would provide useful information for the scientific community and for other end users.

The Editors

Evaluation of Coffee Tree Productive Center Performance to Cycle Conversion at Jimma and Gera

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Abstract

An experiment was conducted to determine the coffee cycle change period in medium and higher agro-ecologies of Jimma and Gera Agricultural Research Center with the objective of identifying coffee tree exhaustion period and indicator parameters to implement the first cycle change period of coffee cultivars. The experiment was super imposed on compact and open varieties with four tree management treatments, which are single stem topped, multiple stem topped, multiple stem un-topped and free growth training and pruning practices, using randomized complete block design with three replications on trees that stayed in the field for fifteen years. In addition to yield this experiment evaluated the raw and cup quality. Results of this study revealed that coffee yield response oscillated for both compact and open varieties at both locations after giving one or two optimum crop across all coffee tree management practices. The overall average crop yield for the last 12 cropping years for all tree management practice were in between 1450 kg/ha to 2450 kg/ha. Four indicator parameters, dead, non-bearing, bearing and new branches are identified to evaluate the coffee tree productive center. Results of evaluation of exhaustion of coffee tree productive center revealed that dead branch part reached at 61% to 75%, the non-bearing branch 3% to 6%, the bearing portion 17% to 28% and the new and future potential branch part 2% to 4% after fifteen years. There is a significant variation on some of the quality parameters among varieties and coffee tree management practices, the raw quality of coffee showed maximum amount of coffee beans under screen no. 16 which is about 55% of the sample coffee bean was medium size. Fewer amounts of coffee beans found from screen no. 20 which is the very large bean size accounted for 1.55% of the total sample. Therefore, coffee trees became exhausted after15 years at medium and higher altitude agro-ecologies like Jimma and Gera, and coffee tree can be more productive only for 12 cropping years if all nursery and field level management practice are intensively applied. As the coffee tree gets older the size of the beans became smaller due to the exhaustion of the source to the sink relationship. In general, when the coffee tree became unproductive up to 70% cycle change is crucial.

Introduction

Coffee producing countries follow a systematic way of tree management and sustenance of life span of coffee trees. This requires knowledge and skill of application and management of coffee tree (Mulugeta, 2009) and time to carrying out those management practices as well. The life span of coffee trees depend on agro-ecologies, management on the field, and other physiological disorder like branch die back, disease, pest, drought and other external factors (Paulos, 1994;

Anteneh *et al.*. 2008; Endale *et al,*. 2008). According to Yacob *et al.* (1996) coffee tree exhausts due to aging, unregulated tree growth and population density, heavy overhead shade, and rugged and undulating topography and associated factors such as soil erosion. Such factors contributes for low yield productivity of coffee in Ethiopia. In most cases, cycle change is practiced when the coffee yields are below the critical level at a given location.

Rejuvenation or cycle change is one of the many versions of coffee pruning methods. It is generally defined as the cutting of vertical stems of old trees to bring old non-bearing coffee trees to profitable production through improved yields, cherry quality, more uniform flower development and cherry maturity. The purpose of rejuvenation is not only to rehabilitate uneconomical coffee trees to obtain more yields from the worn out of old coffee farms, but also as genetic conservation practice (Paulose Dubale, 1977).

Coffee farmers are reluctant to stump their coffee trees due to the reason that old coffee stumping technology is relatively labor intensive activity and risks of loss of production for more than two years until the new suckers emerge, grow and reached production stage (Mulugeta, 2009). The second reason is that, farmers are discouraged due the damage of the newly growing suckers by cattle because of the free grazing system of most coffee areas (Alemseged, 2017).

There are various methods of old coffee tree rehabilitation. The major rehabilitation method is clean stumping. Clean stumping should be carried out soon after harvesting of the previous crop completed. This will counter the temptation to leave the old stem which might have flowered or budded and shown some crop potential. It is a widely accepted practice for revitalizing coffee farms and has been found to be more advantageous than replanting when the coffee trees is healthy and having enough population stands at the field.

On the other hand, there is a prevalence of coffee wilt disease, and to control or minimize dissemination of this disease it is better that every coffee grower know how to protect the disease during stumping, which brings wounding in coffee trees. This practice should be done with properly disinfected tools to protect the spread of coffee wilt disease (Girma *et al.,* 1997).

In Ethiopia, rejuvenation or cycle change is done on the willingness of the individual farmers or producers. Up till now, there is no enough information when to implement a cycle change across different agro-ecologies. Besides, the indictors' parameters to be considered in a coffee tree is going to the next life cycle is not known. Therefore, it is imperative to study and determine the cycle change period as a way of alleviating decline of production due to age of coffee trees.

Objective

- To determine and implement the first cycle change period of different types of improved coffee cultivars

- To identify coffee tree exhaustion indicator parameters to be consider as an uneconomical tree.

Materials and Methods

The experiment was super imposed on compact and open coffee varieties with four tree management treatments, which are single stem topped, multiple stem topped, multiple stem untopped and free growth training and pruning practices using randomized complete block design with three replications which stayed at the field for fifteen years at Jimma and Gera Agricultural Research Center. In addition to coffee yield, the tree productive center was evaluated based on cropping and non-cropping branches zone and other major yield components, i.e., new, bearing, non-bearing and dead branch. The newly bearing heads contribution to yield also considered during the study period. Raw and cup quality of coffee also evaluated at Jimma Agricultural Research Center quality laboratory. The process of determining coffee bean size, or grading, is done by passing unroasted beans through perforated containers, or sieves. All the data were analyzed using SAS program version 9.2 (SAS, 2008).

Result and Discussion

Across all coffee tree management practices, coffee yield response oscillated after giving one or two optimum crop at both locations, but yield variation between cropping years was high at Jimma compared to Gera location on both compact and open varieties. The overall average crop yield for the last 12 years across all tree management practice ranged between 1400- 2453kg/ha (fig.1-4). The mean clean coffee yield of open coffee variety (75227) at Jimma for 12 years ranged from 2184- 2453 kg/ha and also 1417- 1722 kg/ ha for the compact variety (74110). Coffee yield variation between consecutive years is high especially in compact variety than open. Similarly at Gera, the open coffee variety (75227) mean clean coffee yield ranged between 1730- 1865 kg/ha and from 1524-1876kg/ha for the compact variety (74165).

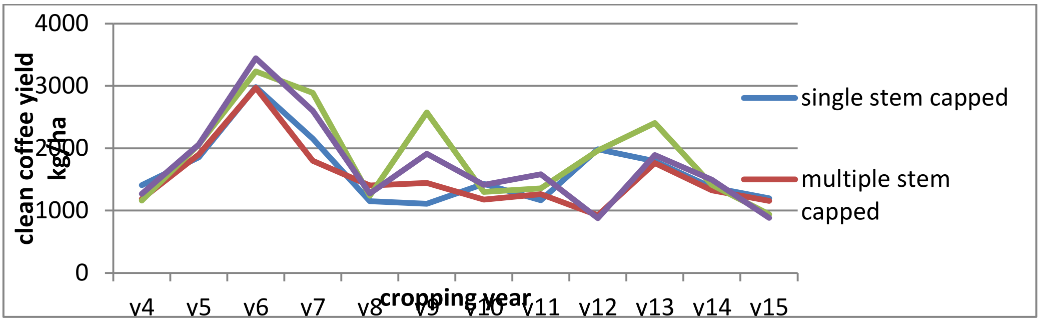

Fig 1. Coffee tree management and yield response trend on compact variety at Gera

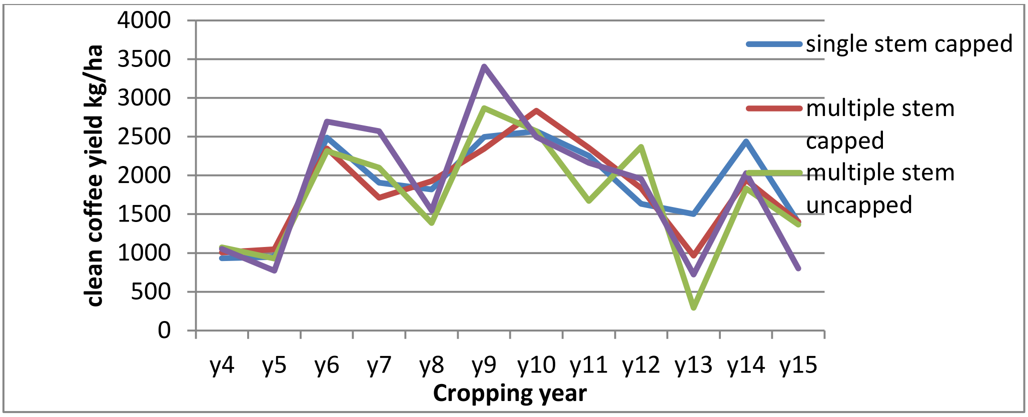

Fig 2. Coffee tree management and yield response trend on open variety at Gera

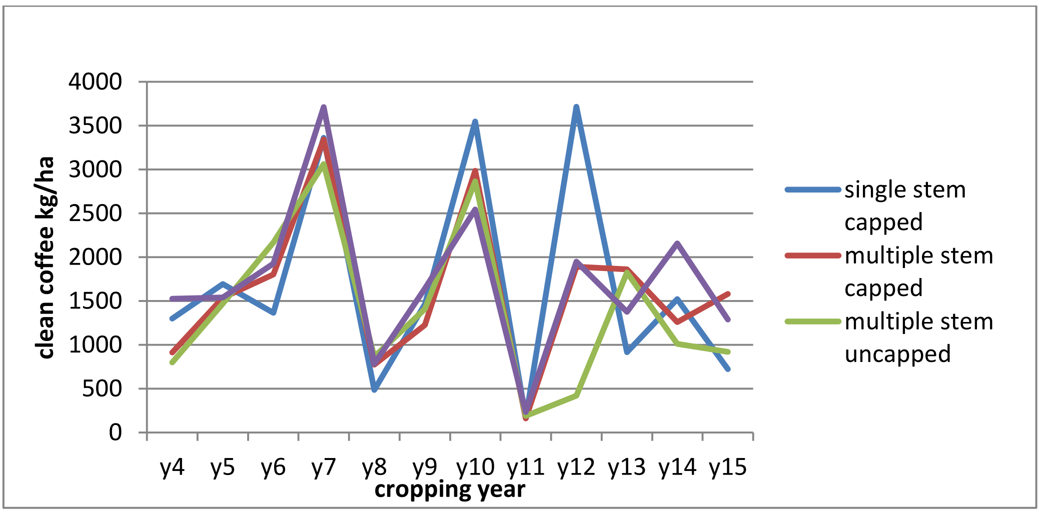

Fig 3. Coffee tree management and yield response trend on compact variety at Jimma

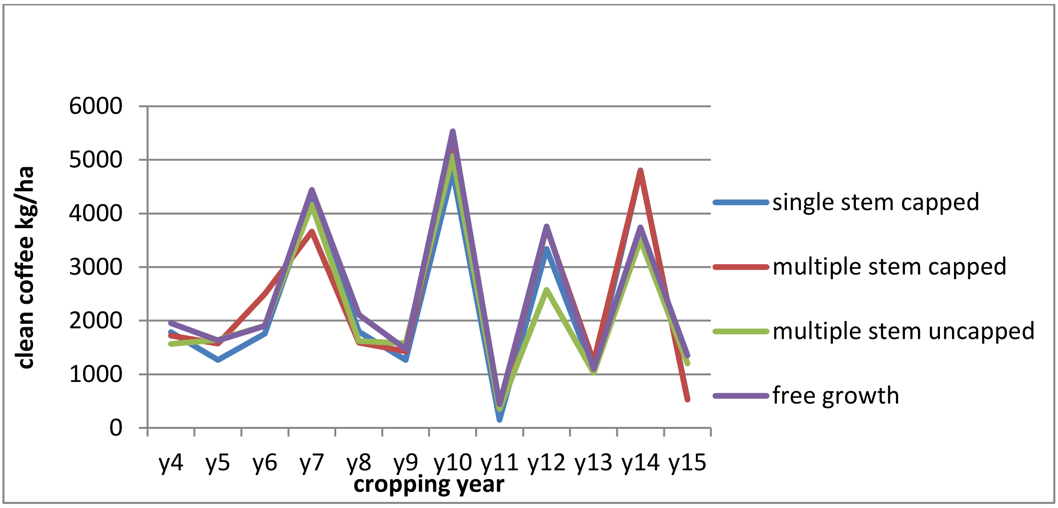

Fig 4. Coffee tree management and yield response trend on open variety at Jimma

Comparing the yield response of the two cultivars in the field, compact varieties is more sensitive to field management such as; shade, water stress, nutrient and seasonal temperature variation than the open varieties especially at medium altitude like Jimma.

Evaluation of exhaustion of coffee tree productive center identified four indicator parameters namely dead, non-bearing, bearing and new branch and grouped in to unproductive (the first two) and potentially productive (the latter two). By considering the indicator parameters at both location across variety mean value, dead branch part reached from 67- 75%, the non-bearing branch 3 -4%, the bearing portion ranged 18 - 25% and the new and future potential branch part ranged 2 -4% at different tree management practices after 15 years (Table 1-4). This indicates that the tree have no more potential bearing portion in the future since the new branch part or future productive zone is almost fewer than 5% in the following crop season's. The bearing portion also became too unproductive zone on the tree for the next cropping season (Table 1-4). Similar to this finding Arcila- Pulgarín *et al*. (2002) and Rena *et al.* (1994) also reported that coffee trees do not produce fruit without new growth, since flower buds are only produced once on specific segments of plagiotropic branches. Hence, if the coffee tree losses about 70% (dead plus non bearing) of the productive center, it fundamentally needs rehabilitation to give new leaves for the life coffee plant.

Table 1. Productive center potential of compact coffee type (75227) after twelve cropping seasons at Gera

Tree management practice	Branch (%)			
	Unproductive		Productive	
	Dead	Non bearing	Bearing	New
Single stem capped	64.12	5.21a	28.01	2.67b
Multiple stem capped	66.84	4.28a	26.0	3.02b
Multiple stem uncapped	70.41	1.47b	23.06	5.07a
Mean value	67.12	3.65	25.69	3.58
LSd (5%)	NS	1.52	NS	1.24
C.V (%)	6.04	18.41	13.68	15.31

Table 2. Productive center potential of compact coffee type (74165) after twelve cropping seasons at Gera

Tree management practice	Branch (%)			
	Unproductive		Productive	
	Dead	Non bearing	Bearing	New
Single stem capped	68.40	2.46b	27.49	1.65b
Multiple stem capped	64.99	5.51a	25.13	4.42a
Multiple stem uncapped	70.24	4.58a	20.05	5.17a
Mean value	67.87	4.18	24.23	3.75
LSD (5%)	NS	1.55	NS	0.87
C.V (%)	2.87	16.38	14.11	10.19

Table 3. Productive center potential of compact coffee type (75227) after twelve cropping seasons at Jimma

Tree management practice	Branch (%)			
	Unproductive		Productive	
	Dead	Non bearing	Bearing	New
Single stem capped	63.22b	3.36b	31.0a	2.42b
Multiple stem capped	72.08a	2.14b	24.02b	1.80c
Multiple stem uncapped	72.74a	5.58a	16.08c	5.66a
Mean value	69.35	3.69	23.7	3.29
LSD (5%)	7.59	174	5.88	0.59
C.V (%)	4.83	20.75	10.94	8.0

Table 4. Productive center potential of compact coffee type (74110) after twelve cropping seasons at Jimma.

Tree management practice	Branch (%)			
	Unproductive		Productive	
	Dead	Non bearing	Bearing	New
Single stem capped	73.78	2.09b	22.18a	1.95b
Multiple stem capped	77.09	2.33b	18.19b	2.52ab
Multiple stem uncapped	73.96	8.52a	14.83c	2.69a
Mean value	74.94	4.31	18.40	2.39
LSD (5%)	NS	1.6	3.16	0.67
C.V (%)	2.19	16.35	7.57	12.26

Due to the nature of free growth, it is separately discussed than to compare with the other tree management. On free growth, the newly emerging suckers or bearing verticals (≥ 6 bearing heads) are more contributing to yield contrary to other training and pruning practices which only depend on the new branches and length of plagiotropic growth. The verticals growing on free growth are described as primary (main stem), secondary and tertiary verticals which grow one on the other. As the age of the coffee tree increase, the contribution of the main stem verticals (primary) decreases slowly and gradually substituted by secondary and tertiary verticals (bearing heads). Secondary verticals are initiated anywhere on the lignified part of the stem, while the tertiary verticals sprout from the chest height to the top part of the secondary vertical where they intercept enough sun light for flower initiation. Mean value of 8 secondary and 17 tertiary and 9 fourth and 2 fifth verticals that have different age were observed on 15 years coffee tree on free growth plot. Therefore, on free growth coffee tree, there are a lot of verticals or bearing heads with different age that can find enough time to sustain the coffee yield as most of the small-scale farmers are applying this practice. However, the contribution of all these verticals to yield is not more than 25% of the coffee tree productive center.

The raw quality of coffee was measured using bean size screener and the result showed maximum amount of coffee beans under screen no 16 which is medium bean size and this accounts for about 55% of the sample coffee bean. The larger bean size is found under screen no.17 and 18 and accounted for about 19%, and the smaller bean size on the screen size no. 14 accounted for about 18% of the total sample. Less amount of sample is counted from screen no. 20 which is the very large bean size and counted 1.55% of the total sample (Table 5). Therefore, as the coffee tree became older, the size of the beans became smaller due to the exhaustion of the source to supply to the sink. According to Vaast P. *et al.,* (2005) tree physiology study, plant age and period of picking all interact to produce the final characteristics of the product. Indeed, it was found that tree age, location of the fruits within the tree (Alemsged *et.al.* 1997.), and fruits-to-leaves ratio had a strong influence on the green beans size and chemical content. However, there is no statistically significant variation on bean size among coffee tree management practice.

Table 5. Mean value of bean size on tree management practice and variety under two contrasting agro ecology

Grade classification	Bean size screen no.	Location and coffee variety (%)				Tree management, Location and variety Mean (%)	Grade Classification, location and variety (%)
		Gera		Jimma			
		74165	75227	74110	75227		
Very large	20	0.51	2.38	0.82	2.07	1.5	1.5
	18	1.97	8.63	1.83	9.47	5.48	
Large							
	17	6.75	16.54	11.26	19.79	13.59	19.06
	16	26.45	31.52	40.6	29.19	31.94	55.16
Medium	15						
		30.03	21.07	24.81	17	23.23	
Small	14	25.99	16.14	15.7	15.82	18.41	18.41
shell	12	7.42	3.03	4.42	5.01	4.97	
	Under screen	0.8	0.28	0.59	0.77	0.61	5.58

At Jimma, most cup quality parameters showed nosignificant difference except shape and make cup total attributes of variety 75227, and acidity and flavor of variety 74110. On the other at Gera, there was no significant difference for almost all cup quality parameters, except cup total attribute of variety 74165. The overall cup total range of the two location and varieties ranged from 77% -88%, which indicate that when coffee tree becoming older the taste of the coffee beans and standard becoming below the specialty level.

Table 6. Quality evaluation of different tree management on 15 years old coffee tree at Jimma and Gera

Location	Vriety	Training and pruning	Shape and make (15%)	Color (15%)	Odor (10%)	Aromatic intensity (5%)	Aromatic quality (5%)	Acidity (10%)	Astringency (5%)	Bitterness (5%)	Body (10%)	Flavor (10%)	Over all cup quality (10%)	Cup total (100%)
Jimma	**75227**	Single stem topped	14a	14.33	10	4.17	4.5	8	4.33	4.33	7.83	8	8	88.67a
		Multiple stem topped	14a	13.67	10	3.83	3.83	7.5	4.17	4.17	7.5	7.5	7.5	83.33b
		Multiple stem untopped	13.33ab	14	9.83	3.83	3.83	7.5	4	4	7.67	7.5	7.56	81.08b
		Free growth	12.67b	13.33	10	3.83	3.67	7.5	4.33	4.33	7.33	7.33	7.5	82.33b
		P≤ (5%)	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*
		CV (%)	2.76	3.41	1.45	7.37	10.1	4.23	6.57	6.57	5.27	3.81	4.45	2.41
		LSD	0.75											4.04
	74110	Single stem topped	13	13	10	4	4.33	7.83a	4.67	4.33	7.67	8a	7.83	85
		Multiple stem topped	13	12.67	10	4.3	4.33	7.83a	4.67	4.43	7.67	8a	7.83	84.77
		Multiple stem untopped	13	13.17	10	3.83	3.67	7.33b	4.17	4.17	7.5	7.5b	7.5	82.17
		Free growth	13	12.83	10	3.83	3.83	7.5b	4	4	7.33	7.33b	7.33	80.67
		P≤(5%)	NS	NS	NS	NS	NS	*	NS	NS	NS	*	NS	NS
		CV (%)	0	2.89	0	9.55	10.1	0.83	13.6	6.31	5.3	1.87	3.28	2.81
		LSD						0.283				0.289		
Gera	**75227**	Single stem topped	13.33	12.83	10	4.33	4.33	7.5	4.33	4.33	7.33	7.33	7.33	83
		Multiple stem topped	13.33	13.17	10	3.67	3.67	7.5	4.6	3.67	7.33	7.33	7.33	81
		Multiple stem untopped	13	12.33	10	4	4	7.5	4.33	4.33	7.17	7.5	7.33	81.5
		Free growth	12.5	12.5	10	4.17	4.33	7.53	4.17	4.17	7.67	7.67	7.67	82.33
		P≤ (5%)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
		CV (%)	3.89	2.7	0	8.5	8.41	6.31	6.57	7.28	8.13	8.13	8.02	3.06
		LSD												
	74165	Single stem topped	12.83	12.5	10	4.33	4.5	8ab	4.67	4.07	7.5	7.67	7.67	84.33a
		Multiple stem topped	12.67	12.17	10	4	4	7.5bc	4	4	7.17	7.5	7.5	80.5ab
		Multiple stem untopped	12.33	12	10	3.83	3.83	6.83c	4	3.67	7.17	6.83	6.93	77.17b
		Free growth	12.33	12.3	10	4.5	4.5	8.5a	4.5	4.5	7.83	8.17	8.16	85.67a
		P≤ (5%)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*
		CV (%)	4.46	3.52	0	10	9.07	5.62	13.87	13.86	5.39	5.95	5.93	3.97
		LSD						0.87						6.495

Conclusion and Recommendation

When the coffee tree gets 15 years old, there is no significant variation in coffee variety and tree management practice for coffee tree exhaustion. The free growth with the newly bearing heads may continue to produce insignificant and low-quality coffee. Losing more than 70% (dead and non-bearing branch) coffee tree productive center invite to rehabilitate the coffee tree. For medium and higher altitude agro-ecology like Jimma and Gera, coffee tree can be more productive only for 12 cropping years after application of intensive management practices starting at nursery and in all cropping year at field level.

As the coffee tree became older up to 15 years, the bean size also became more of medium to small size and cup quality below the specialty standard. In general, the coffee should be rejuvenating after 15 years by considering the first three years of vegetative growth stage and twelve cropping years when progressive yield declines.

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Collection, Evaluation, Characterization and Maintenance of Tepi and its Surroundings Coffee Genetic Resources

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Abstract

Among 124 species, Coffea arabica is the leading species in the world market. Despite the fact that Ethiopia is home land for Arabica coffee and ranks 5th in the world in production, the productivity is still low when compared with its genetic potential. To overcome this problem, yield improvement and other desirable traits using local landrace variety development is prominent. Hence, the present study was implemented with intention of selecting high yielder, disease resistant genotype with other desirable traits for Tepi and its surrounding and to conserve for future breeding work. About 88 coffee accessions were collected from Tepi and its surrounding. These genotypes were established in augmented design with 5 and 6 checks and evaluated for 5 and 4 years at Tepi and Gera, respectively. The collected morphological and yield data were analyzed using SAS version 9.0 and R-software. The accessions showed very highly significant difference ($p<0.001$) in plant height and height up to primary branch at Tepi. Comparison of checks with test accessions revealed the presence of highly significant ($p<0.01$) difference between accessions and checks in plant height, number of primary branch and canopy diameter at Tepi and yield at Gera which indicate the existence of variability. Although there is no significant difference among tested accessions in yield performance at both locations, high yielder accession T-50/2011 exceeded the higher yielding check 7416 by 1206.1 Kgha^{-1} and T- 37/2011 exceed the high yielder check Geisha by 941.89 kgha^{-1} at Gera and Tepi, respectively. About 37 accessions had shown yield range from 1718.8 to 3385.89 Kgha^{-1} at Gera. In general, the result of the present study at both locations implies the possibility of selecting some promising lines for the next breeding program. Accordingly, about 15 lines were selected and promoted to coordinated variety and verification trials based on yield, disease resistance and agronomic traits. The rest of accessions were suggested to be included in to conservation block for future breeding work.

Introduction

Coffee is one of the principal cash crops and trade commodity next to oil crops in the world market. Even though over 124 coffee species identified in the world, only two coffee species *Coffea arabica* L. and *Coffea canephora* P. are dominantly under production (Davis *et al*., 2011). Coffee is exported as raw, roasted, or soluble product to more than 165 countries worldwide providing a livelihood for 125 million people around the world (ICO, 2016).

C. arabica provides 70% of world coffee production when compared with *C. canephora* which is the second most important coffee species in world Coffee production (Stieger *et al.,* 2002) and also has high demand in the world market due to its superior test in quality. The agriculture based Ethiopian economy is highly dependent on Arabica coffee. Hence, around 30 percent of the Ethiopian foreign exchange income comes from this single commodity (Alazar, 2017). Additionally, it provides vital employment opportunities in rural areas and sustains the livelihood of around 16% of Ethiopian population (Davis *et al.*, 2012; ICO, 2016).

Ethiopia is Africa's largest Coffee producer and the world's fifth largest *C. arabica* L. exporter next to Brazil, Vietnam, Colombia and Indonesia (ICO, 2016). C. arabica is grown in wide agro-ecologies of Ethiopia which extends from 560m in the Gambella plain to 2600 m a.s l. in Wollo, Northern Ethiopia (Bayetta, 1986) having different temperature and rainfall; generally known for their different edaphic and climatic condition. This implies the country is rich in coffee genetic diversity in addition to home land for *C. arabica* L. of world's coffee producing countries.

Arabica coffee is produced in large amount within specific agro-ecological zones, over numerous geographical and political boundaries in Ethiopia. These are North Zone (Amhara and Benishangul Gumuz), South West Zone (Wollega, Illubabor, Jimma-Limu, Kafa, Tepi and Bench Maji), Rift Zone (Rift North and Rift South), South East Zone (Sidamo, Yergacheffe, Bale and Central Eastern Highland) and Harar Zone (Arsi, East Harage and West Harage) and recognized as the five main coffee growing Zone areas in Ethiopia (Moat *et al.,* 2017). From these Zones, the main coffee producing areas of Ethiopia are found within the South West and South East (Oromia Region and Southern Nations, Nationalities and Peoples' Region), with modest and minor production in the North (Amhara Region and Benishangul-Gumuz Region, respectively).

The performance of Arabica coffee under these wider agro-ecologies is significantly different across locations; for instance Hararge zone coffee cultivars don not perform very well when grown out of its origin like in south western zone. It may be susceptible to disease and may lose its unique quality due to coffee quality limited to geographical areas. Likewise, when the south western zone cultivar is taken to Hararge zone, its performance seriously affected by climatic condition like drought and other environmental condition in addition to quality blending effect. This has forced coffee breeder to evaluate coffee landrace performance by collection and characterization in order to identify for desirable traits for each location and to release coffee variety of high yielder, disease resistant, insect pest tolerant that maintains its typical quality for that particular area. Thus, the present study was conducted with the intention of collection, evaluation, characterization and maintenance of Tepi and its surroundings coffee genetic resources and to select high yielder and disease resistant promising lines for the next breeding program.

Materials and Methods

Description of studying areas

This study was conducted at Tepi and Gera Agricultural Research Sub-centers. Tepi Agricultural Research Center is located at 611 km south west of Addis Ababa at latitude of 7° 3'0" N and longitude of 35° 18' 0"E. and at an altitude of 1200 meters above sea level. The mean annual rainfall of the area is 1678mm per annum with an average maximum and minimum air temperatures of 30^0C and 16^0C, respectively (Paulos,1994). Gera Research Sub-center is located at 421 Km South west of Addis Ababa and 69 Km far from Jimma town at latitude of $7^{\ 0}$ 7'0"N and longitude of 36^0 00'00"E, and altitude of 1940 m a.s.l. It receive 1878.9mm annual rain fall. Also, it has loam soil type and minimum 10.4°C and maximum 24.4°C temperature (Paulos, 1994).

Experimental planting materials and design

This study was conducted from 2012 to 2019 crop seasons in which 88 *C. arabica* L. accessions collected from Tepi and its surrounding areas and five and six check varieties at Tepi and Gera, respectively were evaluated in augmented design with four blocks and thus each check was replicated in each block. The checks (Geisha, CatimorJ-19, Dessu, 7440 and 7454) included at Tepi are tolerant to coffee leaf rust (CLR), while the checks (7416, 7514, 7576, 7522, 8136 and 741) included at Gera are resistant to Coffee Berry Disease (CBD). Field establishment accessions were at a within plant and between rows spacing of 2m by 2m. The number of plants per plot was 12 at both locations and the spacing between blocks was 4 m. All field management practices such as weeding, shading and fertilizer application were done uniformly as recommended (IAR, 1996).

Data Collection

Five randomly selected plants from each plot were used to record the plant growth parameters including plant height (PH) (cm), height up to first primary branch (HFPB)(cm), total node number of main stem (TNN), internodes length of the main stem (IL)(cm) obtained by computing per tree as (TH-HFPB)/TNN-1, where TH= total plant height, HFPB=height up to first primary branch, diameter of the main stem/or girth (DM) (mm), number of primary branches (NPB), number of bearing primary branches (NBPB) and canopy diameter (CD)(cm) . The total fresh cherry yield was harvested and recorded from all trees in a plot and measured in grams and used to compute mean yield per each tree. The clean coffee bean yield (YLD) in kgha^{-1} was obtained by multiplying the yield of the fresh cherry by percent outturn. Growth parameters and yield data were recorded following the IPGRI descriptor (IPGRI, 1996).

Data Analysis

Quantitative data were subjected to analysis of variance (ANOVA) using SAS version 9.0 (SAS, 2004), R- software and Online analysis of Augmented Designs - V2.0 (Rathore *et al*., 2004; Federer, 1956) to examine the presence of statistical differences among accessions for the characters studied. Least Significant Difference (LSD at P=0.05 and P=0.01) was employed to identify accessions that are significantly different from each other. Analysis of variance for quantitative traits was done using ANOVA model:

$Y_{ij} = \mu + g_i + c_j + \beta_j + \varepsilon_{ij}$ (Federer, 1956).

Where: y_{ij} is the observation of treatment i in j^{th} block, μ is the general mean, g is the effect of test treatment, c_j is the effect of control treatments in j^{th} block, β_j is the block effects, (ε) is the error

Results and Discussions

Analysis of Variance

The treatments had shown highly significant difference ($p<0.01$) in plant height (PH), height up to the first primary branch (HUPB) and inter node length (INL); and significant difference ($p<0.05$) in canopy diameter (CD) at Tepi (Table 1). However, treatments showed non-significant difference in yield (YLD) performance at both locations; and in number of primary branch (NPB), girth and node number (NN) of main stem at Tepi.

The highest plant height was recorded from T-48/2011 followed by T-53/2011, T-50/2011, T-51/2011 and T-75/2011 at Tepi; while T-64/201 showed the lowest height followed by T-02/2011, T-09/2011 and T-86/2011(Table 3). The highest value of plant height of up to first primary branch (89.40cm) was recorded from T-82/2011 and T-68/2011 followed by T-87/2011 and T-14/2011. On the other hands, the longest internodes lengths of main stem diameter were recorded from T-67/2011 followed by T-36/2011. Coffee accessions T-46/2011 and T-45/2011 had shown better performance in canopy diameter. The present results agreed with the finding of Dawit *et al.* (2021) who reported differences in mean yield and agronomic traits performance among coffee accessions at Mugi and Haru locations. Desalegn (2019) also reported variability among 55 coffee genotypes which were collected from southern Ethiopia.

Comparison of performance accessions with the checks indicated the better performance of most of the accessions over that of checks for number of bearing primary branch, plant height and canopy diameter. The highest number of bearing primary branches were recorded by T-50/2011 followed by T-41/2011, T-03/2011and T-14/2011. Plant height (PH), canopy diameter (CD) and number of bearing primary branch (NBP) are traits used as indices for selecting high yielding lines. Several authors revealed the positive genotypic correlation between yield and plant height, canopy diameter and number of primary bearing branch (Lemi *et al.*, 2017; Dawit, 2018 and Masreshaw, 2018). Hence; the present study also confirmed that the high yielder accessions at Tepi had the highest plant height of 300cm to 374cm; height up to the first primary branch of 27.40 cm- 43cm; internodes length of 6.14 cm to 8.67cm; canopy diameter of 152.50cm-217.80cm and number of primary bearing branch of 42 to 66. These performances were better when compared with standard checks.

Table 1. ANOVA of yield and growth parameters for both locations

Traits	Block (adj)	Trt (adj)	Among accessions	Among checks	Checks vs test	Error	CV (%)
Tepi							
YLD	623844ns	113803ns	160276ns	72911ns	13945ns	202348	62.2
PH	134**	642**	590**	1399**	10817***	166	4.2
HUPB	12.2ns	57.6**	61.9***	133***	14.8ns	10.3	8.4
NPB	199**	53.2ns	91.2*	53.3ns	288.7**	29.7	11.5
CD	396ns	301.3*	320*	537.1*	3800**	127.4	6.2
Girth	424.7**	62.9ns	122.6ns	47.7ns	28.5ns	55.8	16.8
NN	16.58 ns	19.79ns	17.37ns	95.63**	18.59ns	13.96	9.08
INL	0.067ns	0.829**	0.64*	5.5***	0.76ns	0.233	7.22
Gera							
YLD	194657ns	443938ns	422019ns	192324ns	3660178**	229612	30

*****-significant difference at 0.05 probability level, ******- highly significant difference at 0.01 probability level, *******-highly significant difference at 0.001 probability level, **ns**- non- significant, CV-Coefficient of variance, YLD- Yield, PH- Plant height, HUPB- Height up to the first primary branch, NPB-Number of primary branch, CD-Canopy diameter, NN-Node number and INL-Inter node length

Accessions did not showed statistically significant difference in yield at both locations, and in girth and node number at Tepi. The difference among accessions for PH and HUPB was highly significant at Tepi. Comparison of checks with accessions showed the presence of highly significant difference in PH, NPB and CD at Tepi; and in yield at Gera. Hence, there is variability among accessions and between accessions and checks. However, non-significant differences were observed in YLD, HUPB, girth, NN and INL between accessions and checks at Tepi. The results of the present study is in accordance with the findings of Dawit *et al.*, (2019) and Masreshaw (2018) who reported significant difference among coffee accessions in PH, NPB, HUPB and CD among different coffee landrace collections at different locations.

Owing to performance differences of coffee genotypes over locations, the yield performance analyses of coffee genotypes were discussed separately at individual location. The yield performance among coffee genotypes is not significantly different at both locations. However, the high yielder accession T-50/2011 exceeded the highest yielding check 7416 by 1206.1 $Kgha^{-1}$ and T- 37/2011 exceeded the high yielder check Geisha by 941.89$Kgha^{-1}$ at Gera and Tepi, respectively (Table 2).

At Gera, out of 88 accessions 37 accessions had shown yield range of 1718.8 to 3385.89 $Kgha^{-1}$ which is recorded by T-19/2011 and T-50/2011 coffee genotypes, respectively (Table 2). These yield performance is greater than yield potential of most standard checks. Accessions T-21/2011, T-38/2011, T-39/2011, T-50/2011, T-53/2011, T-60/2011, T-64/2011, T-67/2011, T-70/2011, T-78/2011 and T-85/2011 performed better than high yielder checks 7416 which produced 2179.82 $Kgha^{-1}$ clean coffee yield.

At Tepi, most accessions performed lower when compared with yield performance at Gera. Seventeen top yielder accessions showed yield performance that ranged from 1039 (T-48/2011) to 1838.07$Kgha^{-1}$ (T-37/2011), which was higher than the standard checks (Table 2). The result of the present study at both locations implies the possibility of selecting some promising lines for for further evaluation of the next breeding program.

Table 2. Mean yield of clean coffee in $Kgha^{-1}$ of top twenty Tepi and its surroundings coffee genetic resources at Tepi (five years mean) and Gera (four years mean).

Tepi			Gera		
No.	**Genotypes**	**Yield $kgha^{-1}$**	**No.**	**Genotypes**	**Yield $kgha^{-1}$**
1	T-37/2011	1838.1	**1**	T-50/2011	3385.9
2	T-38/2011	1731.5	**2**	T-78/2011	3209.1
3	T-43/2011	1681.3	**3**	T-80/2011	2896.2
4	T-40/2011	1663.4	**4**	T-53/2011	2462.0
5	T-42/2011	1572.8	**5**	T-39/2011	2376.5
6	T-36/2011	1563.6	**6**	T-38/2011	2247.2
7	T-22/2011	1560.3	**7**	T-70/2011	2235.6
8	T-41/2011	1440.5	**8**	T-60/2011	2226.3
9	T-51/2011	1432.1	**9**	T-21/2011	2225.3
10	T-21/2011	1369.1	**10**	T-85/2011	2217.9
11	T-16/2011	1357.1	**11**	T-67/2011	2203.9
12	T-35/2011	1276.0	**12**	T-64/2011	2181.3
13	T-17/2011	1192.6	**13**	T-51/2011	2168.3
14	T-24/2011	1132.5	**14**	T-59/2011	2135.1
15	T-39/2011	1101.1	**15**	T-41/2011	2129.2
16	T-04/2011	1054.5	**16**	T-40/2011	2070.6
17	T-48/2011	1039.1	**17**	T-76/2011	2064.5
18	T-01/2011	970.7	**18**	T-69/2011	2040.8
19	T-44/2011	959.3	**19**	T-43/2011	2036.0
20	T-45/2011	946.5	**20**	T-66/2011	2032.9
	Check/s			**Check/s**	
	7440A	640.06		741	2083.90
	7454A	752.34		7416	2179.82
	F-59	584.23		7514	1695.77
	Geisha	896.18		75227	2139.66
	J-19	860.16		7576	1698.97
		722.8		8136	1871.71
	Mean				1598.75
				Mean	
	CD(5%)	**SE(d)**		**CD(5%)**	**SE(d)**
Vi-Vj	1518	696.81		1560	731.95
BiVi-BiVj	1386	636		1444	678
Ci-Cj	693	318		722	339
Ci-Vj	1160	532		1198	562

CD- Critical difference, **SE(d)**- Standard Error of difference, **Ci–Cj**- between two control treatments, **BiVi–BiVj**- between two augmented treatments in the same block, **Vi–Vj**- between two augmented treatments in different blocks, **Ci–Vj**- between control treatment and augmented treatment

Table3. Mean separation among Genotypes of top twenty high yielder Tepi and its surroundings coffee genetic resources for growth parameters at Tepi

No	Genotypes	PH	HUPFB	NN	INL	CD	NPB	Girth
1	T-01/11	303.40	35.60	37.80	7.28	192.00	54.00	76.98
2	T-04/11	288.20	39.00	41.60	6.14	181.80	59.60	43.65
3	T-16/11	315.40	33.60	40.20	7.19	195.10	56.60	45.29
4	T-17/11	318.80	36.80	46.20	6.24	191.30	50.20	45.53
5	T-21/11	323.60	37.20	42.60	6.88	217.50	61.20	53.39
6	T-22/11	330.20	37.80	39.40	7.61	194.60	47.80	50.12
7	T-24/11	330.40	34.80	38.60	7.86	192.60	41.80	41.22
8	T-35/11	307.00	27.40	44.20	6.47	182.80	59.20	48.54
9	T-36/11	314.80	30.40	33.80	8.67	193.50	52.20	56.82
10	T-37/11	288.80	33.60	38.80	6.75	186.40	48.60	47.94
11	T-38/11	323.60	35.60	45.00	6.55	199.10	58.20	55.51
12	T-39/11	310.80	43.00	44.40	6.17	164.90	60.20	55.00
13	T-40/11	280.40	39.00	45.00	5.49	152.80	41.60	45.03
14	T-41/11	300.80	31.60	44.20	6.23	205.60	63.40	60.18
15	T-42/11	319.00	28.60	43.60	6.82	202.00	56.00	53.91
16	T-43/11	317.60	33.40	40.60	7.18	208.80	52.00	56.14
17	T-44/11	316.00	46.80	45.40	6.06	194.60	53.80	47.18
18	T-45/11	294.80	39.00	35.40	7.44	218.70	46.00	48.56
19	T-48/11	374.20	39.20	44.40	7.72	211.30	60.00	54.90
20	T-50/11	365.40	33.60	47.20	7.18	189.50	66.00	57.79
	Checks							
	7440A	300.15	42.40	35.25	7.56	187.48	39.95	44.56
	7454A	292.60	43.45	36.15	7.10	171.08	43.60	47.62
	F-59	298.50	38.00	39.40	6.79	174.05	47.55	42.22
	Geisha	262.25	35.70	44.35	5.29	158.08	39.45	38.03
	J-19	264.40	29.60	46.45	5.20	161.23	46.35	44.86
	Mean	308.49	38.60	41.12	6.68	182.84	46.88	44.50
Vi-Vj	**CD (5%)**	44.00	10.80	12.60	1.63	38.00	18.40	25.00
Vi-Vj	**SE(d)**	20.00	5.00	5.80	0.75	17.00	8.40	11.60
BiVi-BiVj	**CD (5%)**	40.00	9.90	11.50	1.49	35.00	16.80	23.00
BiVi-BiVj	**SE(d)**	18.20	4.50	5.30	0.68	16.00	7.70	10.60
Ci-Cj	**CD (5%)**	20.00	4.90	5.80	0.75	17.00	8.40	12.00
Ci-Cj	**SE(d)**	9.10	2.30	2.60	0.34	8.00	3.90	5.30
Ci-Vj	**CD (5%)**	33.00	8.30	9.60	1.25	39.00	14.10	19.00
Ci-Vj	**SE(d)**	15.30	3.80	4.40	0.57	13.00	6.50	8.80
Vi-Vj	**CD (5%)**	44.00	10.80	12.60	1.63	38.00	18.40	25.00

CD- Critical difference, **SE(d)**- Standard Error of difference, **Ci–Cj**- between two control treatments, **BiVi–BiVj**- between two augmented treatments in the same block, **Vi–Vj**- between two augmented treatments in different blocks, **Ci–Vj**- between control treatment and augmented treatment

Conclusion and Recommendation

The present study result revealed the presence of considerable amount of variability among the studied genotypes in some traits like plant height and number of primary branch though no significant difference was observed between accessions for yield at both locations. Deep and thorough evaluations are required at the respective test locations to confirm the repeatability of the performance of those selections that exhibited better performance. Thus, based on yield and other attributes such resistance to diseases, 15 selections are promoted to the next trails stage. These accessions included: T-01/11, T-24/11, T-16/11, T-43/11, T-46/11, 3/82, T-42/11, T-41/11, T-31/11, T-35/11, T-38/11, T-51/11, T-36/11, T-21/11, and T-22/11. We also recommend that the remaining accessions should be maintained in conservation blocks for future utilization.

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Effects of Coffee (*Coffea arabica* L.) Strip Intercropping with Enset on Growth, Yield and Yield Aspects of the Component Crops

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Abstract

Stripinter cropping is the growing of two or more crops in wide strips enough to permit independent cultivation but also narrow enough for the interaction of the companion crops that may allow better of resources and is a common practice in coffee with enset in Southern Ethiopia. A field experiment was conducted at Awada Agriculture Research Sub-center experimental site between 2012 and 2018/19 to evaluate the effect of strip cropping ratios of coffee to enset on the yield and yield components of both crops and to determine economically optimum coffee to enset strip intercropping ratio for the study area. The experiment comprised of six treatments: sole coffee, sole enset and four coffee-enset strip intercropping with proportion: 1C:1E, 2C:1E, 3C:1E and 4C:1E, using randomized complete block design with three replications. The analysis of variance revealed that both coffee and enset growth, yield and yield components significantly affected by coffee-enset strip intercropping. Strip intercropping of coffee with enset at (3:1) proportion gave the highest total yield response as compared to the other intercropping and sole cropping treatments. A maximum LER value of 1.63 or relative yield advantage of 63% was obtained from 3:1 ratio of coffee-enset strip intercropping treatment. Therefore, this finding recommend that strip intercropping of coffee with enset at 3:1 mixture ratio is a viable option for sustainable productivity in yield and yield profit to farmers as revealed by the highest total LER.

Introduction

Intercropping system allows better resource use efficiency and reduce the needs for external inputs (Dariush *et al*., 2006) through a practice of growing two or more crops in the same piece of land at the same time. It plays an important role in subsistence food production system of developing countries (Tsubo *et al*., 2005). Strip cropping is a prominent part of an intercropping practice in which two or more crops in strips that are wide enough to permit independent cultivation but narrow enough for the crop to interact fairly, synergistically or antagonistically. It has been well known that, intercropping provides many advantages like improved utilization of growth resources by the intercropped species (Banik *et al*., 2006), as method of controlling weeds, insect pests, diseases and control of soil erosion (Matusso *et al*., 2012). Interactions in the component crops under intercropping facilitate each other to achieve maximum yield or productivity (Knudsen *et al*., 2004) and could reduce the yield of the less competitive crops in intercropping.

Ethiopia is a leading Arabica coffee producer in Africa, and the production is concentrated in two major coffee producing regions (Oromia 64%) and Southern

Nation Nationality and People's Regional State (SNNPRS) (35%) and others (1%) (Birhanu, 2017) that serves as the major source of cash crop to the farmers.

Population pressure brought land to be the most limiting production constraint. Due to its limitatione, the available land is mainly allocated to the major staple food crops production such as enset (*Ensete ventricosum*). Enset system is one of the four major agricultural systems in Ethiopia feeding about 13 million people, more than 20% of the population residing in the southern Ethiopian highlands (Amede and Diro, 2005). Enset generates system resilience to climate change improving land-use efficiency, providing in-situ mulch, increase income and food security, modify microclimate and labor use efficiency of the system. In addition to this, several production constraints like production of unimproved coffee cultivars under poor management practices, including high-density coffee and enset planting patterns within the limited land resource is critical production constraints that requires solution. Therefore, the present study was carried evaluate the effect of coffee-enset strip intercropping ratios on growth, yield and yield components, and to determine economically sound coffee-enset strip intercropping ratio that can help intensify the existing cropping system and ensure sustainable productivity in the farming system of the study area.

Materials and Methods

Experimental design and treatment arrangements

The experiment was conducted at Awada Agricultural Research sub-center (AARSC) in Sidama Region of Ethiopia starting from November 2017 up to August 2018. AARSC is situated in the moderate to cool semi-arid mid highland agro-ecology of south Ethiopia (Mesfin and Bayetta, 2008). It is located at $6^{O}3$'N Latitude and 38^{O}E Longitude and an altitude of about 1740 meter above sea level. The area has a semi-bimodal rainfall distribution characterized by double wet and dry seasons (Fig. 1) with an average precipitation of 1342 mm per annum, while the annual average minimum and maximum air temperatures are 110^{C} and 28.4^{0}C, respectively. The major soil types of the center are *Nitisol* and chromatic-cambisols that are highly suitable for coffee production (Mesfin and Bayetta, 2008).

The experiment was arranged in a randomized complete block design (RCBD) with three replications. The treatments consisted of sole coffee, sole enset, 1:1, 2:1, 3:1, and 4:1 ratio of coffee with enset, respectively. Fayate coffee variety released from the sub-center was used as the experimental material. One-year-old seedlings of local e*nset* clone locally known as Genticha was planted in the field following the rainy season at both planting cycle, when rainfall starts, at the spacing of 3 m x 2 m, in sole plots, and the intra row spacing was 2.0 m in the intercropped plot. All recommended agronomic practices desirable are carried out accordingly for both coffee and enset plant.

Data Collection

Representative coffee trees from the central rows of each plot were identified to collect yield and yield contributing characters such as plant height (cm), height up to a primary branch (cm), number of primary branches, number of nodes, inter node length (cm) and. number of primary branches, number of nodes on the primary branch, number of nodes on the main stem. Stem girth (cm) was measured above 5 centimeters at the ground level using caliper meter. Canopy diameter (cm): average length of tree canopy measured twice, east-west and north-south, from the widest portion of the tree canopy. Inter node length on the longest primary branch (cm) and coffee yield (Kg ha^{-1}). The fresh berry harvested and its weight was recorded per tree and converted to clean coffee in 100kg ha^{-1}. Enset growth and yield parameter were also recorded by selecting the sample plant from each central plot of the experimental unit. Pseudo stem length (cm), plant height (cm), number of green leaves, width of green leaves (cm), width of leave sheath (cm), thickness of leave sheath (cm), stem weight (kg), corm weight (kg), Kocho (kg), and bulla (kg) yield data were collected from the central part of each experimental unit. Land Equivalent Ratios (LER) for Coffee and Enset yield were calculated according to Mead and Willey (1980) procedures as follows.

$$TLER = PLER\ coffee + PLER\ enset$$

Where TLER = total land equivalent ratio; PLER coffee = Partial land equivalent ratio of coffee, PLER enset= Partial land equivalent ratio of Enset.

The collected data were analyzed using SAS computer software version 9.0 and the significant difference between any two treatments means were compared by least significant difference (LSD) method at 5% probability level.

Result and Discussion

Coffee Growth Parameters

Results of the analysis of variance data collected from different strip intercropping patterns significantly affected the plant height and stem girth $P<0.05$ and $P<0.001$; (Table 2). The tallest plant height (238.52 cm) was obtained from the plot at which coffee intercropped with enset at 1:1 followed by 2:1 coffee-enset ratio and 4:1 coffee-enset ratio produced the shortest plant height of 206.3 cm (Table 2). The tallest result of plant height obtained at 2:1 coffee-enset ratio might be due to the competition of coffee plant with densely populated enset that was highly shaded over the plots that lead to etiolated growth to get solar radiation. Statistically the wider stem girth (5.26) was obtained from coffee trees which was planted at the ratio of 2:1 ratio of coffee-enset, closely followed by 4:1 coffee-enset ratio which is possibly due to shading advantage and microclimate enhancement contribution of enset to the coffee plant. While the narrow (4.74) steam girth was recorded from sole planted coffee (Table 2). The thicker stem girth could bear many primary branches each bearing many secondary branches seems to leads to higher green bean yield. Conversely, canopy diameter was not significantly affected by different intercropping patterns (Table 2). However, maximum canopy diameter was recorded at 2:1 coffee-enset intercropping pattern.

Table 1: Pooled Mean result of Coffee growth parameter affected by Enset Coffee-intercropping

Treatments	CD (cm)	SG (cm)	PH(cm)	NN	INL (cm)	NPB (cm)	LLPB (cm)	NNLPB
Sole Coffee	181.30	4.78c	207.30c	31.45	7.86	63.48b	83.03bc	24.83c
1C: 1E	179.20	4.80c	238.52a	33.01	8.49	64.66b	82.05bc	26.54bc
2C: 1E	184.50	5.26a	224.30b	37.24	8.26	69.80ab	86.41b	28.52a
3C: 1E	176.10	5.10ab	209.80c	34.25	7.93	76.91a	96.38a	27.47ab
4C: 1E	173.90	4.94bc	206.30c	32.13	7.75	63.07b	78.28c	27.63ab
LSD (0.05)	10.60	0.22	14.01	3.86	1.01	7.98	6.23	1.89
CV%	3.14	2.36	3.5	6.1	6.7	6.5	3.9	3.7

Means followed by the same letter(s) within a column are not significantlydifferent at P≤0.05.
Note: CD = Canopy diameter, SG = Stem Girth, PH = Plant Height, NN = Node Number, INL = Inter node Length, NPB= Number of Primary Branch, LLPB = Length of Longest Primary Branch, NNLPB = Node Number on the Longest Primary Branch

The number of node, internode length, number of primary branch, length of primary branch and node number on the longest primary branch are the major yield contributing traits for coffee. In the present study, different intercropping patterns significantly ($P<0.05$) affected the number of primary branches and length of the longest primary branch. However, number of node and internode length did not significantly influenced by different strip intercropping patterns. The maximum NPB (76.91) and the **LLPB** (96.38) primary branch recorded from the plot at which coffee intercropped with enset at 3:1 ratio (Table 2). Coffee grown with enset at 3:1 ratio produced 1.21 times primary branch compared with sole planted coffee. Various research finding also indicated that the number and length primary branch is positively associated with crop yield. Mesfin and Bayetta (2005) reported the positive correlation of mean yield with a length of the first primary branch and number of nodes on primary branches (0.52), number of bearing nodes on primary branches and the number of secondary branches (0.46). The more number of primary branches a coffee tree lead to getting more number of nodes that bear more number of fruit-bearing secondary branches develop from them and the higher the green bean yield the tree bears (Abdulfeta, 2018). Similarly, node numbers on the longest primary branches was significantly ($P<0.05$) caused by strip intercropping. Statistically, the maximum (28.52) was recorded from coffee trees planted in two rows with one row of enset, which closely followed by 4:1 coffee-enset ratio while the minimum (24.83) was obtained from sole planted coffee (Table 2). The average length of primary branches, percent of bearing primary branches and leaf length, are important components to improve coffee yield (Atinafu G, and Mohammed H, 2017).

Coffee Yield

Analysis of variance revealed that coffee-enset strip intercropping significantly ($p<0.05$) affected clean coffee yield (Table 3). In the first and fourth harvesting season's superior yield observed at sole planted coffee, which is statistically at par with 3C:1E cropping pattern. On the contrary, during the second, third, fourth and fifth harvesting season's, statistically better clean coffee yield was recorded from treatment at which coffee planted with enset at 3:1 ratio (Table 3). In line with this, unlike intercropping, the merits of strip intercropping minimize direct competition between shade tree and coffee plant for the available resources, viz. nutrient, moisture and light have been well-documented (Yacob *et al.*, 1996). Strip planting of coffee trees between two established shade tree species had enhanced coffee yield as compared to intercropping under each canopy.

Table 3. Mean result of clean coffee yields influenced by Enset to coffee strip intercropping

Treatments	2014/15	2015/16	2016/17	2017/18	2018/19
Sole Coffee	13.56^{a}	12.70^{bc}	10.18^{bc}	14.20^{a}	18.79^{b}
1C: 1E	11.68^{bc}	11.51^{c}	11.36^{ab}	8.70^{c}	13.59^{d}
2C: 1E	10.74^{c}	12.62^{bc}	10.48^{abc}	9.40^{c}	17.55^{ab}
3C: 1E	12.8^{ab}	15.95^{a}	12.28^{a}	14.05^{a}	20.76^{a}
4C: 1E	11.44^{bc}	14.98^{ab}	10.08^{bc}	12.20^{b}	16.56^{c}
LSD (0.05)	1.85	3.04	2.05	1.65	1.927
CV%	18.16	11.94	10.30	14.87	5.86

Means followed by the same letter(s) within a column are not significantly different at $P\leq0.05$.

Likewise, the pooled mean analysis result showed that there was a significant variation among different strip cropping patterns, highest (15 Q ha^{-1}) and lowest (11.36 Q ha^{-1}) recorded from coffee intercropped with enset at 3:1 ratio and sole planted, respectively. There has been an increase of yield by 11.27 % in treatment where coffee planted with enset at 3:1 ratio over sole growing. The influence of number of coffee rows per two consecutive enset rows was significant ($p < 0.05$) on coffee yield and the average clean coffee yields significantly increased with increased rows until 3:1 ratio and then decreased at 4:1 ratio as clearly illustrated by Fig 1.

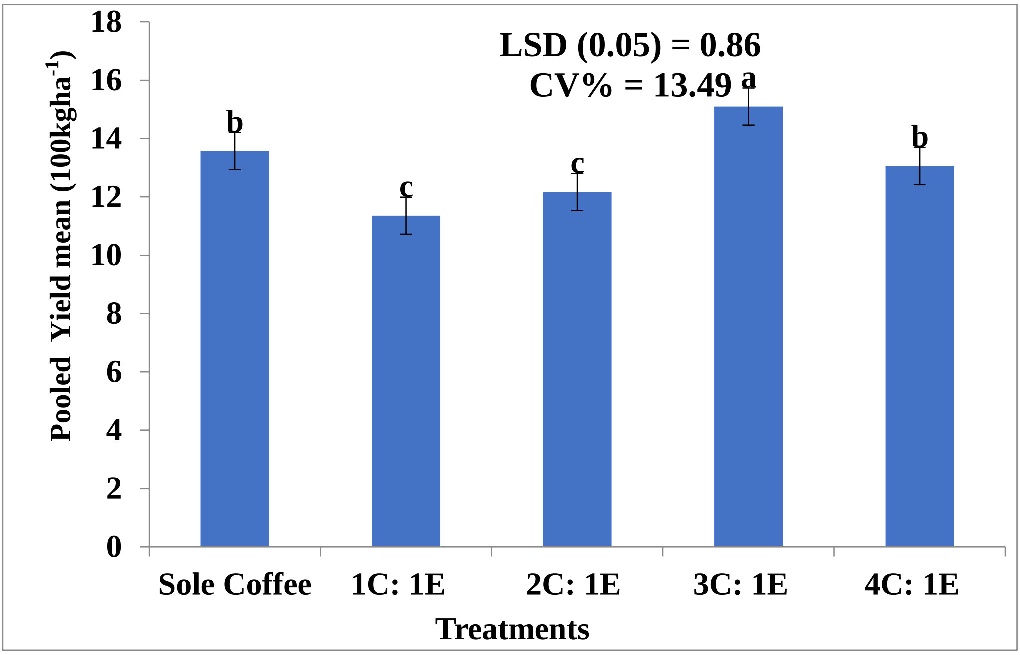

Figure 1. Pooled mean result of coffee yield recorded from each treatment

Enset growth parameters

The data for enset growth parameters are presented in Table 4. Analysis of variance depicted that pseudo stem length and circumstance were significantly (P<0.01) affected by different intercropping patterns (Table 4). The tallest (214.08) and shortest (162.71) pseudo stem length was recorded at sole planted and 4:1 coffee-enset strip intercropping pattern, respectively. The result of this study indicated that the pseudo stem length decreased as number of coffee rows increased between two consecutive enset rows due to diminishing mutual shading effect and competition for growth resource. Conversely, the narrow pseudo stem circumstance (145.63) was recorded at sole planted enset while non-significant variation was observed among the other different strip intercropping patterns.

Width and thickness of leaf sheath was significantly affected by different intercropping patterns; sole planted enset produced minimum width and thickness of leaf sheath (Table 4). However, the other different strip intercropping patterns did not show significant variation. Pseudo stem and corn weights also significantly affected by different intercropping patterns. Even though, non-significant variation was observed among the different strip intercropping patterns, both pseudo stem and corm weights were superior at 3:1 coffee-enset strip intercropping pattern whereas, the lowest values were obtained at sole planted plot which could be due to existence of higher competition on growth factors like water, nutrient and sunlight.

Table 4. Mean result of Enset growth parameter affected by stripintercropping with coffee

Treatments	PSL(cm)	PSC (cm)	PSW (kg)	WLSH (cm)	TLSH(cm)	CW (kg)
Sole Enset	214.08[a]	145.63[b]	94.38[b]	40.46[b]	4.48[b]	34.46[b]
1C: 1E	205.63[a]	173.75[a]	155.54[a]	47.08[a]	5.25[a]	48.21[a]
2C: 1E	196.04[ab]	183.75[a]	178.71[a]	44.54[a]	5.08[a]	51.62[a]
3C: 1E	169.79[bc]	167.91[a]	180.21[a]	45.83[a]	5.08[a]	51.92[a]
4C: 1E	162.71[c]	183.12[a]	158.63[a]	44.58[a]	5.21[a]	49.92[a]
LSD (0.05)	26.33	21.00	29.06	2.95	0.49	11.46
CV%	7.37	6.53	10.05	3.52	5.19	12.89

Means followed by the same letter(s) within a column are not significantlydifferent at P≤0.05. **Note:** PSL = Pseudo stem length, PSW = Pseudo stem weight, CW = Corm weight, WLSH = Width of Leaf sheath, TLSH = Thickness of leaf sheath, PSC = Pseudo stem circumferences.

Enset Yield

Kocho and Bula are one of the economic parts of enset plant. As indicated in Table 5, the cropping system significantly (P<0.05) affected the economic yield of the enset. In both harvesting cycles, sole planted enset gave the highest Kocho and Bulla yields compared with the other strip intercropping patterns. Similarly, total yield harvested in both cycles significantly influenced by the different cropping systems. In the first and second harvesting cycle, sole planted enset produced a total yield of 2.06 and 1.44 times that of the intercropped, respectively. Regarding strip intercropping treatments, during the first harvesting cycle, maximum and minimum Kocho and Bulla yields were recorded at 1:1 and 4:1 coffee-enset strip intercropping ratio, respectively. The yield increment had shown a decreasing trend while number of coffee rows increased. This could be due to the number of enset population varied by intercropping treated plots.

Table 5. Mean yields of Enset harvested during the first and the second cycle

Treatment	1stCycle Yield (2015/16)			2ndCycle Yield (2017/18)		
	Kocho	Bulla	Total yield	Kocho	Bulla	Total yield
Sole Enset	67.46[a]	2.69[a]	70.15[a]	60.04[a]	1.32[ab]	61.36[a]
1C: 1E	47.33[b]	2.60[a]	49.93[b]	51.01[b]	1.50[a]	52.51[ab]
2C: 1E	30.71[bc]	1.24[b]	31.96[bc]	41.56[c]	1.10[ab]	42.67[c]
3C: 1E	28.53[c]	1.13[b]	29.58[c]	44.66[bc]	1.13[ab]	45.80[bc]
4C: 1E	23.14[c]	1.05[b]	24.28[c]	28.40[d]	0.93[b]	29.33[c]
LSD (0.05)	17.94	1.30	18.34	8.97	0.47	9.13
CV%	24.16	39.72	23.65	10.56	21.15	10.46

Means followed by the same letter(s) within a column are not significantly different at P≤0.05.

During the second harvesting cycle, however, inconsistent trend was observed with still higher and lower yields were being obtained from 1:1 and 4:1 coffee-enset strip intercropping ratio, respectively. There has been a total yield increment on enset by 79.03 % when coffee-enset strip intercropped at 1C: 1E ratio compared with 4C: 1E ratio. In general, the result of this study showed that as number of coffee rows per two consecutive enset rows increased, enset productivity decreased simultaneously due to wider row spacing, enset population number per hectare being decrease.

Land Equivalent Ratio (LER)

The results of the current study have proved that growing two or more crops in a piece of land at the same time is significantly advantageous and farmers practicing intercropping gets more crops compared with the one growing sole crops. It was observed that total LER value was significantly (P<0.001) influenced by the intercropping ratio of coffee with enset (Fig. 1). In this study, all intercropping patterns had higher LER than sole planted crops, which indicated the superiority of intercropping over monoculture. In both harvesting cycles, higher total land equivalent ratios were recorded at 1C:1E (1.59), 2C:1E (1.62) and 3C:1E (1.63) than that of 4C:1E (1.36). The highest amount of TLER value of 1.63 was obtained in treatment where coffee strip intercropped with enset at 3:1 ratio (Fig 2). This result indicated that mono cropping would require 0.63 more units of land to have the same yield as intercropped. This implies that the association of coffee and enset at 3C:1E strip-intercropping ratio is vital for efficient growth resources utilization since they are complementary to each other.

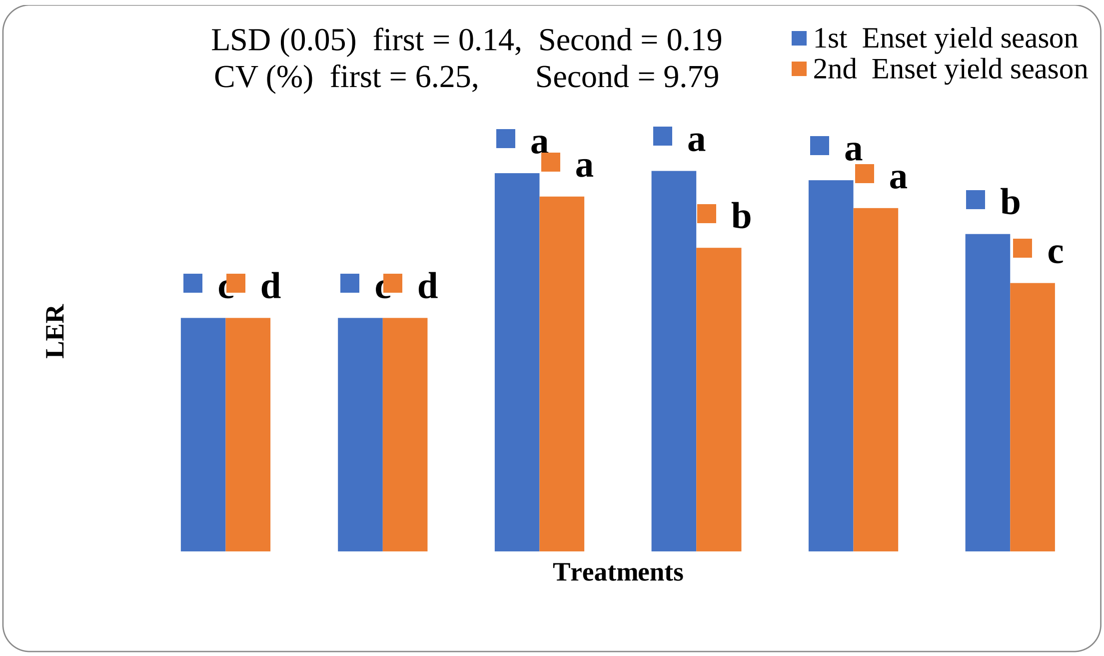

Figure 2. Total LER. Bars capped with the same letter/s are not significantly different at (P<0.05).

Summary and Recommendation

The results of this study revealed that coffee and enset growth, yield and yield components were significantly influenced by coffee-enset strip intercropping. The pooled mean analysis result showed the presence of significant variation among different strip intercropping patterns with the highest (15 Q ha^{-1}) and lowest clean coffee yield (11.36 Q ha^{-1}) being recorded from coffee intercropped with enset at 3:1 ratio and sole planted, respectively. The 1C: 1E coffee-enset strip intercropping produced significantly higher total yield and the 4C: 1E gave the lowest yield. There has been a total yield increment on enset by 79.03 % when coffee-enset strip intercropped at 1C: 1E ratio compared to 4C: 1E ratio. Similarly, total land equivalent ratio value was significantly ($P<0.001$) influenced by the intercropping ratio of coffee with enset. Highest amount of TLER value of 1.63 was obtained from the treatment where coffee strip intercropped with enset at 3:1 ratio, indicating strip intercropping at this level is more advantageous to produce higher yields per unit area of land through efficient utilization of growth factors. Therefore, this finding recommend that strip intercropping of coffee with enset at 3:1 ratio since it increased total productivity per unit area and time by improving land equivalent ratio and generate additional economic advantage.

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Chemical Composition of Essential Oils of Released Black Cumin Varieties Grown in Ethiopia

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Abstract

In Ethiopia black cumin seed and oil are used for folk medicine, for bread flavoring and as a spices. The essential oil of black cumin seeds were extracted by hydro-distillation with Clevenger apparatus and their constituents were identified using GC/MS. The essential oil content of black cumin seeds of the three registered variety Eden, Dirshaye and Silingo were studied. The essential oil content of these varieties 0.80%, 0.4% and 0.6% for Eden, Dirshaye and Silingo, respectively. Moreover, about 75, 66 and 60 constituents or compounds of these varieties were identified in their respective order. The major constituent of the oil was the hydrocarbon monoterpene p-cymene, with a relative concentration of about 45.5%. The main constituents of essential oils as detected by GC/MS were p-cymene (45.85 - 44.31%), α-thujane (17.30 - 12.57%), trans-4-methoxy thujane (8.86 - 7.39%), 9,12-Octadecanoic acid, 9Z,Z)- (6.04% - 0.07%), β-pinene (4.08 - 3.04%), α-pinene (3.94 -2.68%), gamma-terpinene (3.83 - 2.50%), thymoquinone (3.53 - 2.13%), α-terpinene (3.00 – 0.00%) and D-limonene (2.29 - 2.08%). About 2.46% of cis-vaccenic acid was found only in Eden variety. All the main compounds are similar among varieties and numerical variation in content to each varieties were recorded. The Ethiopian black cumin essential oil contain the required major secondary metabolite for pharmacological and other application.

Introduction

Spice is a natural compound that is extracted from the seed, fruits, flowers or trunks of several plants and add to food in order to provide taste, smell or flavor. Spices are a diverse group of wide variety of staple dietary additives consumed all over the world. Each spice has a unique aroma and flavor which derive from compounds known as phytochemical or secondary metabolite. These chemicals evolved in plant to protect them against herbivorous insect, vertebrates, fungi pathogens and parasites (Srinivasan, 2005; Hossain *et al*., 2008).

Black cumin or *Nigella sativa* L *(N. sativa)* belongs to the family *Ranunculaceae* and is widely distributed and cultivated in Mediterranean countries, middle Europe and western Asia. The ancient Egyptians, Greeks and Romans were already aware of the therapeutic properties of *N. sativa*, the essential oil and seeds of which are still used in folk medicine, in bread or cheese flavoring and as a spice in various kinds of meals (Wais *et al*., 2008). The seeds have been reported to contain mainly fixed oils, proteins, alkaloids, saponins, and essential oil that was previously characterized by a higher percentage of monoterpenes, the main constituents being thymoquinone and *p*-cymene (Ali and Blunden, 2003).

Black seed, the seed of *Nigella sativa* has been employed for thousands of years as a spice, food preservative and curative remedy for numerous disorders (Abdulelah and Zainal-Abidin, 2007). The historical tradition of black seed use in medicine is substantial. *N. sativa* is known to have beneficial effects on a wide range of diseases, antiasthmatic, antitumor, antiviral, antibacterial, anti-inflammatory, antimalarial, antihypertensive, antidiabetic (Buyukozturk *et al*., 2005; Majdalawieh *et al*., 2010; Salem and Hossain 2010; Kamal. *et al.,* 2010; Meddah *et al*., 2009). In Ethiopia black cumin seed and oil are used in folk medicine, in bread flavoring and as spices. Therefore the objective of this study was to identify the chemical composition of essential oil of black cumin varieties cultivated in Ethiopia.

Materials and Methods

Isolation of essential oils

The collected seeds were air dried, ground with a laboratory mill, weighed and particular samples (100g) from each varieties were subsequently submitted to hydro-distillation for 4h using Clevenger type apparatus. Three replicates were distilled simultaneously. All oil samples were weighed, dried over anhydrous sodium sulphate and stored in dark at 4^{O}C until identification of chemical constituent. The yields obtained were averaged and calculated as a relative percentage (V/W).

Gas chromatography- Mass spectrometry (GC-MS)

GC-MS analyses were carried out to identify chemical constituent present in oil (Omoruyi *et al*., 2014) by using Agilent 5977A system equipped with a DB-5MS fused silica column (30 m x 0.25 mm; film thickness 0.25μm internal diameter). Oven temperature was held at 40^{o}C for 5 min and then programmed until 240^{o}C at a rate of 4^{o}C/min, transfer line temperature 260^{o}C, injector temperature 250^{o}C, carrier gas Helium was used with flow rate of 1 mL/min. A total run time of 55 min, split ratio 1:60; 0.1μL of oil; ionization energy 70 ev; scan time 1s; mass range 40-350 amu.

Identification of compounds

The constituent of the oils were identified by comparison of their mass-spectra with those of a computer NIST 2014 library and confirmed by comparison of their compounds (Adams, 1995). Retention indices were determined using retention times of n-alkanes that have been injected to the same instrument and under the same chromatographic condition. Relative percentage amounts were calculated from the total area under the peak by the software of the apparatus at Jije Analytical Testing Service Laboratory, Ethiopia, in this study).

Results and Discussions

Hydro-distillation of Ethiopian black cumin seeds were yellowish oil and resulted in 0.80%, 0.60% and 0.40% essential oil for Eden, Dirshaye and Silingo varieties, respectively. The obtained result in this study confirmed that there is a variation in essential oil content among varieties. This variation might be due to their genetic makeup among varieties and effects environmental factors on varieties. Our results agree with findings of the other researchers that reported values ranging between 0.5 to 1.5% (Prabudha and Ria, 2002) and 0.48 to 0.51% (Tuncturk *et al*., 2005). However, it was higher than the report of Ozel *et al*. (2009) who reported a value ranging between 0.24 to 0.43%. Many factors can influence the essential oil content of plants. These variations are heredity, age of the plant, climatological, harvesting time, fertilization and irrigation regimens, distillation procedure and isolation method (Gora *et al*., 2002).

Table 1 Chemical composition of essential oils of seeds of black cumin varieties

No	Identified compounds	Compound in varieties (%)		
		Eden	Dirshaye	Silingo
1	P- Cymene	44.36	45.85	44.31
2	α-Thujane	12.57	17.3	13.66
3	trans-4-methoxy thujane	7.39	7.91	8.86
4	9,12-Octadecanoic acid, (Z,Z)-	6.04	0.07	0.16
5	β-pinene	3.04	4.08	3.45
6	α- pinene	2.68	3.94	3
7	gamma-terpinene	2.5	3.83	3.24
8	cis-vaccenic acid	2.46	-	-
9	Thymoquinone	2.13	2.4	3.53
10	Longifolene	1.83	1.56	1.95
11	D-limonene	2.08	2.29	2.27
12	Phenol-2-methyl-5-(1-methylethyl)-	1.6	1.18	2.56
13	Bicyclo[3,1,0]hexane,4-methylene-1-(1-methylethyl)	1.52	2.29	1.87
14	Terpinen-4-ol	1.13	0.92	1.31
15	cis-4-methoxy thujane	1.06	1.3	1.35
16	n-hexadecanoic acid	0.96	0.02	0.04
17	1,3-Cyclohexadiene, 1-methyl-4-(1-methylethyl)	0.93	-	-
18	1-Cyclohexene-1-carboxaldehyde, 2,6,6-trimethyl	0.91	0.93	1
19	Behenic alcohol	0.88	0.13	0.4
20	9,12-octadecadieenoicacid (Z,Z)-,2-hydroxy-1-(hydroxymethyl)ethylester	0.61	0.03	0.02
21	2-caren-4-ol	0.34	0.03	0.43
22	Tricyclo[5,4,0,0(2,8)undec-9-ene,2,6,6,9-tetramethyl-,(1R,2S,7R,8R)	0.3	0.3	0.28
23	Glycidyl oleate	0.22	0.02	-
24	Bicycle[2,2,1]heptan-2-ol,1,7,7-trimethyl-,acetate,endo	0.18	0.16	0.26
25	p-Mentha-1,5,8-triene	0.15	-	0.1
26	Oleic acid	0.13	0.03	0.06
27	Isoledene	0.12	0.1	0.12
28	7-Tetradecenal, (Z)	0.12	0.08	0.13
29	Glycidyl palmitate	0.1	-	-
30	Cyclohexanol, 1-methyl-4-(1-methylethenyl)-,cis-	0.1		0.1
31	Benzenemethanol,α,α,4-trimethyl	0.1	0.04	0.06
32	(-)-Carvone	0.09	0.08	0.15
33	Bicycle[3,1,0]hexan-2-ol,2-methyl-5-(1-methyethyl)-(1α, 2β,5α)	0.08	0.07	0.08
34	Cyclohexene,1-methyl-4-(methylethyl)	0.08	0.09	0.08

35	Eucalyptol	0.07	0.08	0.07
36	1,2,4-methenozulene,decahydro- 1,5,5,8a-tetramethyl-,[1S-(1α,2α,3αβ,4α,8αβ,9R*)]	0.07		0.07
37	Caryophylene	0.07	0.06	0.08
38	Humulane-1,6-dien-3-ol	0.07	0.04	0.07
39	p-Cymenene	0.06	0.06	0.08
40	1,2-15,16-diepoxyhexadecane	0.06		-
41	(1R,3R,4R,5S)-1-Isopropyl-4-methylbicyclo[3,1,0]hexan-3-yl acetat-rel-	0.05	0.04	0.06
42	Tetradecanal	0.06	0.04	0.08
43	α-Terpineol	0.04	0.02	0.04
44	Camphene	0.04	0.06	0.05
45	α-phellandrene	0.04	0.06	0.06
46	2-Cyclohexen-1-ol,1-methyl-4-(methylethyl)-,cis	0.04	0.02	0.04
47	1H-Indene, 1,ethylideneoctahydro-7a-methyl-, cis-	0.04	0.04	0.07
48	Benzene, 1-(1,5-dimethyl-4-hexenyl)4-methyl	0.04	0.04	0.06
49	Ar-tumerone	0.04	0.04	0.1
50	Phenanthrene, 7-ethyl-1,2,3,4,4a,4b,5,6,7,9,10,10a-dodecahydro-1,1,4a,7-tetramethyl-,[4aS-(4aα,4bβ,1β,10aβ)]	0.04	0.02	0.04
51	Tetradecanoic acid, 2-hydroxy	0.04	-	-
52	Bicycle[3,1,0]hex-2-ene,4-methylene-1-(1-methylethyl)	0.02	0.03	0.03
53	β-myrcene	0.03	0.04	0.04
54	Thymol	0.03	0.02	0.04
55	Cis-9-tetradecen-1-ol	0.03	0.02	0.07
56	2-Caren-4-ol	0.02	0.02	-
57	1,3,8-p-Menthatriene	0.02	0.02	0.02
58	(+)-(E)-Limonene oxide	0.02	0.02	0.03
59	β-Bisabolene	0.02	0.02	0.03
60	trans-2-Decen-1-ol,trifluroacetate	0.02	-	-
61	Dodecanal	0.02	0.01	0.04
62	p-Cymene-2,5-diol	0.02	0.04	0.06
63	Tumerone	0.02	0.02	0.04
64	Curlone	0.02	0.02	0.04
65	7-Hexadecenal,(Z)	0.02	-	-
66	1,5-Dodecadiene	0.01	-	-
67	α-Terpinene	-	1.26	3
68	7-Oxabicyclo[4,1,0]heptane,1-methyl-4-(2-methyloxiranyl)	-	0.01	0.02
69	endo-Borneol	-	0.03	0.05
70	2-cyclohexen-1-ol, 1-mrthyl-4-(1-methylethyl)-,trans	-	0.02	0.02
71	α-Copaene	-	0.02	-
72	Citronellal	-	-	0.08
73	1,2,5,9-Tetradecatriene,3,12-diethyl	-	-	0.09
74	Cyclohexene, 1-methyl-4-(1-methylethylidene)	-	-	0.09
75	E-7-Tetradecenol	-	-	0.08
76	Bicycle[2,2,1]heptane-2-one, 1,7,7-trimethyl-,(1S)	-	-	0.04
77	Benzaldehyde,4-(methylethyl)	-	-	0.02
78	Carvenone	-	-	0.01
79	2-cyclohexen-1-one, 3-methyl-6-(methylethylidene)	-	-	0.02
80	α-Cubebene	-	-	0.02
81	Azulene,1,2,3,5,6,7,8,8a-octhahydro-1,4-dimethyl-7-(1-methylethyl)-,[1S-(1α,7α,8aβ)]	-	-	0.03
82	Cis-Dodec-5-enal			0.04
83	1-Dodecanol	-	-	0.02
84	(1S,5S)-2-Methyl-5-(R)-6-methylhept-5-en-2-yl)bicyclo[3,1.0]hex-2-ene	-	-	0.03
85	1H-benzocyclohepten-9-ol,2,4aβ,5,6,7,8,9,9aβ-octahydro-3,5,5,9β-tetramethyl	-	-	0.02
	Total number of compounds	66	60	75

Black cumin seeds essential oils constituents were analyzed using GC-MS. From the GC-MS result identified 66, 60 and 75 constituents or compounds constituting

99.8%, 99.27% and 99.17% in Eden, Dirshaye and Silingo black cumin seeds essential oils, respectively. The main constituents of essential oils of Ethiopian black cumin seeds was p-cymene accounted for about 45% of overall compounds. The major compounds varietal constituents ranged p-cymene (45.85 - 44.31%); α-thujen (17.30 - 12.57%); trans-4-methoxy thujane (8.86 - 7.39%); 9, 12-Octadecanoic acid, 9Z, Z) - (6.04% - 0.07%); β-pinene (4.08 - 3.04%), α- pinene (3.94 -2.68%), gamma-terpinene (3.83 - 2.50%), thymoquinone (3.53 - 2.13%). Other compounds like α-terpinene; D-limonene; phenol-2-methyl-5-(1-methylethyl); cis-vaccenic acid; longifolene; terpinen-4-ol ; and cis-4-methoxy thujane were also identified in black cumin essential oils by sharing greater than 1%, and they had great importance in industry as intermediate for synthesis of fragrances, pharmaceuticals and herbicides.

In Eden variety the main compound identified were p-cymene (44.36%), α-thujen (12.57%), trans-4-methoxy thujane (7.39), 9,12-Octadecanoic acid, 9Z,Z)-(6.04%). β-pinene (3.04%), α- pinene (2.68), gamma-terpinene (2.50%), cis-vaccenic acid (2.46%), thymoquinone (2.13%), D-limonene (2.08%), longifolene (1.83%), phenol-2-methyl-5-(1-methylethyl) (1.60%), bicyclo[3,1,0]hexane,4-methylene-1-(1-methylethyl) (1.52%), terpinen-4-ol (1.13%), cis -4-methoxy thujane (1.06%). Cis-vaccenic acid (2.46%), Glycidyl palmitate (0.1%), 1, 3-Cyclohexadiene, 1-methyl-4-(1-methylethyl) (0.93%), 1, 2-15, 16 diepoxyhexadecane, Tetradecanoic acid 2-hydroxy, trans-2-Decen-1-ol, trifluroacetate, 7-Hexadecenal, (Z) and 1, 5-Dodecadiene is a compound found only in Eden variety.

The percentage composition of P-cymene (45.85%) and α-thujane (17.30%) in Dirshaye variety was found higher than other studied varieties. This variation might be due to their genetic potential and environmental effects. The percentage of β-pinene, α- pinene, gamma-terpinene, D-limonene and bicyclo [3, 1, 0] hexane, 4-methylene-1-(1-methylethyl) were also higher than their constituents in Eden and Siling varieties. Trans-4-methoxy thujane was found as a third major compound in Dershaye variety.

In Silingo variety p-cymene (44.31%), α-thujen (13.66%), trans-4-methoxy thujane (8.86%), β-pinene (3.45%), α- pinene (3.00), gamma-terpinene (3.24%), thymoquinone (3.53%), phenol-2-methyl-5-(1-methylethyl) (2.56%), D-limonene (2.27%) longifolene (1.95%), bicyclo[3,1,0] hexane,4-methylene-1-(1-methylethyl) (1.87%), longifolene (1.56%), cis -4-methoxy thujane (1.35%) 1-Cyclohexene-1-carboxaldehyde (1.53) and 2,6,6-trimethyl terpinen-4-ol (1.31%). In this study p-cymene was found as a major compounds. However, Nickavar *et al*. (2003) reported *trans* anethole (38.3%), p-cymene (14.8%), limonene (4.3%), and carvone (4.0%) as the major compound of black cumin oil. High level of p-cymene (60%) was also reported from Tunisian species (Martin-Luengo et al., 2008). The percentage of thymoquinone quantified in this study was very low when compared to results of Ali and Blunden (2003) who reported thymoquinone and *p*-cymene as major compound.

In this study P-cymene was found to be about 45%; 9, 12 Octadecanoic acid, 9Z, Z) which was found higher (6.04%) in Eden variety and lower (0.07- 0.16%) for other two varieties. α-Thujane was higher for Dirshaye variety (17.30%) and lower for Eden and Silingo (12.57-13.66%). The results indicated that the essential oil was characterized by the presence of appreciable levels of P-cymene, α-thujene, trans-4-methoxy thujane, 9, 12 Octadecanoic acid, 9Z, Z)-, γ-terpinene, thymoquinone β-pinene, α-pinene and so forth. The present study revealed that the essential oil isolated from each black cumin variety seeds cultivated in Ethiopia are similar to each other and some other reports (Khalid *et al.*, 2016) and (Hajhashemi et al., 2004 in respect of presence of main compounds.

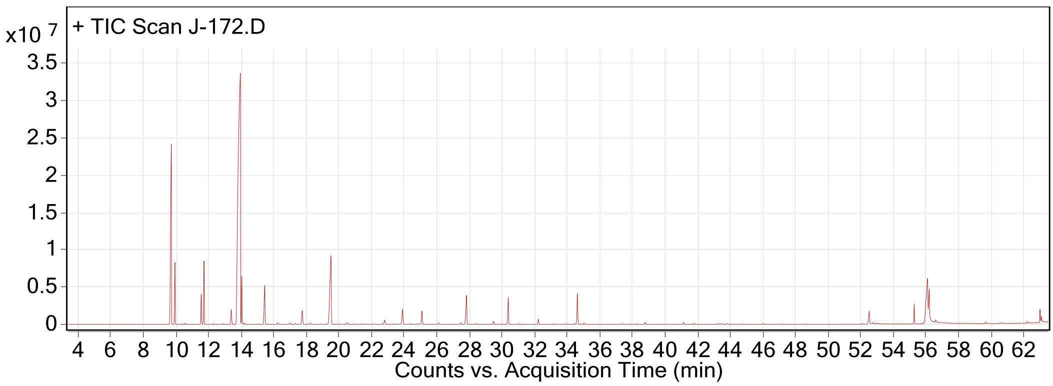

Figure 1. GC-MS chromatogram of Eden variety

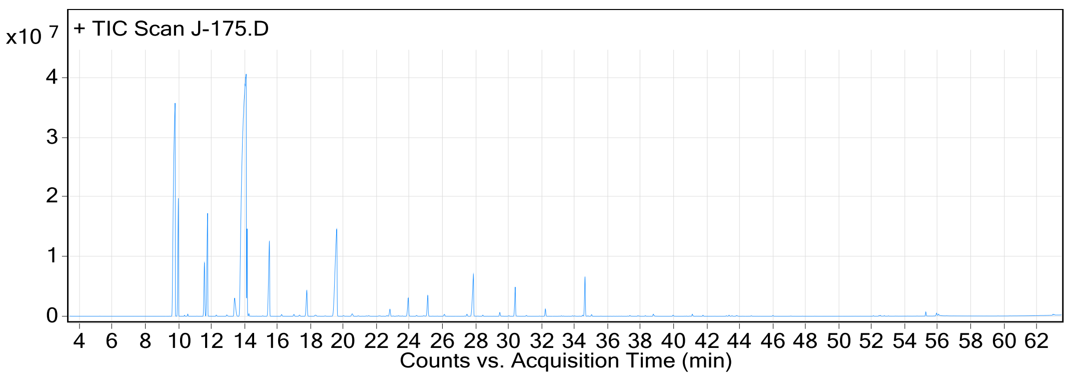

Figure 2. GC-MS chromatogram of Dirshaye variety

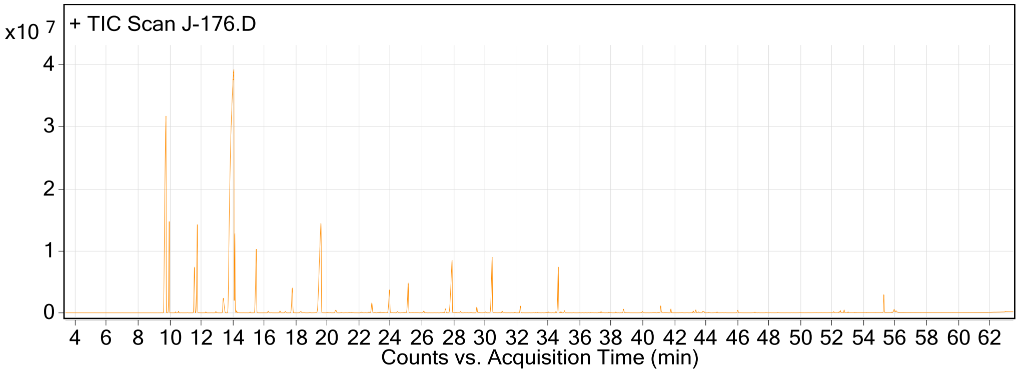

Figure 3. GC-MS chromatogram of Silingo variety

Summary and Conclusion

Essential oil content and composition of black cumin can be affected by types of genetic material, ecological condition and origin of the plant. Variations in black cumin essential oil was observed among the three varieties studied. Chemical composition among the three varieties cultivated in the same agro-ecology had p-cymene (45.85 - 44.31%), α-thujane (17.30 - 12.57%), trans-4-methoxy thujane (8.86 - 7.39%), 9,12-Octadecanoic acid, 9Z,Z)- (6.04% - 0.07%), β-pinene (4.08 - 3.04%), α- pinene (3.94 -2.68%), gamma-terpinene (3.83 - 2.50%), thymoquinone (3.53 - 2.13%), α-terpinene (3.00 – 0.00%), D-limonene (2.29 - 2.08%), phenol-2-methyl-5-(1-methylethyl) (2.56 -1.52%), longifolene (1.95 - 1.83%), terpinen-4-ol (0.92 – 1.31%) and cis-4-methoxy thujane (1.35 – 1.06%) as the major constituents of the three black cumin varieties essential oils cultivated in Ethiopia. The Ethiopian black cumin essential oil contain the required major secondary metabolite for pharmacological and other application and could be used after extraction.

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Essential Oil Yield and Compositions of Bark, Leaf and Seed of Cinnamon (*Cinnamomum verum*)

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Absract

Cinnamomum verum is one of an important spice plants that come from cinnamon family. The study was conducted to analyze oil yield and chemical composition in the essential oils of cinnamon leaf, bark and seed. The essential oil from the leaf, seed and bark plant of cinnamon was extracted using Clevenger by hydro distillation and characterized by GC-MS. The percentage of essential oil yield in cinnamon by hydro-distillation method ranged from 0.60- 0.72 in leaves; 0.60-0.75% in cinnamon bark and 0.65-0.78% in cinnamon seed collected from Tepi and Bebeka, locations. The essential oil in the leaf of cinnamon contains the highest eugenol (82.90%), linalool (4.35%) and caryopyllene (3.13%). The highest essential oil composition in the seed of cinnamon were identified to be Cadina-1(10), 4-diene (26.90%); γ-Cadinene (11.10%); alfa.-Copaene (9.60%) and Caryophyllene (8.99%). Cinnamaldehyde and Acetic acid cinnamyl ester were the major compounds identified from the bark of cinnamon from the two locations and ranged between 19.88 and 21.04% and 22.08 and 35.69%, respectively. Cinnamaldehyde and Acetic acid cinnamyl ester are important in flavor and fragrant chemicals constituting together about 41.96 to56.73% of cinnamon barks essential oils. In addition to barks, the leaves and seeds of cinnamon have high oil content and its constituents that could be used in food, chemicals and pharmaceuticals industry for future use.

Introduction

The genus *Cinnamomum* (Laureaceae family) consists of 250 spices of trees and shrubs distributed in Southeast Asia, China, and Australia. It is a small, evergreen tree, 10–15m tall. The bark is widely employed as a spice, its leaves are ovate oblong in shape, and 7 to 18cm long. The flowers, arranged in panicles, have a greenish color and have a rather disagreeable odor. The fruit is a purple 1 cm berry containing a single seed (Leela, 2008). For commercial use it could be coppiced or pruned from time to time or it could be maintained as a bush from 2 to 2.5 m height with multiple stems arising from its base. It requires a warm and wet climate with average temperature of 20^0c to 30^0c and high rainfall. The cinnamon genotype was introduced in Ethiopia in 1975. In Ethiopia it was commercially grown mainly in Bebeka Coffee Estate Share Company for export purpose and in country use. It has been mentioned by the company expert that they had about 8 hectares of cinnamon plantation.

Cinnamon barks and leaves are widely used as spice and flavoring agent in foods, beverage industry and for various applications in medicine (Schmidt *et al*., 2008;

Elumalai *et al*., 2011). Cinnamon is used as an ingredient and flavoring agent worth US$ 107 million in 2017 as a trade commodity and used by 76 countries worldwide (Thibbotuwawa and Hirimuthugodage, 2017). In Ethiopia, cinnamon is used as a flavoring agent in a variety of spiced foods, for flavoring tea, butter, Ethiopian shiro wot, vegetables and meat dishes as sole or mixed with other spices. Cinnamon harvesters' only cultivate the tree bark and sell it as raw material rather than other parts of the tree, i.e., stem, leaves, and twigs that can be developed into a variety of economically valuable products like essential oils with low volume of harvesting which has higher market price (Sidi Menggala and Damme, 2018). Essential oils are aromatic oily liquids obtained from plant materials. Essential oils are complex mixes comprising many of single compounds. Chemically, they are derived from terpenes and their oxygenated compounds. Each of these constituents contributes to beneficial or adverse effects (Prabuseenivasan *et al*., 2006).

Cinnamon essential oil may be extracted by hydrodistillation, solvent extraction, and by microwave-assisted extraction. Yield and composition of the extracted essential oil are affected by the extraction method and species type (Golmohammad *et al*., 2012). Determination of cinnamaldehyde and trans-cinnamic acid has been done by spectrophotometry (Rind *et al*., 2011) or with high performance liquid chromatography (Lee *et al*., 2015). Cinnamaldehyde is a pale yellow liquid with a warm, sweet, spicy odor and a pungent taste and is widely used in medicine, bakery goods, spices and chemical industry. It is also used as anti-diabetic and antifungal agent (Rao and Gan, 2014). Eugenol, a major compound in leaves are responsible for protecting the gut from injury from conditions of inflammation, infections, and oxidative stress (Dorri, *et al.,* 2018).
Demand for cinnamon bark has increased the last few years. There was a limitation of knowledge on production and processing of cinnamon among farmers, different coffee and spice growers private limited company, other agricultural investors and agricultural experts. Even though production of cinnamon was commenced in our country there is still a limited information on the main chemical composition and oil yield of Cinnamon produced in Ethiopia. Buyers are complaining about the lack of information on quality of cinnamon produced in Ethiopia and stressed the need for research on its quality. In research, cinnamon variety registration is under way in Ethiopia and quality profile of cinnamon is highly needed. So, this study is aimed to identify oil yield and analyze chemical constituents concerned with qualitative and quantitative measurements of compounds present in the oil of cinnamon products for wider use and to generate information on registered Ethiopian cinnamon variety.

Materials and Methods

Plant material

Leaf, seed and bark samples were collected from *Cinnamomum* spice plants, namely *Cinnamomum verum* cultivated at the Teppi Agricultural Research Center and Bebeka Coffee Share Company, Ethiopia. Harvesting of the bark of cinnamon is usually done in the rainy season (Muhammad and Dewettinck, 2017) from July –August in 2019 and 2020 to be easily peeled. The shoot having brown stem color and basal stem diameter of 30 to 50 mm are coppiced at a height of about 12 cm from ground level (Pathiratna *et al*. 2006) during the morning using saw at 45^0 angle position. Long sharpen blade locally known as 'gajara' was used to remove lateral stems, branches and leaves from main stem. Peeling was done at each harvesting date as late peeling could reduce peeling ability of the bark from stem. The bark is removed starting from the basal shoot. Peeling of bark from the stems was usually done by hand using sharp moon ended knife, by trained peelers and the bark is stripped off. At 30cm intervals the barks were cut longitudinally around using a small pointed stainless steel knife with blade and stripped of from stem. The stripped quills were placed inside one another to make long compound quills for drying. Drying was commenced in shade using black tender net below the sample for six days. Similarly the cinnamon leaf (green stage) and seed (when its color turns to black brown) were harvested and dried under shade for four days.

Extraction of leaf, seed and bark of cinnamon

Essential oil extraction from the cinnamon products were performed by the Hydro-distillation in Clevenger apparatus. All dried samples of *Cinnamomum verum* (leaves, bark and seed) were grounded using hammer mill. About 100 g of each powdered samples were placed in a 2000 mL round bottom flask and then 1000 mL water was added into the flask and positioned on a heating mantel. The flask was connected to Clevenger apparatus and hydro-distillation process was carried out with boiling water at temperature 100°C for 5 hours (Gursale *et al*., 2010). The essential oils of cinnamon leaves mostly layer on water and some quantity settled at the bottom of Clevenger. After the distillation process, oils were collected using separator funnel to yield (v/w, dry basis) and separated several times until no oil and water mixture was found.

GC-MS analysis of cinnamon oil

Gas Chromatography-Mass Spectrometry analysis was conducted in order to analyze the constituents which are present in the extracted oil. The extracted oil samples were analyzed with the aid of a GC– MS instrument (Agilent 5977A MS inert, Jije Analytical Testing Service Laboratory) coupled with a mass spectrometer. The GC system model (Agilent 7890B GC) was paired with a DB-5 MS column with the dimensions of 30 m length × 0.25 mm internal diameter × 0.25 μm film thickness. The GC conditions were: oven temperature from 60 to

240 ^{o}C at 3 ^{o}C/min; The GC experimental conditions functioned with inlet temperature of 260^{o}C with injection volume of 1μl and at a flow rate of 1 mL/min; splitting ratio, 1:60. The detector temperature was maintained at 240 ^{o}C. A total run time was 60 minutes. The mass selective detector was operated in the electron impact mode with electron energy of 70 eV (source temperature 230°C to evaluate the constituent of the oil extracted from the cinnamon leaf, seed and bark (Kasim *et al*., 2014; Jeyaratnam *et al*., 2016). The percentage composition of the identified components was calculated from the GC peak area. The components were identified by comparing their retention times and mass spectra with those of pure reference components. Mass spectra were also compared with those in the NIST (National Institute of Standards and Technology) at Jije Analytical Testing Service Laboratory in this study).

Results and Discussion

The oil fraction isolated from cinnamon bark had a pale yellowish color appearance with a sweet taste and strong aroma. The leaf of cinnamon oil have also pale yellowish color and a lighter taste and aroma compared to cinnamon bark oil. The essential oil yield of leaf was 0.60% and 0.72% (dry weight) for Tepi and Bebeka collected samples, respectively. About 0.75% and 0.60% of oil yield was recorded from cinnamon bark collected from Tepi and Bebeka, respectively. The percentage of essential oil yield in cinnamon seed from hydro-distillation was about 0.65% and 0.78% from Teppi and Bebeka locations. This oil yield result in barks was lower by half compared to the report of Paranagama *et al*. (2001), El-Baroty *et al*. (2010), and Kamaliroosta *et al*. (2012). This variation might be caused due to geographical locations, harvesting stage, plant part used or extraction methods. However, it was in agreement with the report of Paranagama *et al*. (2001) for leaf and seed oil yield of cinnamon, 0.75% and 0.50%, respectively. The percentage of cinnamon oil also depends on many factors such as location, season, time of harvest and the age of tree, genus, species, plant stage at which the material is collected, dried and procedure used for extracting as reported by Parthasarathy *et al*. (2008) and Hussain *et al*.(2008).

Table 1. Essential oil Yield of Cinnamon bark, leaf and seed collected from two location

Locations	Leaf (%)	Bark (%)	Seed (%)
Tepi	0.60±0.1	0.75 ±0.08	0.65±0.08
Bebeka	0.72±0.07	0.60±0.10	0.78±0.05

Essential oil composition of Cinnamon leaf

Essential oil compositions of leaf was identified using GC/MS. A total of 49 to 64 compounds were identified from yearly collected leaf of Cinnamon. It was presented in Table 2 that the leaf constituent of Cinnamon was more dominated by

Eugenol (the principal compound in leaf). The highest constituent Eugenol was about 88.25% and 82.91% for leaf collected from Bebeka during 2020 and 2019, respectively, and was 69.60% for sample collected from Tepi. Linalool was the second compound found in cinnamon leaf and was higher for sample collected from Tepi (about 6.4%), and about 4.35 and 2.07% for sample collected during 2019 and 2020 from Bebeka. Similarly, caryophyllene was identified as the third major compound found in leaf and were higher for sample collected from Tepi (4.64%) and were 3.13 and 2.74% for consecutive Bebeka site harvest. In addition, Acetic acid cinnamyl ester was more in leaf of cinnamon harvested from Tepi (5.54%) and was very low for Bebeka site (0.76% to 0.84%). This variation might have occurred due to geographical factors and growth stage of the leaves across location. Wang *et al*. (2005) similarly reported that essential quality depends on genetic, developmental state of the plant, environmental factors such as temperature, luminosity, relative humidity, soil composition and post-harvest operations and the extraction method. The other compound having more than 1% were alfa.-copaene and β –phellandrene. This study was in agreement with that of Singh *et al*. (2007) and Vangalapati *et al*. (2012) in percentage eugenol recorded from Cinnamomum zeylanicum and higher than 59.56% of Cinnamomum burmannii (Khasanah *et al*., 2017); and 17.30% for Cinnamomum tamala (Kapoor *et al*., 2009) leaf oleoresin. Other compounds viz β-caryophyllene, linalool, Benzyl Benzoate and α-terpene identified as leaf constituents found in cinnamon (Paranagama *et al*., 2001).

Essential oil composition of Cinnamon seed

A total of 63 compounds were identified from seed of Cinnamon essential oil (trace compound not presented in Table 2). It was presented in Table 3 that the seed constituent of Cinnamon was more dominated by Cadina-1(10), 4-diene yielding (26.9%) and γ-Cadinene (11.10%), alfa.-Copaene (9.60%) and Caryophyllene (8.99%). Also 1H-Cycloprop[e]azulene, 1a,2,3,5,6,7,7a,7b-octahydro-1,1,4,7-tetramethyl-, [1aR-(1a.alpha.,7.alpha.,7a.beta.,7b.alpha.)] (6.43%); alpha Muurolene (4.83 %); α-Cadinene (3.23%); α-Pinene (2.82%); and Humulene (2.57%). Caryophyllene was a compound found in both leaf (as 4th compound) and seed (as 3rd compound) in cinnamon oil. Beside other trace compound identified from seed of cinnamon Isoledene, Alloaromadendrene, Î´-Cadinene, (+)-; β-Pinene; α-Gurjunene, alpha.-Cadinol; Cubenene and Aromandendrene were identified consist greater than 1%. The variation in chemical compositions in cinnamon products might be due to the differences in different plant parts used, the soil characteristics and agro-climatic conditions. In this study Cadina-1(10), 4-diene was identified as major compounds. Similarly, Paranagama *et al*. (2001) reported α- and y- cadinene (36.0%); T- cadinol (7.7%) and β- caryophyllene (5.6%) as a major constituents of Cinnamon seed oil. However, in other study Vangalapati *et al*. (2012) reported higher percentage of trans-Cinnamyl acetate (42-54%) and caryophyllene (9-14%) from cinnamon seed oil.

Table 2. Composition (%) of the essential oil of cinnamon leaves.

Compounds	Bebeka 2020 (%)	Bebeka 2019 (%)	Teppi 2019 (%)	Mean (%)
Eugenol	88.25	82.91	69.6	80.25
Caryophyllene	2.74	3.13	4.64	3.5
Linalool	2.07	4.35	6.44	4.29
aR-Turmerone	1.41	0.84	0.45	0.9
Acetic acid, cinnamyl ester	0.84	0.76	5.54	2.38
Humulene	0.55	0.64	0.85	0.68
Caryophyllene oxide	0.41	0.32	0.31	0.35
Curlone	0.33	0.19	0.08	0.2
o-Cymene	0.3	0.09	0.18	0.19
L-.alpha.-Terpineol	0.23	0.2	0.25	0.23
Benzyl Benzoate	0.18	0.64	0.56	0.46
Thymol	0.14	0.06	0.02	0.07
.alpha.-Phellandrene	0.12	0.1	0.74	0.32
Tumerone	0.1	0.01	0.05	0.05
Cyclohexane, methyl-	0.09	0.04	0.04	0.06
Benzoic acid, 2-phenylethyl ester	0.07	0.12	0.14	0.11
Acetic acid, chloro-, 2-phenylethyl ester	0.06	0.17	0.17	0.13
Benzaldehyde	0.05	0.09	0.07	0.07
Phytol	0.05	0.03	0.04	0.04
Terpinen-4-ol	0.05	0.2	0.13	0.13
cis-Linalool oxide	0.02	0.04	0.04	0.03
alpha Terpinene	0.02	0.11	0.31	0.15
trans-Linalool oxide (furanoid)	0.02	0.07	0.07	0.05
α-Cubebene	0.02	0.03	0.03	0.03
Eucalyptol	0.17	-	0.05	0.11
.gamma.-Terpinene	0.13	-	0.05	0.09
α-Curcumene	0.11	0.1		0.11
Tetradecanal	0.06		0.04	0.05
β-Sesquiphellandrene	0.06	0.03		0.05
(1R,3E,7E,11R)-1,5,5,8-Tetramethyl-12-oxabicyclo[9.1.0]dodeca-3,7-diene	0.04	-	0.05	0.05
β-Pinene	0.04	-	0.06	0.05
Cyclohexane, 1-methylene-4-(1-methylethenyl)-	0.03	-	0.08	0.06
α-Pinene	0.03	0.05		0.04
Bicyclo[3.1.0]hex-2-ene, 2-methyl-5-(1-methylethyl)-	0.01	-	0.04	0.03
alfa.-copaene	-	1.45	1.33	1.39
n-Hexadecanoic acid	-	0.27	0.52	0.4
Tau-Cadinol acetate	0.23	-	-	0.23
(E)-Atlantone	0.05	-	-	0.05
D-Limonene	0.04	-	-	0.04
β-Bisabolene	0.03	-	-	0.03
.alpha.-Terpinyl acetate	0.02	-	-	0.02
β-Myrcene	0.01	-	-	0.01
oleic acid	-	0.13	-	0.13
Tricyclo[2.2.1.0(2,6]heptane,1,3,3-trimethylethyl-	-	-	0.15	0.15
camphene	-	-	0.06	0.06
β-myrcene	-	-	0.05	0.05
E,Z-3-Ethylidenecyclohexene	-	-	0.08	0.08
β -phella-rene	-	-	1.04	1.04
Acetic acid, phenylmethyl ester	-	-	0.2	0.2
benzofuran, 2-methyl-	-	-	0.18	0.18
Methyleugenol	-	-	0.03	0.03

Table 3. Major essential oil composition of Cinnamon seed

Compounds	Retention time	Area (%)
Cadina-1(10),4-diene	47.28	26.9
γ-Cadinene	46.06	11.1
.alfa.-Copaene	34.18	9.6
Caryophyllene	37.07	8.99
1H-Cycloprop[e]azulene, 1a,2,3,5,6,7,7a,7b-octahydro-1,1,4,7-tetramethyl-, [1aR-(1a.alpha.,7.alpha.,7a.beta.,7b.alpha.)]-	43.33	6.43
.alpha.-Muurolene	44.33	4.83
α-Cadinene	48.89	3.23
α-Pinene	10.52	2.82
Humulene	38.71	2.57
isoledene	41.3	2.05
Alloaromadendrene	40.11	1.93
Î´-Cadinene, (+)-	47.38	1.77
β-Pinene	12.24	1.72
α-Gurjunene	35.99	1.67
.alpha.-Cadinol	58.95	1.62
Cubenene	48.24	1.37
Aromandendrene	38.27	1.32
isoledene	33.68	0.93
D-Limonene	14.44	0.91
Eugenol	32.91	0.75
Di-epi-1,10-cubenol	57.33	0.74
Epicubenol	56.53	0.66
Globulol	54.27	0.59
2-Naphthalenemethanol, decahydro-.alpha.,.alpha.,4a-trimethyl-8-methylene-, [2R-(2.alpha.,4a.alpha.,8a.beta.)]-	57.05	0.5
.tau.-Cadinol	58.51	0.49
Fenchol	19.99	0.4
Camphene	11.11	0.37
o-Cymene	14.23	0.36
.alpha.-Calacorene	49.18	0.33
β-Myrcene	12.76	0.31
endo-Borneol	23.23	0.27
L-.alpha.-Terpineol	24.64	0.25
Dodecanoic acid, ethyl ester	55.95	0.23
Linalool	18.83	0.22
Terpinolene	17.53	0.21
gleenol	54.71	0.21
.alpha.-Maaliene	37.87	0.18
.gamma.-Terpinene	15.92	0.14
Eucalyptol	14.59	0.09
1H-Cycloprop[e]azulen-7-ol, decahydro-1,1,7-trimethyl-4-methylene-, [1ar-(1a.alpha.,4a.alpha.,7.beta.,7a.beta.,7b.alpha.)]-	53.48	0.09
Cyclohexane, methyl-	3.9	0.08
.alpha.-Phellandrene	13.38	0.08
Camphene hydrate	22.1	0.08
Cyclohexene, 1-methyl-4-(1-methylethylidene)-	13.85	0.07
Hexadecanoic acid, ethyl ester	68.65	0.07
(Z)-3-Phenylacrylaldehyde	28.75	0.05
Safrole	29.55	0.05
γ-Elemene	31.75	0.04
Ethyl Oleate	70.79	0.04
Toluene	4.86	0.03
α-Cubebene	32.38	0.03
Bicyclo[3.1.0]hex-2-ene, 2-methyl-5-(1-methylethyl)-	10.21	0.02
Terpinen-4-ol	23.69	0.02

Undecanal	30.61	0.02
(+)-Sativen	31.59	0.02
Bicyclo[2.2.1]hept-2-ene, 1,7,7-trimethyl-	9.36	0.01
3-Carene	10.03	0.01
Bicyclo[3.1.0]hexane, 4-methylene-1-(1-methylethyl)-	12.06	0.01
β-Ocimene	15.32	0.01
trans-4-methoxy thujane	19.78	0.01
L-Borneol	22.65	0.01
Tetradecane	30.23	0.01
Aciphyllene	32.7	0.01

Essential oil composition of Cinnamon bark

A total of 79, 48, and 64 compounds were identified from Teppi 2019, Bebeka 2019 and Bebeka 2020 harvest of bark of Cinnamon, respectively (compounds having less than 0.01 % not listed in this paper (Table 3)). It was presented that the bark constituent of Cinnamon were more dominated by acetic acid cinnamyl ester and Cinnamylaldehyde. Samples collected from Bebeka during 2020 had higher content of Acetic acid cinnamyl ester (35.69%) followed by 31% for Tepi site and 22.08% for Bebeka site of the same harvest year. Similarly the Cinnamylaladehyde content at both site during 2019 were about 21.04 and 19.88% for Teppi and Bebeka site, respectively. It was low at 2020 for Bebeka site which might presumably be due to harvesting year. According to Tao *et al*. (2002), (*E*)-cinnamyl acetate (21.14%), (*E*)- cinnamaldehyde (16.46%), and linalool (7.65%) were major components in *C. wilsonii* bark oil which was in agreement with our study in quantitative as well as major compounds identified. In other case Linalool was also found in bark of cinnamon, beside of its occurrence in leaf. Linalool and Benzyl Benzoate were also found in a range of 11.20 to 17.85% and 4.28 to 7.67% at both location in this study. The variation in chemical composition might be related to species genetic variation and environmental factors of the same species where they were grown. In other study, Liang *et al* (2019) reported from *C. cassia* extract, (*E*)- cinnamaldehyde as the major compound with highest area percentage of 62.96%, and other main components included coumarin, α- copaene, 3-methoxy- 1, 2- propanediol, and α- guaiene.

Table 3. Major Compound identified from essential oil of cinnamon bark

Name of compound	Tepi2019 (%)	Bebeka2019 (%)	bebeka2020 (%)	Mean (%)
Acetic acid, cinnamyl ester	31	22.08	35.69	29.59
Cinnamaldehyde	21.04	19.88	11.87	17.6
Linalool	11.2	17.85	12.47	13.84
Benzyl Benzoate	4.28	4.66	7.67	5.54
Eugenol	1.79	1.78	8.01	3.86
α- Phellandrene	1.41	1.67	0.12	1.07
Caryophyllene	1.23	1.66	8.82	3.9
α-Cymene	1.17	1.6	1.58	1.45
Terpinen-4-ol	1.11	1.33	0.46	0.97
L-α-Terpineol	0.94	1.18	0.67	0.93
Bicyclo[3,1,0]hex-2-ene,2-methyl-5-(1-methylethyl)	0.61	0.58	0.1	0.43
ar-Turmerone	0.59	0.45	0.8	0.61
Benzaldehyde	0.56	0.56	-	0.56
Caryophyllenyl alcohol	0.54	0.2	0.67	0.47
3-Phenyl-1-propanol, acetate	0.5	0.45	0.42	0.46
gamma,Terpinene	0.4	0.43	0.24	0.36
2-cyclohexen-1-ol, 1-methyl-4-(1-methylidene)-, cis	0.38	0.44	0.2	0.34
Cyclohexene, 1-methyl-4-(1-methylethylidene)	0.15	0.3	0.52	0.32
2-propen-1-ol, 3-phenyl-,(E)-	0.15	0.1	0.49	0.25
Benzoic acid, 2-phenylethyl ester	0.14	0.11	0.42	0.22
Oleic acid	0.12	0.17	0.07	0.12
Thymol	0.05	0.05	0.12	0.07
β-Phellandrene	9.11	9.98	-	9.55
α-Terpinene	3.53	3.65	-	3.59
α-pinene	1	1.03	-	1.02
Benzofuran, 2-methyl-	0.62	0.43	-	0.53
n-Hexadecanoic acid	0.51	0.76	-	0.64
Camphene	0.47	0.53	-	0.5
Benzenepropanal	0.41	0.37	-	0.39
β-Pinene	0.35	0.41	-	0.38
β-myreene	0.34	0.34	-	0.34
2-Propenal, 3-(2-methoxyphenyl)-	0.3	0.31	-	0.31
2-cyclohexen-1-ol, 1-methyl-4-(1-methylidene)-, trans	0.25	0.29	-	0.27
α-Copaene	0.2	0.184	-	0.19
cis-linanalool oxide	0.16	0.22	-	0.19
2-Cyclohexen-1-ol,3-methyl-6-(1-methyl)-,trans-	0.16	0.4	-	0.28
Caryophyllenyl alcohol	0.16	0.2	-	0.18
(Z)-3-Phenylacrylaldehyde	0.15	0.15	-	0.15
9,12-Octadecadienoic acid (Z,Z)-	0.15	0.16	-	0.16
trans-linalool oxide	0.12	0.17	-	0.15
Humulene epoxide II	0.08	0.13	-	0.11
β-copaene	0.06	0.11	-	0.09
Epicubebol	0.06	0.07	-	0.07
Benzaldehyde, 2-hydroxy	0.06	0.01	-	0.04
3-Carene	0.05	0.06	-	0.06
Butanoic acid, 2-methyl-,phenylmethyl ester	0.05	0.17	-	0.11
Di-epi-1.10-cubenol	0.03	0.04	-	0.04
2-Carene	0.03	0.03	-	0.03
3-Phenylpropanol	0.03	0.05	-	0.04
Styrene	0.02	0.02	-	0.02
10,10-Dimethyl-2,6-dimethylenebicyclo[7.2.0]undecan-5.β.-ol	0.03	0.05	-	0.04
.tau.-muurolol	0.05	-	0.06	0.06
Alloaromadendrene oxid-(1)	0.04	-	0.04	0.04
Caryophyllenyl oxide	-	0.82	1.47	1.15

β-Logipinene	0.01	-	0.06	0.04
Bicyclo[3,1,0]hexene,4-methyl-1-(1-methylethyl)	0.32	-	-	0.32
trans-β-Ocimene	0.26	-	-	0.26
2-propnol, 2-methyl-5-(1-methylethyl)-	0.2	-	-	0.2
Acetic acid, chloro-, 2-phynylethyl ester	0.11	-	-	0.11
1H-Inden-1-ol, 2,3-dihydro-	0.06	-	-	0.06
2-Cyclohexen-1-one,4-(1-methylethyl)-	0.04	-	-	0.04
2-(4a,8-Dimethyl-2,3,4,4a,5,6-hexahydronaphthalen-2-yl)propan-1-ol	-	-	0.47	0.47
Tetradecanal	-	-	0.71	0.71
Piperine	-	-	0.76	0.76
alfa.-Copaene	-	-	1.94	1.94
Benzoic acid, 2-hydroxy-, phenylmethyl ester	-	-	0.41	0.41
Î´-Cadinene, (+)-	-	-	0.39	0.39
Benzaldehyde	-	-	0.17	0.17
trans-4-methoxy thujane	-	-	0.17	0.17
β-Turmerone	-	-	0.14	0.14
.alpha.-Muurolene	-	-	0.13	0.13
.alpha.-Phellandrene	-	-	0.12	0.12
α-Curcumene	-	-	0.11	0.11
2-Cyclohexen-1-ol, 1-methyl-4-(1-methylethyl)-, cis-	-	-	0.1	0.1
cis-Calamenene	-	-	0.1	0.1
Thymoquinone	-	-	0.09	0.09
Di-epi-1,10-cubenol	-	-	0.09	0.09

Summary and Conclusion

The essential oil yield in cinnamon ranged from 0.60 to 0.72 in leaves; 0.60 to 0.75% in bark and 0.65 to 0.78% in seed. The main essential oils of cinnamon bark were Acetic acid cinnamyl ester and Cinnamaldehyde. The seed constituent of cinnamon oil were more dominated by Cadina-1(10), 4-diene yielding (26.9%) and γ-Cadinene (11.10%), alfa.-Copaene (9.60%) and Caryophyllene (8.99%). However, the leaf of cinnamon essential oil was dominated by the principal compound Eugenol (88.25 to 69.60%. Linalool was the second compound found in the leaf of cinnamon and the yield was about 6.44 to 2.74%. The Cinnamaldehyde obtained in this result was very low and undertaking of research on stage of harvesting, season of harvesting, extraction methods and stem thickness is recommended to exploit yield of cinnamaldehyde content of cinnamon produced in Ethiopia.

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Evaluation of Ethiopian Rue (*Ruta chalapensis L.)* Genotypes for Yield and Yield Components

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Abstract

Rue is an aromatic evergreen plant used for multipurpose utility in traditional medicine and in Ethiopia mainly used for flavoring coffee in addition to its medicinal benefit. There is limitation of knowledge, experience, scientific evidences and information on Ethiopian R. chalenpesnsis genotypes. The present experiment was therefore undergone to minimize the aforementioned gaps. The study was conducted for one year in 2019 up to 2020 G.C at three different locations using 10 (ten) selected promising superior genotypes from collected accessions. These genotypes were tested using Randomized Complete Block Design in three replications. Rue genotypes were planted in six rows of 3-meter length at the commencement of main rainy season using 60 cm between plant and row spacing. Data was collected on different traits such as plant height, number of branches/plants, fresh leaf weight/branch, fresh leaf weight/plant, leaf to stem ratio, leaf yield/ha, percent essential oil content and essential oil yield/ha. All measured traits were very significantly affected by locations and genotypes. The phenology of the genotypes is also highly affected by location with rue genotypes planted in highland give more fruits early while more leaves at low lands. Maximum leaf yield and leaf essential oil yield/ha was obtained at Arba Minch and maximum fruit essential oil yield/ha at Wondo Genet from genotypes 1and 5, respectively. Based on this experiment result, high altitude agroecology is more suitable for fruits production and low altitude is for leaf production.

Introduction

Rue *(Ruta chalepensis*) is an aromatic evergreen herb or small shrub that belongs to *Rutaceae* family (Akkari *et al*., 2015). *Rutaceae* family contains about 160 genera and more than 1600 species. The genus name "Ruta” came from the Greek word "reuo ", to set free, showing its reputation as a free from disease (Kasimala *et al*, 2014). All these species are with bluish-green leaves that emits a powerful odour and have a bitter taste (Touwaide *et al*., 2008). From all this species, Ruta graveolens and *Ruta chalepensis* are the mainly used species in traditional medicine with various benefit (Ratheesh and Helen, 2007). R. *chalepensis* is a native to the Mediterranean region and later widely diffused in many parts of the world, in temperate and tropical countries worldwide (Gonzalez-Trujano *et al*, 2006). Both species (*R.chalepensis and R.graveolens) are* mainly used as traditional medicine to treat a variety of diseases by many countries (Lauk *et al*., 2004). It has been introduced in various parts of North, Central and South

America, China, India, Middle East and South Africa for different cultural and medicinal value due to its medicinal and different cultural value (Miguel, 2003). In Chile, it is traditionally cultivated for its pharmacological uses; infusions of its fresh leaves are widely used as treatment for gastric disorders, headache and rheumatism (Quiroz *et al.*, 2016). In Ethiopia *R.chalepensis* is known as 'Tena Adam' in Amharic, 'Cirakota' in Afan Oromo, 'Chena-Adam' in Tigrigna and called in different names by different Ethiopian ethnics (Tesfaye Awas, 2007). All Ethiopian population are highly familiar with rue and grow it in their farm guard as spices and also used as traditional healer for children and matured person. In Ethiopian coffee ceremony the plant rue or 'Tena Adam' comes together with because coffee and Rue are highly attached in use. The leaves are boiled with tea or coffee and drunk alternatively, the leaves are crushed and pounded and mixed with cold water and drunk as a treatment to stomachache. Crushed seeds of *R. chalepensis* and seeds of Lepidium sativum are added to water and sprayed in homes or home compounds or crop fields to repel evil (bad) spirits. Crushed seeds and/or leaves of *R. chalepensis* and bulb of *A. sativum* are smeared or rubbed on bleeding head or forehead physical damage when someone falls over or beaten by someone to prevent infection (Kasimala *et al*, 2014). Despite that fact that rue is popularly used by all Ethiopian population, there are limitation of knowledge, experience, improved variety and scientific information for production and further variety improvement works. This experiment was aimed to minimize the information gaps and to resolve related problems on Ethiopian rue thereby quantify yield and yield components of Ethiopian rue genotypes for the selection of superior genotypes for next breeding program.

Materials and Methods

Description of experimental site

The study was undertaken for one year (2019-2020) at three locations, i.e., Jajura, Wondo Genet and Arba Minch (Table 1) using 10 selected genotypes collected from different locations throughout the country from farmers' garden.

Table 1. Experimental site description

Location	Latitude	Longitude	Altitude (m)	Soil type	Temperature		Annual mean rain fall
					Minimum	Maximum	
Wondo Genet	7°192' N	38° 382' E	1780	Sandy loam	14 °c	26 °c	1078.7mm
Arba Minch	6° 0' 0" N	37° 35' 0" E	1200	clay loam	20 °c	27 °c	1100 mm
Jajura	Unavailable	Unavailable	2200	clay loam	18 °c	25 °c	2370 mm

Experimental Material and methods

Following preliminary screening and characterization 10 Ethiopian *R.chalepensis* promising genotypes were evaluated using Randomized Complete Block Design (RCBD) in three replications. Rue genotypes were planted in six rows/plot of 3-meter length at the commencement of main rainy season using 60 cm between plant and row spacing. All agronomic management practices such as hoeing, weeding and pinching of flowers flowered at very early stage to have enough leaf biomass and fruit yields were carried out uniformly to each experimental plot whenever needed. Supplemental irrigation was given for the experimental plants at all location when rain was not enough at off season. No fertilizer or chemical was applied during experimentation. Respective spacing of 1.5m and 1m was maintained between replications and plots.

Data collection

Data on plant height, number of branches/plants, fresh leaf weight/branch, fresh leaf weight/plant, leaf to stem ratio, leaf yield/ha, percent essential oil content and essential oil yield/ha were recorded. Experimental quantitative data analysis of variance (ANOVA) was carried using SAS PROC GLM (2002) at P <0.05. Differences between means were assessed using the least significance difference (LSD) test at $P < 0.05$.

Results and Discussions

Morphological and phonological traits

Genotypes tested were highly variable morphologically and phonologically at tested locations. All genotypes flowered at Jajura and Wondo Genet with only two genotypes flowered and bear fruit lately. The performance of all genotypes was significantly different and highly affected by location and genotype (Table 2). Production of leaf was more favorable at low altitude and fruit was more productive at high altitude and mid-latitude. Giant genotypes were high yielders and dwarf or rue genotypes with stunted growth were less productive and flowered earlier than the giant one. This results revealed that *R.chalepensis* nearly flower uniformly at mid and high altitude but lately flower or not totally flower at low land altitude.

Plant height

Plant height was highly significantly affected by genotypes, location and interaction between genotype and location (Table 2). Maximum mean plant height (105.29 cm) was obtained at Arba Minch from genotype 1 and minimum (63.0 cm) at Jajura from genotype 6.

Fruit yield

Genotypes are variable in fruit size, arrangement and yield at different location (Figure 1). It was observed that genotypes bear small size, medium-size and large size fruits and some genotypes did not bear fruits at all. Fruit bearing genotypes produced fruit yield ranging from 597-3213 kg/ha at Wondo Genet and Jajura but only two genotypes (treatment 1 and treatment 3) bear fruit at Arba Minch site. This result revealed that mid-altitude areas like Wondo Genet and Jajura is suitable for rue fruit yield and low altitude like Arba Minch is not suitable for fruit production.

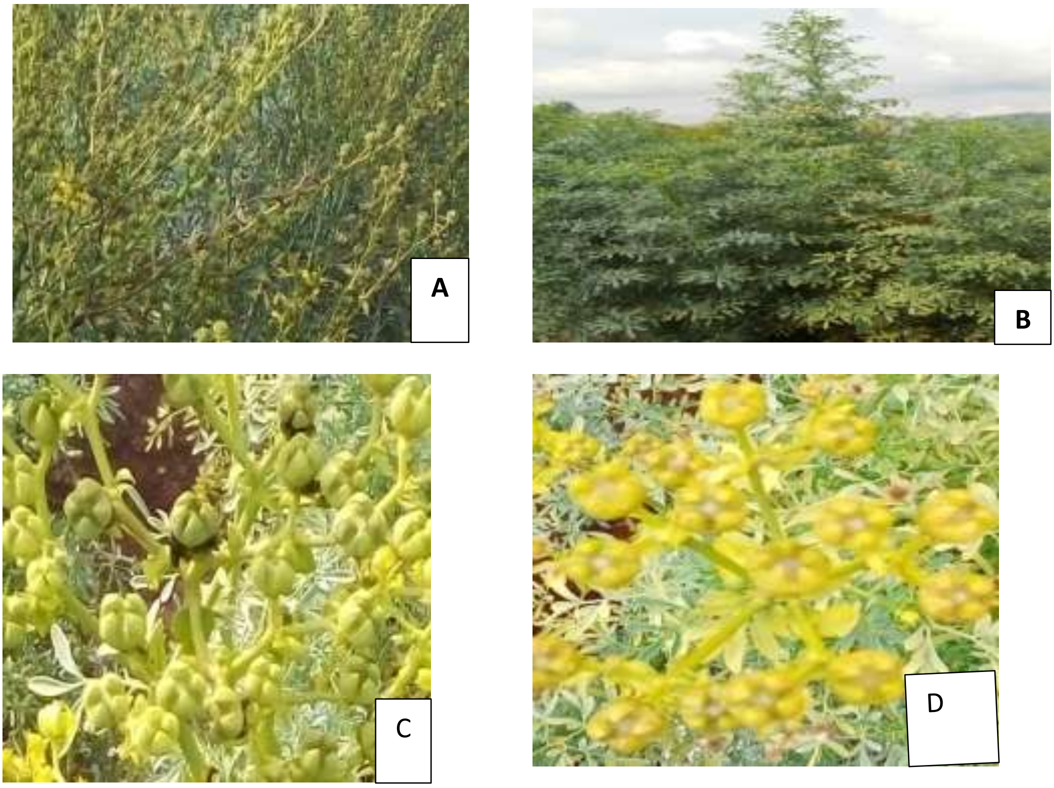

Figure 1: Ethiopian ruta chalepensis genotypes fruit variability, (A) small size fruit, (B) genotype with no fruits, (C) genotype with large fruit size (D) central ruta chalepensis with five fingers

Leaf weight /plant and leaf yield /hectare

Leaf weight/plant and leaf yield/hectare is highly significantly affected by genotypes and locations (Table 2). Maximum leaf weight/plant was obtained from genotype 5 (849.8g) at Arba Minch and low weight/plant obtained from genotype 6 at Jajura (28.73g). This experiment revealed that as altitude increase leaf yield decrease. Lowland area is more suitable than highland areas for the leaf production of rue. Based on this result, rue can be cultivated on mid-high-altitude locations but agroecology of Arba Minch and similar agroecology is very suitable for rue leaf yield and yield component.

Leaf essential oil content

Leaf is one the main economical part of rue used as spices and for essential oil extraction to be used for numerous benefits. Ethiopian rue genotypes essential oil content of was significantly different and showed significant difference across tested locations (Table 2). Maximum fresh leaf essential oil was obtained from genotype 9 (0.261%) at Wondo Genet (Table 3).

Leaf essential oil yield /hectare

Essential oil yield is highly significantly affected by genotypes and location. Inaddition to these, essential oil content of leaf and leaf yield directly affected essential oil yield. Maximum essential oil was obtained from genotype 2 (18.43 kg) at Arba Minch (Table 3).

Fruit Essential oil content and Fruit essential oil yield/hectare

Maximum essential oil content was obtained from genotype 9 (0.33 %) and maximum essential oil yield was obtained from genotype 1 (7.25 kg) at Wondo Genet (Table 5). This result came from genotypes nature for essential content and leaf yield.

Table 2. ANOVA Table for traits evaluated three locations for variability of Ethiopian Rue Genotypes

SV	DF	PH	IL	BN	FLWP	FLYHA	FLEOC	FLEOYHA
Trt	9	1067.30***	1.74***	517.35***	18550.1***	20258279*	0.018***	75.91ns
Rep	2	1.72ns	0.044ns	253.61ns	28511.5ns	19729535ns	0.0001ns	36.16ns
Loc	2	14411.93***	3.56***	13172.58***	2630631.3***	1723039911***	0.23***	1789.71***
Trt*Loc	18	203.94***	0.39***	517.24***	27349.73ns	16256266ns	0.02***	70.012***
Error	58	42.93	0.11	132.57	14273.08	11328961	0.0004	34.07
R2 %		94.42	81.99	84.15	87.84	85.77	97.28	73.90
CV %		8.11	18.79	30.71	44.82	41.69	13.20	61.00
Mean		80.81	1.79	37.49	266.56	8073.51	0.16	9.57

Where PH (Plant height), IL (Internode length), BN (Branch number), FLWP (Fresh leaf weight per plant), FLYH (Fresh leaf yield per hectare), FLOC (Fresh leaf essential oil content), FLEOYH (Fresh leaf essential oil yield per hectare)

Table 3. Mean comparison of Ethiopian rue genotypes performance at Wondo Genet Arbaminc and Jajura

Treatment	Evaluated traits						
	PH	IL	BN	FLWP	FLYHA	FLEOC	FLEOYHA
1	100.74[a]	2.60[a]	42.70[abc]	240.61[ab]	6111.118[bc]	0.209[b]	7.99[abc]
2	84.48[bc]	1.63[c]	28.89[de]	292.71[a]	9008.76[ab]	0.212[b]	13.02[a]
3	63.22[e]	1.56[cd]	35.44[bcde]	282.75[ab]	8828.36[ab]	0.158[c]	9.82[ab]
4	89.55[b]	1.63[c]	25.89[e]	237.24[ab]	7559.65[abc]	0.124[de]	8.114[abc]
5	86.44[bc]	2.20[b]	35.67[bcde]	340.42[a]	10085[a]	0.136[de]	12.99[a]
6	69.07[e]	1.86[c]	51.41[a]	178.73[b]	5109.65[c]	0.12[e]	4.48[c]
7	83.33[c]	1.78[c]	45.67[ab]	296.38[a]	8837.03[ab]	0.158[c]	12.07[a]
8	73.70[d]	1.23[de]	38.00[bcd]	231.31[ab]	7628.78[abc]	0.132[de]	8.843[ab]
9	74.52[d]	1.25[de]	33.85[cde]	271.60[ab]	8582.41[ab]	0.244[a]	11.88[ab]
10	83.00[c]	2.24[b]	37.41[bcd]	293.60[a]	8984.632[ab]	0.122[e]	6.48[bc]

Where: PH (Plant height), IL (internode length), BN (branch numbers), FLWP (fresh leaf weight per plant), FLYH (fresh leaf yield per hectare), FLOC (fresh leaf essential oil content), FLEOYH (fresh leaf essential oil yield per hectare)

Table 4. Mean comparison of Ethiopian genotypes performance at Wondo Genet Arbaminc and Jajura

Traits	**Location name**		
	Wondo Genet	Jajura	Arba minch
PH (cm)	74.12[b]	63.0[c]	105.29[a]
IL	1.94[a]	2.04[a]	1.40[b]
BN	17.92[c]	34.55[b]	59.60[a]
FLWP (g)	59.09[c]	134.92[b]	605.68[a]
FLYHA (kg)	3648.85[b]	3747.38[b]	16824[a]
FLEOC	0.261[a]	0.114[b]	0.106[b]
FLEOYHA (kg)	5.986[b]	4.287[b]	18.434[a]

Where: PH (Plant height), IL (internode length), BN (branch numbers), FLWP (fresh leaf weight per plant), FLYH (fresh leaf yield per hectare), FLOC (fresh leaf essential oil content), FLEOYH (fresh leaf essential oil yield per hectare)

Table 5. ANOVA table of Ethiopian Ruta chalepensis tested at Wondo Genet and Jajura in 2019

SV	DF	PH	IL	BN	IL	FLWP	FLYH	FFWP	FFYH	LEOC	LEOYH	FEOC	FEOYH
Trt	9	513.40**	1.59**	346.13**	108.2**	3079.76**	1913022^{ns}	69117.60**	6527929.74**	0.03**	21.04**	0.025**	24.24**
Rep	2	5.95^{ns}	0.02^{ns}	600.00**	20.11^{ns}	3223.19**	2919370^{ns}	95861.78^{ns}	5411421.42^{ns}	0.00^{ns}	4.56^{ns}	0.000^{ns}	14.32^{ns}
Loc	2	1852.04**	0.145^{ns}	4351.68**	14.35^{ns}	86220.23**	145606^{ns}	1040685.5**	1644335.31^{ns}	0.33**	43.30**	0.096**	9.24^{ns}
Trt*Loc	9	44.06^{ns}	0.37ns	210.40**	34.81**	7148.23**	2229935^{ns}	36982.45	2987463.24^{ns}	0.03**	11.17**	0.07**	22.76**
Error	38	31.07	0.137	64.89	7.62	1720.7062	1667351.9	21345.097	1623792.3	0.00	1.88	0.003	3.91
R^2 %		85.35	0.77	81.07	82.24	73.86	40.5803	72.9487	61.39	99.92	82.76	99.03	75.61
CV %		8.13	18.63	30.47	10.47	42.77	34.9167	76.5762	69.43	2.20	26.67	5.26	60.52
Mean		68.56	1.99	26.44	26.37	97.00	3698.12	190.79	1835.47	0.19	5.14	0.19	3.27

Where: PH (Plant height), IL (internode length), BN (branch numbers), FLWP (fresh leaf weight per plant), FLYH (fresh leaf yield per hectare), FLOC (fresh leaf essential oil content), FLEOYH (fresh leaf essential oil yield per hectare)

Table 6. Mean Comparison of genotypes tested at Jajura and Wondo Genet in 2012 E.C

TRT	PH	BN	INMS	FLWP	FLYHA	LSR	LEOC	LEOYH	NFP	FFWP	FFYH	FEOC	FEOYH
1	79.11	20.67	24.72	147.47	3237.82	1.33	0.28	8.365	128.72	285.29	2400.58	0.25	7.25
2	76.61	16.67	31.53	113.44	4467.93	2.04	0.255	8.045	19.22	118.91	1170.25	0.24	2.66
3	56.34	24.22	27.06	107.36	4443.47	2.75	0.16	4.373	18.84	133.98	841.22	0.165	1.367
4	78.33	15.99	31.17	74.12	3513.55	1.63	0.13	3.357	13.89	145.48	1446	0.175	2.34
5	72.22	35.45	21.45	85.74	3324.82	0.91	0.145	4262	83.89	250.13	3195.54	0.18	5.45
6	53.66	31.28	20.16	91.14	2749.20	0.78	0.147	3.585	100.94	297.66	3213.78	0.135	4.46
7	75.61	35.11	26.17	106.17	3855.70	1.38	0.152	6.023	53.99	225.01	2610.81	0.15	4.46
8	62.45	26.06	28.42	89.77	4298.87	2.32	0.13	3.525	5.61	51.86	597.01	0.125	0.753
9	63.44	23.22	31.11	70.17	3506.17	2.20	0.303	6.008	5.78	43.72	519.94	0.33	1.5
10	67.89	35.72	21.89	84.59	3583.52	1.00	0.152	3.85	77.45	355.88	2359.6	0.14	3.27

Where: PH (Plant height), BN (branch numbers), FLWP (fresh leaf weight per plant), FLYH (fresh leaf yield per hectare), FLOC (fresh leaf essential oil content), FLEOYH (fresh leaf essential oil yield per hectare)

Treat.	Loc.	N	PH		BN		FLWP		FLYHA		FLEOC		FLEOYHA	
			Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	S Dev	Mean	Std Dev	Mean	Std Dev
1	WG	3	86.78	7.62	14.9	1.5	156.2	45.2	2623.06	701.39	0.43	0	11.7	1.49
1	Jajura	3	71.44	4.83	26.4	4.07	138.7	27.67	3852.78	768.7	0.13	0	5.01	1
1	AM	3	144	6.11	86.8	13.43	426.9	145.82	11857.7	4050.39	0.07	0.03	7.23	0.65
2	WG	3	81.67	6.23	14.9	1.35	33.49	1.09	3563.64	640.46	0.37	0	8.57	0.64
2	Jajura	3	71.56	4.5	18.4	4.54	193.4	59.02	5372.22	1639.23	0.14	0	7.52	2.29
2	AM	3	100.22	6.84	53.3	29.49	651.3	155.7	18090.4	4325.08	0.13	0.02	23	6.36
3	WG	3	61.56	7.88	19.6	3.95	28.62	20.93	3717.5	1403.8	0.23	0	4.09	1.07
3	Jajura	3	51.11	7.85	28.9	10.57	186.1	114.54	5169.45	3181.81	0.09	0	4.65	2.86
3	AM	3	77	5.51	57.9	16.52	633.5	264.32	17598.2	7342.22	0.11	0.05	20.7	16.66
4	WG	3	80.22	3.27	13.9	2.99	28.73	4.93	3707.34	967.37	0.13	0	2.4	0.11
4	Jajura	3	76.44	4.83	18.1	4.3	119.5	34.68	3319.75	963.39	0.13	0	4.31	1.25
4	AM	3	112	7.05	45.7	17.04	563.5	184.51	15651.9	5125.47	0.11	0.04	17.6	9.03
5	WG	3	80.33	4.04	19.8	2.46	75.03	16.85	3970	2096.84	0.22	0	6.65	1.08
5	Jajura	3	64.11	6.77	51.1	17.34	96.46	16.03	2679.63	445.28	0.07	0	1.88	0.31
5	AM	3	114.89	6.71	36.1	6.95	849.8	381.82	23604.3	10606.1	0.12	0.04	30.5	20.61
6	WG	3	62	3	19.8	7.56	104.9	41.2	3348.09	971.06	0.17	0	4.5	0.41
6	Jajura	3	45.33	1.73	42.8	10.36	77.41	9.79	2150.31	271.8	0.12	0.01	2.67	0.56
6	AM	3	99.89	10.46	91.7	10.39	353.9	110.4	9830.56	3066.71	0.07	0.05	6.26	3.87

Treat.	Loc.	No	PH		BN		FLWP		FLYH		FLEOC		FLEOYH	
			Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
7	WG	3	83.00	9.33	19.78	7.19	57.68	32.70	3415.40	983.83	0.22	0.00	6.59	2.31
7	Jajura	3	68.22	3.56	50.45	16.85	154.66	77.89	4295.99	2163.62	0.12	0.01	5.41	3.02
7	AM	3	98.78	13.96	66.78	5.68	676.79	158.11	18799.69	4391.95	0.13	0.01	24.20	4.07
8	WG	3	70.22	2.50	21.11	5.06	28.60	33.67	4405.15	797.86	0.17	0.00	3.27	0.11
8	Jajura	3	54.67	3.85	31.00	1.76	150.93	53.34	4192.59	1481.63	0.09	0.00	3.78	1.33
8	AM	3	96.22	5.68	61.89	17.71	514.39	128.36	14288.58	3565.49	0.14	0.01	19.48	4.75
9	WG	3	64.89	2.22	17.33	0.67	9.33	2.48	3373.15	901.10	0.50	0.00	8.13	0.59
9	Jajura	3	62.00	8.09	29.11	3.65	131.01	11.83	3639.20	328.46	0.11	0.01	3.88	0.45
9	AM	3	96.67	6.03	55.11	5.35	674.46	61.44	18734.88	1706.62	0.13	0.06	23.63	10.05
10	WG	3	70.55	5.18	18.22	3.86	68.31	12.49	4365.19	779.30	0.17	0.00	3.95	0.40
10	Jajura	3	65.22	2.46	53.22	27.80	100.87	33.00	2801.85	916.78	0.13	0.01	3.75	1.29
10	AM	3	113.22	8.27	40.78	11.00	712.32	232.12	19786.82	6447.59	0.06	0.02	11.75	2.11

Where: PH (Plant height), BN (branch numbers), FLWP (fresh leaf weight per plant), FLYH (fresh leaf yield per hectare), FLOC (fresh leaf essential oil content), FLEOYH (fresh leaf essential oil yield per hect

Conclusion and Recommendation

Ethiopian rue genotypes highly influenced by location and genotypes and some genotype prefers high land for fruit bearing and all genotypes require low altitude for maximum leaf yield. This experiment revealed that rue is highly variable across location and there are different genotypes in Ethiopian. Based on morphological character 6 different genotypes selected and promoted to national variety trial for further performance evaluation. Nevertheless, there was some limitation in this experiment such as traits for more identification of fruit and phenology determination parameters was not included well as well as the experimentation site was limited to three location which cannot represents all Ethiopian agroecology for rue production. Hence, in the next experiment the aforementioned issues should be included for more important information of Ethiopian Rue genotypes.

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Proximate and Mineral Compositions of the Released Varieties of Black Cumin (*Nigella sativa* L)

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Abstract

Black cumin (Nigella sativa L.) is a highly valued nutraceutical spice crop with a wide array of health benefits that has attracted growing interest from health-conscious individuals, the scientific community, and the pharmaceutical industries. This study was carried to determine the nutritional composition and mineral contents of released black cumin varieties (Nigella sativa L.). The results of this study showed the presence of significant ($p \leq 0.05$) differences among black cumin variety in quality attributes. It contains appreciable quantities of carbohydrates, proteins, and fats. The variety Silingo was the most consistent and higher in terms of crude protein composition (24.46%) to other varieties. The highest carbohydrate content of 14.79 % and 14.36% were recorded from Darbera and Dershaye variety, respectively. Moreover, all varieties contained predominant minerals like potassium, calcium, phosphorous, and magnesium. The maximum values of potassium (809.34 mg/100g), magnesium (229.03 mg/100g) and sulfur (85.44 mg/100g) were recorded in Eden variety. Considerable quantities of sodium, iron, manganese, zinc, and copper were also present among varieties. These results indicate the high nutritional composition of Ethiopian black cumin seeds especially protein (22.14-24.46%), fat (37.74-40.20 %), and minerals that could be utilized in food formulation and pharmaceutical industry.

Introduction

Black cumin (*Nigella sativa* L) belongs to the family *Ranunculaceae* and is widely distributed and cultivated in Mediterranean countries, middle Europe and western Asia. Black cumin was used in ancient Egyptians, Greeks and Romans for therapeutic purpose; and recently as essential oil. The seeds are also used in traditional medicine for many diseases, for bread or cheese flavoring and as a spice in various kinds of meals (Wais *et al.*, 2008), in the form of essential oil, paste, powder, and extract (Chaudhry *et al*., 2020). Black cumin has a high food value due to its adequate quantity of protein and fat, and an appreciable amount of essential fatty acids, amino acids, vitamins, and minerals (Kabir *et al*., 2019).

The oil of black cumin are known for their nutraceutical and pharmaceutical properties (Ramadan, 2007; Sen, Kar and Tekli, 2010); for bringing aroma to different medicines, sterilizing of surgical operation fiber, for veterinary and agricultural medicines production and plastic parts (Aminpour and Karimi, 2004). Cumin seeds are small in size with about 2-3 mm long. They have an aromatic odor, intense dull black color and remarkably angular shape with wrinkled surfaces. The seeds are very diverse and rich in nutrients, organic compounds and vitamins (Eltayeb, 2005). The seeds have been reported to contain mainly fixed oils, proteins, alkaloids, saponins, and essential oil with a higher percentage of monoterpenes, the main constituents being thymoquinone and *p*-cymene (Ali and Blunden, 2003) and a higher constituents of p-cymene (44.31- 45.85 %), α-thujane (12.57-17.30 %), trans-4-methoxy thujane (7.39-8.86%) (Sileshi and Biruk, 2020).

Now a day's industry carries out different evaluations on medicinal and aromatic plants including black cumin (Yilmaz, 2008). The nutritional composition of black cumin seeds differs with the geographic area, harvesting period, and field management. Different scientists have reported moisture, oil, proteins, ash and total carbohydrates contents that ranged from 3.8–7.0%, 22.0–40.35%, 20.85–31.2%, 3.7–4.7% and 24.9–40.0%, respectively (Atta, 2003, Takruri and Dameh, 1998).

The quality of spice, medicinal and aromatic plants is as important as yield. Black cumin is a plant having potential in Ethiopia. However, knowledge on using black cumin for home consumption and in food industry as additives or in formulation is low compared to many other crops in our country. Limited research information is available on the proximate and mineral constituent of seed and variety of spices for future use in nutrition, in industrial product and pharmaceutical use. Therefore, the present study was undertaken with the objectives of comparing the proximate and mineral constituent among four black cumin varieties.

Materials and Methods

Materials collection and preparation

Black cumin (*Nigella sativa* L.) varieties: 'Darbera', 'Silingo' 'Dershaye' and 'Eden' were collected from experimental site of Kulumsa Agricultural Research Centre, Horticulture and Spice Research site. The samples were cleaned from foreign materials and placed in labeled, dry plastic bags and transported to Ethiopian Institute of Agricultural Research Food and Nutrition Research Laboratory for Proximate analysis. The black cumin seed flour was milled using pestle and mortar for powder preparation and sieved through 75 μm sieve and packaged in plastic bags prior to analyses.

Proximate analysis

Proximate parameters (carbohydrate, fats, protein, moisture, and ash) of the black cumin varieties were determined using the Association of Official Analytical

Chemists (AOAC, 2000) method. The nitrogen content of the samples was determined by micro-Kjeldhal method. The nitrogen content obtained was multiplied by 6.25 to change it to crude protein. The carbohydrate content was calculated as the difference:

%Total carbohydrate = [100 − % (protein + fat + moisture + ash + crude fiber)]

Mineral analysis

One gram of dried and ground black cumin seeds was weighed and placed in a porcelain crucible. Then the sample was placed in a muffle furnace at 500°C for 6 hr. The ash was cooled and dissolved in 5-ml of 20% HCL. Then the solution was warmed through an acid washed filter paper in to a 50-ml volumetric flask and the solution was diluted to volume with deionizer water and mixed well (AOAC 1990). Minerals were determined using a Perkin Elmer PE model 5000 atomic absorption spectrophotometer (Analytical method, 1994) with wet digestion method under optimum conditions of nitric acid- perchloric acid mixture used as a reagent.

Statistical Analysis

All the data were analyzed according to the analysis of variance (ANOVA) using SAS Statistical Package Program. Significant differences between means were separated using the LSD (Least Significant Difference) test at 5% LSD value.

Results and Discussions

Crude protein content of the of black cumin varieties presented in (table 1). Silingo variety had significantly the highest amounts of crude protein (24.46%) to other studied varieties of Darbera, Dershaye and Eden valuing 21.14, 22.33 and 23.25%, respectively. The crude protein content of the varieties in this study suggests that it may be useful in food formulation systems, especially with a lower protein content of cereal crops. These results are in close agreement 20.30, 22.80, and 26.60% crude protein reported by (Kabir *et al.,* 2019), (Sultan et al., 2009), and (Salem, 2001), respectively. The protein contents vary in amounts among the four studied varieties. This may be related to the origin of the plant (Tulukcu 2011; Cheikh-Rouhou, 2007), maturation of seeds (Botnick *et al*., 2012), and agronomic practices (Ashraf *et al*., 2006; Karimi-Yeganeh and Zeinali, 2010 and Mozaffari *et al*., 2000). It may also be due to geographical and climatic differences where grown (Atta, 2003).

There is no significant difference among the studied variety in their Fat content. However, their higher fat content range (37.74-40.20%) may contribute significantly to the energy requirement for human diet and it could be useful in food formulation systems, especially with lower fat content crops. This results also made black cumin a better source of fat than the other spices. The fat content obtained in this study was found higher than another report (Nergis and Otles¸ 1993) 32%, (Salem, 2001) 34.90 % and (Mamun and Absar, 2018) 32.74% and lower than 45.4 % (Kabir *et al*., 2019) in black cumin.

There was a significant difference among variety for crude fiber content. The Darbera variety exhibited the highest fiber (10.88%) than Dershaye, Eden and Silingo variety. This differences might be attributed to the variations of variety constituents. Crude fiber content in N. sativus varieties (9.72-10.88%) was higher than 8.40% reported by (Boskabady and Shirmohammadi, 2002; Ali and Blunden, 2003) and higher than 6.60% as reported by (Nergis and Otles¸ 1993) and (Babayan *et al*., 1978); than 6.0% reported for the same crop. Crude fiber helps in the prevention of heart diseases, colon cancer, diabetes, etc. Crude fiber helps in the prevention of heart diseases, colon cancer, diabetes, etc. Therefore, it will be useful if N. sativus is added to daily diet and used in food formulation to help relieve constipation.

Ash content is an indication of the mineral content of a food. The ash content of the Darbera variety exhibited 4.66% larger than the other varieties as shown in (Table 1). This varietal result was close to 4.80% ash of black cumin (Boskabady and Shirmohammadi, 2002; Ali and Blunden, 2003) and 4% ash of black cumin (Nergis and Otles¸ 1993). The study revealed the presence of distinct variations with respect to varieties which could be used as an important sources of minerals. The differences in ash content may be due to the differences in genotypes, climatic condition, type of soil and milling process.

The moisture content of tested varieties ranged from 9.15-9.25%, which is optimum for the storage of spices. This percentage of each variety might be influenced by the type of product, variety, and storage condition. The low moisture content enhanced their stability by avoiding mold growth, biochemical reaction and extends the shelf life. In another research study, Cheikh-Rouhou *et al*., (2007) reported 8.65 and 4.08% moisture content in Tunisian and in Iranian variety respectively. Similarly, Nergis and Otles (1993) and Babayan *et al*. (1978) reported about 6.40% moisture content for black cumin. The spice industry aims to maintain its products at less than 14% moisture to prevent spoilage from molds and above 5% to avoid crumbling and loss of shape (Murphy *et al*., 1978). The moisture content percent in the present study had shown to meet the standard for moisture content.

The carbohydrate content was slightly higher in Darbera varieties (14.79%) followed by Dershaye (14.36%) and Eden (13.64%) varieties. This result is found to be lower than the carbohydrate of the black cumin seed of 26.90% reported by

Salem (2001); 29.18% of the figure reported by Mamun and Absar (2018) and 24.9% of the report of Ali and Blunden (2003).

Table 1. Proximate composition of black cumin varieties (%)

Varieties	Moisture content (%)	Ash (%)	Fat (%)	Protein (%)	Fiber (%)	Carbohydrate (%)
Darbera	9.25[a]	4.66[a]	39.72[a]	22.14[c]	10.88[a]	14.79[a]
Dershaye	9.26[a]	4.13[c]	39.77[a]	22.33[c]	9.88[b]	14.36[ab]
Eden	9.26[a]	3.76[d]	40.20[a]	23.25[b]	9.85[bc]	13.64[bc]
Silingo	9.15[b]	4.41[b]	37.74[b]	24.46[a]	9.72[c]	13.37[c]
LSD (0.05)	0.05	0.2	1.08	0.26	0.15	0.95
CV (%)	0.27	2.47	1.46	0.6	0.77	3.59

Mean values down the columns with the same letters are not significantly different at 5% level significance. LSD= Least significant difference; CV = coefficient of variation

Mineral composition

The analysis result revealed the presence of significant difference ($p < 0.05$) among varieties for potassium, calcium, phosphourus and magnesium content (Table 2). Potassium is the most dominant minerals that ranged between 736.03-809.34 mg/100g followed by calcium (472.93-531.83 mg/100g), phosphorous (489.45-497.61 mg/100g) and magnesium (210.97-229.03 mg/100g), respectively. Eden variety had significantly different potassium content of 809.34mg/100g followed by 751.10, 736.03, 712.56 mg/100g for Silingo, Dershaye and Darbera varieties, respectively. Similar to this results of mineral composition dominated by potassium (808.00 mg/100g) followed by calcium (570mg/100g), phosphorous (543 mg/100g) and magnesium (265 mg/100g) were reported by Sultan *et al.* (2009), respectively. In contrast major mineral contents of Bangladeshi black cumin seeds was calcium (579.33 %) as the prime element followed by potassium (510.30 %) (Mamun and Absar, 2018) showing 36% lower in potassium as compared to this study. These type of variation was also reported by Babyan *et al.* (1978) and Eltayeb (2005) as black cumin seeds are very diverse and rich in nutrients, organic compounds and vitamins. The highest calcium content in the present study was recorded in Darbera (531.83 mg/100g), followed by Dershaye (529.20 mg/100g) and Silingo 529.05 mg/100g. Thus, an essential guarantee for the quality of a food product. In contrast, the least was observed in Eden was 472.93 mg/100g).

Table 2. Mineral composition of black cumin varieties.

Varieties	Mineral composition (mg/100g)								
	Ca	K	Mg	Na	P	S	Cu	Fe	Zn
Darbera	531.83^{a}	712.56^{d}	227.57^{b}	1.71^{d}	492.33^{c}	72.48^{c}	0.13^{a}	53.98^{a}	4.07^{a}
Dershaye	529.20^{b}	736.03^{c}	225.09^{c}	4.74^{b}	497.61^{a}	71.833^{c}	0.14^{a}	19.28^{c}	3.77^{b}
Eden	472.93^{c}	809.34^{a}	229.03^{a}	3.58^{c}	489.45^{d}	85.44^{a}	0.06^{b}	12.79^{d}	4.16^{a}
Silingo	529.05^{b}	751.11^{b}	210.97^{d}	4.93^{a}	495.42^{b}	75.38^{b}	0.02^{c}	25.39^{b}	4.06^{a}
CV (%)	0.13	0.07	0.32	1.45	0.14	0.52	13.61	1.23	1.61
LSD (0.05)	0.56	0.41	0.58	0.04	0.58	0.33	0.01	0.28	0.05

Mean values down the columns with the same letters are not significantly different at 5% level significance. LSD= Least significant difference, CV = coefficient of variation.

Eden variety had the highest value of 809.34 mg/100g of potassium, 229.03 mg/100g of magnesium and 85.44 mg/100g of sulfur. However, Darbera variety had significant difference among varieties in Ca, Cu and Fe having the highest composition values of 531.83, 0.13, and 53.98 mg/100g. Moreover, considerable quantities of sodium, iron, sulfur, copper and zinc were present in the all black cumin varieties tested.

Varieties also differed significantly ($p < 0.05$) in sodium (Na) and phosphorous (P) content. The values for sodium and phosphorous composition of the studied varieties ranged from 1.71 to 4.93 mg/100g and 489.45-497.61mg/100g, respectively (Table 2). The highest sodium and phosphorous values were obtained in Silingo (4.93 mg/100g) and Dershaye (497.61 mg/100g), respectively. The phosphorous content in this finding were in accord with the report of Sultan *et al*. (2009), i.e., 543 mg/100g.

Variation in iron content was also significant ($p < 0.05$) among the varieties. In this study, the iron content of the varieties was found to be in the range of 12.79 to 53.98 with an average of 27.86 mg/100g (Table 2). The highest Fe content was observed in ‘Darbera’ followed by ‘Silingo’, whereas the least was observed in ‘Eden’ variety. Zemenay *et al*. (2021) reported Nigella sativa, Ocimum basilicun, and Ruta chalepensis are good sources of Zn, Cu and Fe with value of 5.55% of Fe from three cultivars of black cumin.

The varietal content of zinc ranged between 3.77-4.16% implying black cumin as a good source of zinc. Bhishnurkar *et al* (2016) reported zinc is an essential human nutrient. It acts as a catalyst for over 300 enzymes and is found in all tissues. It plays a role in immune function, protein synthesis, wound healing, DNA synthesis, and cell division. It was also reported that *Nigella sativa* seeds contain a good amount of various vitamins and minerals like Cu, P, Zn, and Fe (Boskabady and Shirmohammadi, 2002; Ali and Blunden, 2003). In addition to their genetic makeup the environmental factors could contribute for varietal variations in mineral constituents.

Conclusion and Recommendation

Moisture, ash, fat, proteins, fiber and carbohydrate contents were found to be in the range of 9.15-9.26%, 3.76-4.66%, 37.74-40.20%, 22.14-24.46%, 9.72- 10.88% and 13.37-14.79%, respectively, indicating Ethiopian black cumin varieties had nutritive value that had a significant roles in human nutrition. The distribution of ash, fiber, carbohydrate, calcium, and copper content varies clearly among the black cumin seeds, with the Darbera variety containing the highest content. On the other hand, Silingo is high in protein as other varieties were recommended for their high fat content. Eden variety had shown the highest value of potassium (809.34 mg/100g) and magnesium (229.03 mg/100g). Hence, classification of black cumin seeds according to their proximate composition affords advantage of their nutrition in functional foods. Our findings now provide a valuable basis for developing black cumin as valuable food additives to enhance human nutrition via their dietary fiber, protein, fat and their mineral content. The quantitative characterization of black cumin seed should be taken into consideration as a criterion in a varietal development for food industry, for health and nutritional benefits.

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Yield and Yield Components of Black Cumin As Affected By Seed Rate and Inter–Row Spacing

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Abstract

Field experiment was conducted to determine optimum seed rate and inter-row spacing to boost seed yield and yield attributes of black cumin in Arsi highlands. It was executed in 2017, 2018 and 2019 cropping seasons at Kulumsa Agricultural Research Center. Twelve treatment combinations; four seed rates (5kg ha^{-1}, 10kg ha^{-1}, 15kg ha^{-1} and 20kg ha^{-1}) and three inter-row spacings (20cm, 30cm and 40cm) were studied using 'Aden' variety. The experiment was laid out in a randomized complete block design (RCBD) with factorial arrangement in 3 replications. The interaction effect of seed rate and inter-row spacing did not significantly ($p>0.05$) influenced all growth and yield parameters. However, the main effect of seed rate significantly affected ($p<0.05$) most of the parameters studied while inter-row spacing had significant effect ($p<0.05$) on only days to emergence and plant height. Yield and yield contributing factors; number of primary branches $plant^{-1}$, number of secondary branches $plant^{-1}$, number of pods $plant^{-1}$and seed yield (qt ha^{-1}) were significantly influenced by seed rate. Seed yield increased from 4.62 qt ha^{-1} to 6.36 qt ha^{-1} as seed rate increased from 5kg ha^{-1} to 20kg $ha^{-1}$and showed a decrease in yield from 6.01 qt ha^{-1} to 5.07 qt ha^{-1}. Decreasing population density from 20 cm to 40 cm did not result in statistically significant difference on seed yield. In general, 15 $kgha^{-1}$ seed rate and 30 cm inter-row spacing could be recommended for optimum black cumin production. However, further research needs to be undertaken in different black cumin growing areas of Ethiopia on recent varieties to arrive at the optimum seed rate and inter-row spacing by including information related to cost of production.

Introduction

Black cumin (*Nigella sativa L.*) is an annual spicy and a medicinal herb that belongs to the *Ranunculaceae* family. Sometimes it is referred to as nigella or black seeds or 'Tikur azmud' in Amharic. This specie is originated in Egypt and East Mediterranean, but is widely cultivated in Iran, Japan, China and Turkey (Shewaye, 2011). Ethiopia is among the major black cumin producing and exporting countries like India, Sri Lanka, Bangladesh, Afghanistan, Pakistan, Egypt, Iran, Iraq, Syria and Turkey (Samima *et al*., 2018). The majority of Ethiopia's black cumin exports go to Arabic and some Muslim countries and it reached to 98% of the national exports in 2008 (Orgut, 2007). According to Ethiopian Investment Agency Report (2015) Ethiopian annual production of black cumin seed was 18 000 metric tons during the cropping year of 2014/15 (EIC, 2016).

Black cumin grows as a rain fed crop within 1500 to 2400 meters of altitude on heavy black soils and prefers loamy sand soils (Datta *et al*., 2001) with a pH of 7.0 to 7.5 (Orgut, 2007). In Ethiopia, it has a similar ecological requirement to teff and chick pea and usually cultivated on residual moisture following harvest of teff and chick pea. It is a major spice crop in Dembia, South Gonder, Shirka in Arsi Zone and Goro in Bale Zone (Getinet *et al.,* 2010).

In addition to its use as spice and culinary purposes, black cumin has multiple uses in cosmetic as well as medicinal industries (Ali and Blunden, 2003; Arici *et al*., 2005; Black *et al.,* 2005; Kokdil *et al*., 2005; Ashraf and Orooj, 2006: Kokdil *et al*., 2006). In Ethiopia, it is commonly used in Amharic "Berbere" preparation (Hedberg *et al*., 2003), for preparation of curries, bread, "katikala" (Jansen, 1981),"Shamita" (Mogessie and Tetemke, 1995), traditional Ethiopian stews, "Wot" and preservation of butter. It is principally used to flavor food, either as whole grain, in powdered form or as an oleoresin extract.

Among the factors that affect crops yield, suitable planting density play major role and agronomists believe that the establishment of optimum density for a given plant in a field is the basis for the successful cropping that could boost the productivity. Optimum plant density is a density at which all environmental parameters (water, air, light, soil) are fully exploited by the plants and at the same time, intra-species and extra-species competitions are minimized (Alizadeh and Koucheki, 1995). Regardless of its high importance, in Ethiopia, black cumin lacks research recommendations on the major agronomic practices such as optimum plant population density (seed rate) that could reduce growth performance and lead to the poor yield of the crop. In order to increase its productivity and the income of the farmers, it is vital to determine the proper seed rates and inter-row spacing for black cumin. Therefore, this experiment was initiated to determining optimum seed rate and inter-row spacing to boost seed yield and yield related traits of black cumin in Arsi highlands and other suitable growing areas in the country.

Materials and Methods

Description of the study area

The experiment was conducted at Kulumsa Agricultural Research Center (KARC) during the main growing seasons of 2017, 2018 and 2019. KARC is located at 8° 00' to 8° 02'N latitude and 39° 07' to 39° 10'E longitude at an elevation of 2210 m.a.s.l in Tiyo District, Arsi Administrative Zone of the Oromia Regional State. It is located at 167 km in the Southeast of Addis Ababa. The research center is located on a very gently undulating topography with a gradient of 0 to 10% slope

(Abayneh *et al*., 2003). The agro- climatic condition of the area is wet with 832 mm mean annual rainfall and has a uni- modal rainfall pattern with extended rainy season from March to September with June to August being the peak months. The mean annual maximum and minimum temperatures of KARC are 23.2 and 10°C, respectively and have three major soil types: Eutric Vertisol, Vertic Luvisol and Vertic Cambisol (Abayneh *et al*., 2003).

Experimental material, design and treatment

The experiment was carried out using a popular black cumin variety 'Aden', which was released by Ethiopian Institute of Agriculture Research (EIAR), Melkasa Agricultural Research Center (MARC) (MoANR, 2009). Aden is a widely popularized and cultivated variety with a yield potential of up to 1.5 ton ha^{-1} under research management and 0.8 to 1.2 ton ha^{-1} under farmers' management (Alemaw *et al.,* 2010). The experiment included two factors namely; three (3) inter-row spacings (S) (S1 = 20 cm, S2 = 30 cm and S3 = 40 cm) and four (4) seed rates (R) (R1 = 5 $kgha^{-1}$, R2 = 10 $kgha^{-1}$, R3 = 15 $kgha^{-1}$ and R4 = 20 $kgha^{-1}$) which were combined factorially and formed twelve treatments all together. The experiment was laid out in randomized complete block design (RCBD) with three replications.

Data collection and analysis

Phenological and agronomic data on days to emergency (DE), days to 50% flowering (DF), days to maturity (DM), plant height (PH), number of primary branches per plant (NPB), number of secondary branches per plant (NSB), number of pods per plant (NPDPP), number of seed per pod (NSPPD), seed yield per pant (SYLDPP) and seed yield per hectare (SYLDHA) were collected either from whole experimental plot or from five randomly selected representative samples of plants from the middle rows. For individual plant traits, the mean values of 5 samples plants from each plot were used. The collected data were subjected to analysis of variance (ANOVA) using SAS Statistical Package Program (SAS 2009). Significant differences detected among treatment means were separated using Duncan's multiple range test (DMRT) at 5% probability level.

Results and Discussion

Results of ANOVA (Table 1) of days to emergency (DE), plant height (PH) (cm), number of primary branches per plant (NPB), number of secondary branches per plant (NSB), number of pods per plant (NPDPP) and seed yield per hectare (SYLDHA) indicated the significant ($p<0.05$) influence of the main factor seed rates. Contrarily, days to 50% flowering (DF), days to maturity (DM), number of seeds per pod (NSPPD) and seed yield per plant (SYLDPP) were not significantly ($p>0.05$) affected by seed rates. However, inter-row spacing affected only days to emergence (DE) and plant height (PH). Unfortunately, the interaction effect of seed rate and inter-row spacing was significant to none of the traits recorded.

Days to seed emergence was not significantly affected by increased seed rate from 5-15 kg ha-^{1} but started to increase at the rate of 20kg ha-^{1} (Table 1). The higher the seed rate, the longer the time the seed took to emerge from the soil and the lower the seed rate the earlier the seed took emerge (Figure 1a, r^2=0.94). Likewise inter-row spacing significantly affected days to emergence (Table 1). The narrower the spacing, the late the emergence while the wider the spacing the earlier the seed took to emerge (Figure 1b, r^2=0.91). Plant height was also affected by the main effects of seed rate and inter-row spacing (Table 1). When seed rate increased plant height was also increased and vice versa (Figure 1a, r^2=0.76), while plant height reduced highly (Figure 1b, r^2=0.97) as inter-row spacing get wider.

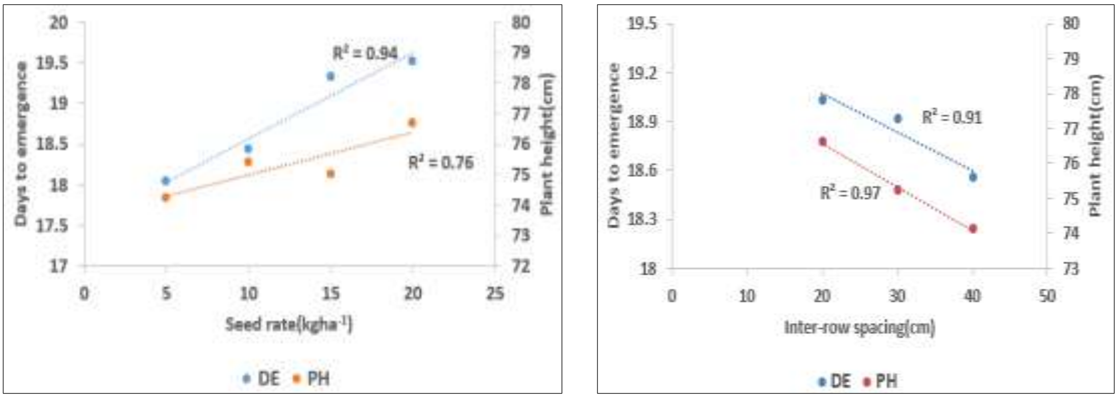

Figure 1. Responses of days to emergence and plant height to seed rate (a) and inter-row spacing (b). DE=days to emergence, PH=plant height.

Table1. Effect of seed rate and inter - row spacing on seed yield and yield attributes of Black cumin

Treatments	DE	DF	DM	PH (cm)	NPB	NSB	NPDPP	NSPPD	SYLDPP (g)	SYLDHA (qt ha^{-1})
Seed rate ($kgha^{-1}$)										
5	19.52[a]	93.07	153.56	74.23[b]	5.56[a]	19.53[a]	25.10[a]	94.23	2.68	4.62[b]
10	19.33[a]	93.00	154.18	75.41[ab]	5.096[b]	15.78[b]	20.62[b]	93.94	2.29	5.06[ab]
15	18.44[ab]	93.18	153.78	75.00[ab]	5.22[ab]	17.40[ab]	21.76[b]	101.01	2.65	5.84[ab]
20	18.04[b]	92.96	153.81	76.70[a]	5.00[b]	15.73[b]	20.84[b]	96.30	2.36	6.36[a]
LSD	0.45	0.69	0.86	2.38	0.36	2.48	2.80	11.21	0.42	1.39
Significance	**	ns	ns	**	**	**	**	ns	ns	**
Inter-row spacing (cm)										
20	19.03[a]	92.69	153.78	76.62[a]	5.13	16.84	21.70	92.47	2.49	6.01
30	18.92[ab]	93.28	153.89	75.23[ab]	5.33	17.71	22.78	98.74	2.43	5.33
40	18.56[b]	93.19	153.83	74.14[b]	5.20	16.77	21.74	97.89	2.56	5.07
LSD	0.39	0.60	0.74	2.06	0.32	2.15	2.42	9.71	0.37	1.2
CV (%)	4.26	1.33	0.99	5.63	12.46	25.85	22.58	20.70	30.22	45.20
Significance	*	ns	ns	*	ns	ns	ns	ns	ns	ns

Means within a column that have the same letters are not significantly different * - Significant at 5% level, ** - Significant at 1% level. DE=days to emergency, DF= days to 50% flowering, DM=days to maturity, PH=plant height, NPB= number of primary branch per plant, NSB=number of secondary branch per plant, NPDPP= number of pod per plant, NSPPD= number of seed per pod, SYLDPP= seed yield per pant, and SYLDHA= seed yield per hectare, cm = centimeter, g = gram, qt ha^{-1} = quintal per hectare

In general, optimum plant density is a density at which all environmental parameters (water, air, light, soil) are fully exploited by the plants and at the same time competitions are minimized (Alizadeh and Koucheki, 1995).

A higher seed rate and closer inter-row spacing obviously increased competition among plants for the available resources such as soil moisture, air and nutrients for emergence and consequently delayed seed emergence. The reverse happened at lower seed rates and wider inter-row spacing in which competition for the aforementioned resources reduced and resulted in early emergence. At the same time, at higher seed rates and closer inter-row spacing, a higher plant height was recorded due to high competition for light, space and prefer to proportionate the available soil nutrients, moisture and of course the photosyntate to vertical growth than lateral growth. At lower seed rates and wider inter-row spacing however plants allocate more food/energy for lateral growth than height due to availability of enough space, sufficient light interception thus low population density. Resultred in a lower plant height. According to Janick (1972) increasing competition is similar to decreasing the concentration of growth factors. Eventhough scarce, similar results was reported by Sharmeen (2013) who stated that increasing the population of black cumin (higher seed rate and closer inter-row spacing) within an area of land increased plant height, and this may be due to higher competition among the plants. From the physical observation of the experiment, as population density decreased there were an increase in lodging. Conversely, with the wider spacing and lower seed rate, the open canopy resulted in less uniformity in stand that favored weeds development.

Besides, the present study results confirmed that the main effect of seed rate significantly affected black cumin seed yield but inter- row spacing did not (Table 1). Seed yield increased in the range of 4.62 to 6.36 qt ha^{-1} as seed rate increased from 5 $kgha^{-1}$ to 20 $kgha^{-1}$. The highest average seed yield (6.36 qt ha^{-1}) was obtained at the higher seed rate (25$kgha^{-1}$) and the least (4.62 qt ha^{-1}) was obtained from the lowest seed rate (5 $kgha^{-1}$). This results is in agreement with the report of Akintoye *et al*. (2009) in they stated yield per unit area tends to increase as plant density (seed rate) increased up to a certain point and then declines. However, a declining yield trend was not shown in our finding indicating that there is still a room to increase the yield with increasing seed rate until the optimum point reached (Figure 2a). Mazumder *et al*. (2007) stated that plants grown under normal spacing will have optimum population density per unit area that provides optimum conditions for luxuriant crop growth and better plant canopy area due to maximum light interception, photosynthetic activity, assimilation and accumulation of more photosynthates into plant system and hence they produce more seed yield of best quality.

Verzalova *et al*. (1988) reported that row spacing of funnel did not have effect on the plant height but number of umbel and seed yield per plant increased at the wider spacing. Norman (1992) reported that increasing plant density does not affect individual plants if the plant density is below the level resulting in competition. This finding was observed in the present study results of seed yield plant^{-1}. Increasing neither the seed rate nor the inter-row spacing affected the seed yield per plant (Table 1) for the reason that the plant densities studied were below the level for the competition to occur between plants. This phenomenon was also observed for the seed yield ha^{-1} in since increasing seed rates increased the seed yield ha^{-1} owing to the fact that the plant densities studied did not reached the level to create maximum competition (Figure 2a). Besides, although the number of pods plant^{-1} (NPDPP) was significantly affected by seed rate, its contribution to the seed yield ha^{-1}(SYLDPHA) was not observed as it decreased with increasing seed rate. The contribution of the number of seeds pod^{-1} (NSPPD) rather affected the seed yield ha^{-1} as it showed increasing trend with increasing seed rate (Table 1).

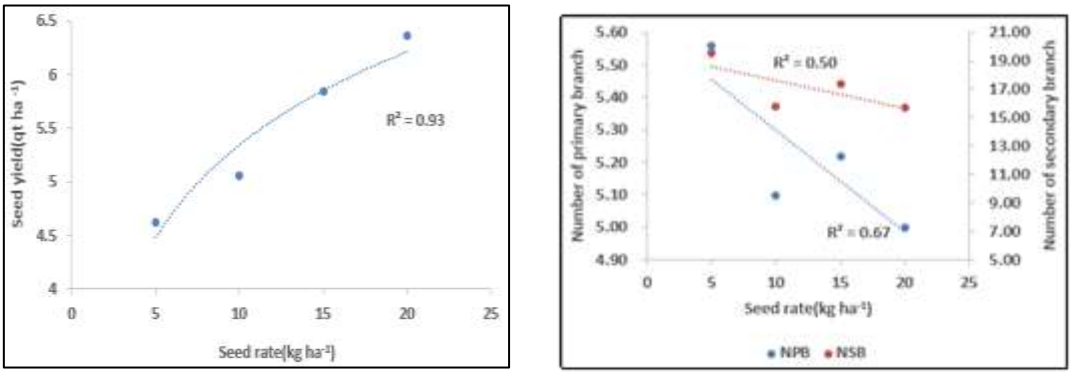

Figure 2. Responses of seed yield (a), and number of primary branch and number of secondary branch (b) to seed rate. NPB=Number of primary branch, NSB=Number of secondary branch.

As components of yield, the number of primary and secondary branches per plant were significantly affected by the seed rate studied but not by the inter-row spacing (Table 1). Increasing seed rate significantly reduced the number of primary branches (NPB) per plant (Figure 2b, r^2=0.67) as well as the number of secondary branches (NSB) per plant (Figure 2b, r^2=0.50). This finding is in accordance with the report of Degenhardt and Kondra (1981), Roy and Paul (1991) and Kızıl (2002) who concluded that as seed rate increased, number of branches per plant decreased linearly probably due to created higher interplant competition. Completions between plants for resource are mostly a result of denser and lengthy canopy with few number of branches and ends with lower yields.

Conclusion and Recommendation

In general, the interaction effect of seed rate and inter- row spacing was not found significant for all of the growth and yield related traits as well as for seed yield. However, the main effect of the individual factors was significant on most of the traits studied. Statistically significant variations were obtained on growth and seed yield attributes of black cumin with increasing seed rates. Increase of seed rates from 5 kgha^{-1} to 20 kgha^{-1}resulted in increased average black cumin seed yields of 4.62 qt ha^{-1}, 5.6 qt ha^{-1}, 5.84 qt ha^{-1} and 6.36 qt ha^{-1} as seed rates increased to 5 kgha^{-1}, 10 kgha^{-1}, 15 kg ha^{-1} and 20 kg ha^{-1}, respectively. Nevertheless, inter- row spacing of 20 cm, 30 cm and 40 cm showed statistically non-significant differences for most of the growth and yield related traits except days to emergence and plant height. Although increasing seed rate showed increasing trend of seed yield with no point of return, 15 kg ha^{-1}seed rate combined with 30 cm inter-row spacing could be recommended for use for black cumin production. Yield and yield related traits showed reasonable performances which were not statistically different from the maximum seed rate (20 kgha^{-1}) and inter-row spacing (40cm). However, further research needs to be undertaken in different black cumin by including other black cumin producing areas of the country on recent varieties to arrive at solid economically optimum recommendation on seed rate and inter-row spacing by including information related to cost of production.

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Evaluation of Banana (*Musa* spp.) Cultivars for Growth, Yield and Quality traits in Ethiopia

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Abstract

Banana (Musa spp.) is one of the most important food and cash crops in Ethiopia. Despite its food and economic importance, most of the cultivars grown by banana producers are low yielders with poor fruit qualities. Thus, this study was conducted to find the best cultivar for major banana growing areas of Ethiopia. A study was conducted to evaluate four introduced and five local banana cultivars with a check variety for growth, yield and quality performances at four locations for two crop cycles, i.e., July 2015 to June 2017. *The experiment was laid out in a randomized complete block design (RCBD) with three replications. The results revealed significant differences among the studied cultivars in plant height, days to shooting, time from planting to harvest, bunch weight, finger diameter, length and weight, yield, peel thickness, pulp-to-peel ratio, soluble solids, titratable acidity, pH, moisture and ash contents. The cultivars had generally short and thick plants. Days to flowering of cultivars ranged from 243.8 to 316.8 while days to first harvest ranged 374.4 to 446.7 days. The yield ranged from 43.67 to 52.46 t ha^{-1}. Five cultivars had comparable yields to the standard check Williams-I'. The sensory results indicated that all the cultivars were generally preferred. The candidate cultivars recorded higher soluble solids, phosphorus and potassium, but lower titratable acidity than the check. The moisture and ash contents ranged from 71.53 to 76.56% and 2.50 to 3.36%, respectively. Considering the growth and yield performances as well as fruit physicochemical and sensory characteristics, 'Lady Finger' and 'Dinke-1' are recommended for production in the major banana growing areas of Ethiopia.*

Introduction

Banana (*Musa* spp.) is one of the most important fruit crop in the worldwide. It is a staple food for millions of people in the developing world, and provides income and employment to rural populations (Vuylsteke *et al*., 1993; Honfo *et al*., 2007). The total annual production of banana worldwide is estimated at 153 million tons from an estimated area of 11.1 million hectare of land (FAOSTAT, 2017). As export commodity, banana has high contribution to the economies of many low-income countries (Arias *et al*., 2003).

Ethiopia is among the tropical countries where its vast areas are suitable for banana cultivation (Wiersinga et al., 2008; CSA, 2020). Banana ranks first among fruit crops in area (64,033 ha) as well as volume of production (563,395 tons) (FAOSTAT, 2017), where the bulk is produced in traditional agricultural system mainly for home consumption and to supply the nearby local markets purpose (Seifu, 1999; Dawit and Asmare, 2008; Asmare and Derbew, 2013). Banana plays an important socioeconomic role in food security and income generation of the rural communities (Dawit and Asmare, 2008; Natnael, 2016). It provides both on-farm and off-farm employment opportunities all along the value chain (Seifu, 2003; Joosten, 2007; Joosten *et al*., 2011; EHDA, 2012; Asmare and Derbew, 2013).

Despite its importance, the national average yield of banana is estimated at 8.8 ton ha^{-1} (FAOSTAT, 2017), in small-scale farms is 7.6 ton ha^{-1} and commercial plantations is 9.4 ton $ha\text{-}^{1}$ (CSA, 2019). This is far less than the world average banana yield of 20.2 ton ha^{-1}/year (FAOSTAT, 2017). The low productivity of banana is mainly attributed to limited provision of production technologies such as improved varieties and crop management practices, diseases and insect pests, poor postharvest handling and marketing, and insufficient support from the extension system (Seifu, 1999; Asmare and Derbew, 2013; Natnael, 2016). Over the years, ten dessert and four cooking improved banana varieties have been registered and made available for production (MoARD, 2006; MoA, 2019). However, these varieties have not met the ever-growing demand for improved banana varieties suitable for different agro-ecological conditions across the country. Introduction of improved cultivars from foreign sources and local collection of superior genotypes for evaluation and adoption is found vital and a shortcut to a long, tedious and expensive banana breeding programs to boost yields. Therefore, multi-locational variety trials were undertaken to identify the best banana cultivar for the target agro-ecologies that have better yield and other quality traits.

Materials and Methods

Description of the study sites

The trials were conducted at Melkassa, Jimma, Tepi and Arba Minch Agricultural Research Centers from July 2015 to June 2017. The description of experimental sites are briefly described in Table 1.

Table 1. Agro-ecological descriptions of the study sites

Locations	Geographic Coordinates Latitude	Longitude	Altitude (m.a.s.l)	Annual Rainfall (mm)	Average Temperature (°C) Minimum	Maximum	Soil Type
Melkassa	8°24' N	39°21' E	1550	763	14.0	28.4	Andosol (Sandy loam)
Jimma	7°46' N	36°00' E	1753	1561	9.0	28.0	Eutric Nitosols (Reddish brown)
Tepi	7°30' N	35°18' E	1200	1522	15.0	30.0	Nitosols (Sandy clay loam)
Arba Minch	6°05' N	37°33' E	1170	930	16.0	30.5	Black sandy loam

m.a.s.l = meters above sea level

Experimental materials and design

Over 20 banana cultivars sourced from the Bioversity International and eight locally collected banana genotypes were evaluated at Melkassa Agricultural Research Center before 2015. Based on the preliminary results, four introduced ('Chinese Dwarf', 'Lady Finger', 'Paracido al Rey' and 'Williams Hybrid') and five local ('Ambo-2', 'Ambo-3', 'Amboweha Selle-3', 'Dinke-1' and 'Dinke-2') banana cultivars were selected and promoted further evaluated in multi-location variety trials at four sites (Table 1) in the major banana producing areas of Ethiopia. The cultivars were tested in RCBD with three replications at each experimental site. The registered banana variety 'Williams-I' was used as a standard check. Eight plants of each cultivar were planted on each plot. The plants were spaced at 2.5m x 2.5m (Seifu, 1999), providing a population of 1600 plants ha^{-1} in the first year, and three different aged plants (parent, first ratoon and second ratoon) per mat in the remaining two years. Supplementary irrigation was applied during dry period through furrow. Diammonium phosphate and Urea were broadcasted by hand, each at the rate of 300g per mat per year in three equal splits. Weeds were controlled by hand hoeing.

Data collection and measurement

Data on plant growth, yield and fruit quality characteristics were collected for two crop cycles, and averaged over locations and years.

Growth parameters

The agronomical traits measured were plant height, pseudostem girth, number of days to flowering, days from flowering to harvest and days from planting to harvest. Plant height was measured from ground level to the point where the leaf petioles of the youngest two leaves intersect (to the neck of the inflorescence), while pseudostem girth was measured at 30 cm above the ground by using tape. The total numbers of functional leaves were determined by counting all the existing green leaves on a plant. The functional leaves had at least 50% green leaf surface area.

Yield and yield components

Bunch weight (kg), number of hands per bunch, number of fingers per hand, fruit length (cm), fruit diameter (cm), fruit weight (g), marketable and total fruit yields were among yield and yield component traits recorded. Bunch and finger weights were measured using balances. Fruit length and diameter were determined using tape and caliper, respectively. Marketable and total fruit yields were estimated from plot yields and expressed in ton ha^{-1} $year^{-1}$.

Sensory and physicochemical characteristics of fruits

The sensory and physicochemical characteristics of the genotypes were determined to establish their quality profile. Sensory attributes and consumer acceptability of fruits including color, aroma, taste, texture, peel-ability and general acceptability were scored by panelists based on a five-point of scale with 1=poor, 2=fair, 3=good 4= very good and 5=excellent. The fruit physical characteristics like peel thickness, pulp and peel weights, and pulp-to-peel ratio were evaluated. Peel thickness was measured with a digital caliper between two edges and the values are expressed in mm. Peel and pulp weights were determined by separating the peel and pulp by hand peeling and weighing the peel and pulp separately. Pulp-to-peel ratio was obtained by dividing the pulp fresh weight by the peel fresh weight. The chemical composition as TSS, TTA and pH. The TSS were estimated using a digital hand refractometer and the results obtained were expressed in °Brix. The TTA was estimated by titrating to a pH of 8.2 with a standard solution of 0.1 N NaOH and the values were expressed in grams of malic acid per 100g of pulp. The ratio of TSS to TTA was determined by dividing the TSS value by the TTA value. The pH of fresh fruits was estimated by using a digital pH-meter. The moisture content (%), ash content (%) and mineral concentrations (phosphorous, potassium and sodium in mg/100g pulp) were determined following the standard methods.

Disease reaction

Data on major diseases of potato such as Fusarium wilt and black Sigatoka were recorded based on a one to five rating scales; Fusarium wilt: 1=no symptom, 2=initial yellowing mainly in the lower leaves, 3=yellowing of all the lower leaves with some discoloration of younger leaves, 4=all leaves with intense yellowing, and 5=plant dead; Black Sigatoka: 1=no symptom, 2=reddish flecks on lower and upper surface, 3=regular or irregular reddish circular spots on the lower surface, but no symptoms on the upper surface, 4=black or brown circular spots, possibly with yellow halo or chlorosis of the adjacent tissues, on the upper surface area of green tissue sometimes present, and 5=black spot with dry center of the grey color, leaf completely necrotic, sometimes hanging down.

Data analysis

The collected data were subjected to analysis of variance (ANOVA) using the Statistics Analysis System software (SAS Institute, v 9.2, 2009), and means significant differences were separated using the Fisher's protected Least Significant Difference (LSD) test at $p < 0.05$.

Results and Discussion

Plant growth characteristics

The results of the study showed highly significant variations ($p < 0.001$) among the ten banana cultivars for growth characteristics like plant height, and phonological traits like days to flowering and days from planting to harvest (crop cycle duration) (Table 2). On the other hand, cultivars did not depict significant differences for pseudostem girth, number of functional leaves and time from flowering to bunch maturity (Table 2).

The mean plant height of cultivars varied from 2.12 m for 'Dinke-2' to 3.16 m for 'Ambo-3', with an average of 2.78 m (Table 2). Plants of 'Ambo-3' and 'Williams Hybrid' (3.15 m) were taller than the check variety 'Williams-I' (3.10 m). Plants of six cultivars had plant height below the mean height of all cultivars studied (Table 2). Genetic differences among banana genotypes in plant height were reported by various authors (Melon, 2000; Njuguna *et al*., 2008; Uazire *et al*., 2008; Mattos *et al*., 2010; Ara *et al*., 2011; Sagar *et al*., 2014; Tesfa and Mikias, 2015; Kamira *et al*., 2016; Aquino *et al*., 2017). Plant height exhibited high contribution towards genetic divergence among banana genotypes (Adeyemi and Oladiji, 2009) and is also an important trait that influences the planting density and the crop management, and directly interferes with the production. Taller plants of some cultivars are prone to loss of leaf area due to strong winds (Aquino *et al*., 2017). Short cultivars are usually preferred as they are less prone to toppling than tall ones in areas which experience strong winds (Menon, 2000; Njuguna *et al*., 2008). Also, short genotypes are preferred by farmers for their ease to harvest (Menon, 2000), needing not support and the increase in planting density may result in greater economic return (Goncalves *et al*., 2018).

All the cultivars had higher mean pseudostem girth than 'Williams I' (Table 2). 'Williams Hybrid' had the highest plant girth (88.13 cm), while 'Williams-I' had the smallest plant girth (81.40 cm). The average plant girth was 84.43 cm. This result is in agreement to other findings that reported genetic variations among banana genotypes for plant girth (Melon, 2000; Njuguna *et al*., 2008; Uazire *et al*., 2008; Mattos *et al*., 2010; Sagar *et al*., 2014; Tesfa and Mikias, 2015; Kamira *et al*., 2016). Plant girth is a valuable trait which is related to vigor and resistance to pseudostem tipping and breakage caused by wind. Banana genotypes with thicker pseudostems are less prone to toppling over and is indicator of plants ability to support the bunch, a result of genetic variability among genotypes (Menon, 2000; Mattos *et al*., 2010; Aquino *et al*., 2017; Goncalves *et al*., 2018).

'Chinese Dwarf' was the first to reach flowering stage (243.8 days) followed by 'Williams Hybrid' (246.4 days). Whereas, 'Ambo-2' and 'Paracido al Rey' were very late to flower taking 316.8 and 307.9 days, respectively (Table 2). 'Ambo-2' with 126.7 days and 'Williams Hybrid' with 128 days were the earliest to reach fruit maturation time; about 23 days earlier than 'Ambo-3' which took 150.8 days from flowering to harvest (Table 2). 'Williams Hybrid' with 374.4 days and 'Chinese Dwarf' with 379.3 days took the shortest crop cycle duration from planting to harvest. In contrast, 'Paracido al Rey' (446.7 days) followed by 'Ambo-2' (443.5 days) had the longest crop cycle duration. Other cultivars were intermediate in production cycles (Table 2). In this study, cultivars that took shorter time to shooting were early in attaining maturity. Similar findings were reported by previous works (Gaidashova *et al*., 2008; Njuguna *et al*., 2008; Kamira *et al*., 2016; Goncalves *et al*., 2018). Njuguna *et al*. (2008) reported a longest time to shooting (648.7 days) which was almost twice the shortest (314.5 days). Also, they noted a difference of 53 days between the cultivar that took the shortest time (148.8 days) and the one that took the longest time (201 days) from shooting to harvest. Banana cultivars can generally be categorized as early, medium and late maturing ones. Early maturity is a desirable characteristic because such cultivars are more likely to give higher yields (Njuguna *et al*., 2008). Maturity period and attainment of acceptable eating quality at an early stage of development are the agronomic attributes of importance to banana end-users (Nowakunda *et al*., 2000). These considerable variations among the banana cultivars in terms of time taken to flowering, from flowering to bunch maturity and from planting to harvest could result from the inherent genetic variability of the cultivars (Njuguna *et al*., 2008).

Table 2. Mean plant growth performance of ten banana cultivars across four sites and two crop cycles in Ethiopia from 2015 to 2017.

Cultivars	PHT	PGM	DPF	DFH	DPH
Chinese Dwarf	2.55c	85.45	243.8d	135.5	379.3e
Lady Finger	2.62bc	82.35	269.7c	136.0	405.7d
Paracido al Rey	2.55c	85.42	307.9a	138.8	446.7a
Williams Hybrid	3.15a	88.13	246.4d	128.0	374.4e
Ambo-2	2.75b	82.85	316.8a	126.7	443.5ab
Ambo-3	3.16a	83.27	289.5b	150.8	440.3ab
Amboweha Selle-3	3.05a	86.25	291.6b	136.2	427.8c
Dinke-1	2.75b	85.48	265.3c	139.2	404.5d
Dinke-2	2.12d	83.68	279.8bc	139.0	418.8c
Williams-I (check)	3.10a	81.40	274.1c	148.3	422.4c
Mean	2.78	84.43	278.5	137.9	416.3
LSD (5%)	0.18	4.91	15.27	18.94	9.31
Significance	***	Ns	***	ns	***
CV (%)	5.63	4.98	3.45	11.76	1.91

Means with the same letter(s) in a column are not significantly different at 5% probability; PHT = plant height (m); PGM = pseudostem girth measurement (cm); DPF = days from planting to flowering; DFH = days from flowering to harvest; DPH = days from planting to harvest; *** significant at $p < 0.001$; ns = non-significant at $p < 0.05$; LSD = least significant difference; CV (%) = coefficient of variation

Yield and quality related traits

The results of yield and yield related characteristics are presented in Table 3. Significant variations were observed among the ten banana cultivars in terms of bunch weight, fruit weight, fruit length, marketable yield and total yield. In contrast, cultivars did not show statistically significant differences in number of hands per bunch, fruits per hand and fruit diameter.

The bunch weight varied from 23.15 to 30.38 kg (Table 3). 'Dinke-1' produced the heaviest bunches followed by 'Williams-I' (28.21 kg). The smallest bunch weight was recorded from 'Dinke-2'. 'Dinke-1' and 'Amboweha Selle-3' produced comparable bunches weight to the check variety. Similar results were reported by different authors (Menon, 2000; Gaidashova *et al*., 2008; Njuguna *et al*., 2008; Kamira *et al*., 2016; Sagar *et al*., 2017; Goncalves *et al*., 2018) who found varietal differences in bunch weight, the lowest being 3.46 kg (Sagar *et al*., 2017) while the highest was 53.4 kg (Gaidashova *et al*., 2008) for different banana genotypes. Although ecological factors could have influenced the performances of bananas, the type of genotype had more important influence on bunch sizes (Njuguna *et al*., 2008; Kamira *et al*., 2016). Sagar *et al*. (2017) indicated that plant girth, number of leaves per plant, finger length, number of fingers per hand and hands per bunch had significant contribution to the bunch weight. Also, Tushemereirwe *et al*. (2014) reported that large bunch weight was highly and positively correlated with the plant height, plant girth, number of hands, finger circumference, finger length and number of functional leaves at flowering. Hence, these parameters can be used to estimate yields when bunches are lost or damaged. Based on the bunch size, it is possible to identify genotypes that produce higher or comparable yield to the check variety.

The number of hands per bunch ranged from 10 to 12 with mean value of 11 (Table 3). 'Paracido al Rey' and 'Williams Hybrid' had the highest number of hands per bunch, while 'Ambo-3' and 'Dinke-2' recorded the least number of hands. Goncalves *et al*. (2018) and Mattos *et al*. (2010) also reported average number of hands per bunch of 7.04 and 6.0, respectively, which are less than the result of the present study (11 hands). Also, Menon (2000) obtained from 5.0 to 10.2 hands per bunch. The number of fingers per hand varied from 15 to 18 (Table 3). 'Chinese Dwarf' and 'Ambo-3' had the highest number of fingers per hand followed by 'Paracido al Rey' (17), while four cultivars produced the least number of fingers per hand (15). Mattos *et al*. (2010) reported a mean number of fingers per hand of 13.8, which is low compared to the present result. The number of hands and fingers are important traits in banana genetic studies, because hands constitute the market unit, and the increase in the number of hands can increase the bunch weight, a trait that expresses the genotype yield (Mattos *et al*., 2010).

The results of fruit characteristics are presented in Table 3. The mean finger weight varied from 120.74 to 218.80 g. 'Williams-I' followed by 'Amboweha Selle-3' (203.07) had the heaviest fruits; while 'Dinke-2 had the smallest fruits. Finger length and finger diameter ranged from 14.41 to 15.44 cm and 3.89 to 4.13 cm, respectively. 'Amboweha Selle-3' (15.44), 'Dinke-1' (15.38 cm) and 'Williams-I' (15.09 cm) had longer finger than other cultivars. 'Paracido al Rey', 'Dinke-1' and 'Williams-I' had higher finger diameters of 4.13, 4.10 and 4.09 cm, respectively. 'Lady Finger' recorded the lowest finger length and diameter. Varietal differences in fruit size were reported by different researchers (Gaidashova *et al*., 2008; Njuguna *et al*., 2008; Uazire *et al*., 2008; Mattos *et al*., 2010; Sagar *et al*., 2017). Results of the present study showed that cultivars that had bigger bunches generally had longer fingers than those with smaller ones. Similar result was reported by Njuguna *et al*. (2008). Large finger size is a major factor contributing to the bunch weight (Sagar *et al*., 2017). Finger length is a characteristic used in banana classification (Goncalves *et al*., 2018). Cultivars with long and slender fingers, an important attribute for bananas, have better market preference (Nowakunda *et al*., 2000; Njuguna *et al*., 2008).

Highly significant differences were also observed among the cultivars in mean marketable and total yields (Table 3). The mean marketable and total yields ranged from 37.33 to 45.87 ton ha^{-1}/ year and from 43.67 to 52.46 ton ha^{-1}/year, respectively. The lowest mean marketable yield was recorded from 'Chinese Dwarf' while the highest was obtained from 'Williams-I'. Similarly, the maximum and the minimum total yields were recorded from 'Williams-I' and 'Ambo-2', in their order. 'Dinke-1', 'Paracido al Rey', 'Amboweha Selle-3', 'Williams Hybrid' and 'Lady Finger' gave total yields of 51.88, 49.81, 49.43, 46.70 and 46.51 ton ha^{-1}/year, respectively; which are comparable to the check variety 'Williams-I' (Table 3). The present findings are consistent with previous results (Fonsah *et al*., 2007; Gaidashova *et al*., 2008; Sagar *et al*., 2014, 2017; Tushemereirwe *et al*., 2014; Kamira *et al*., 2016) who reported significant differences among genotypes in fruit yields. A yield that ranged from 35.9 to 42.3 ton ha^{-1}/year was reported by Ara *et al*. (2011). Sagar *et al*. (2014; 2017) also reported a yield that varied from 3.84 to 43.07 ton ha^{-1}/year while Tushemereirwe *et al*. (2014) reported yield ranges of 8.47 to 38.67 ton ha^{-1}/year for hybrids and from 7.5 to 15.22 ton ha^{-1}/year for parental banana genotypes. Also, Tesfa and Mikias (2015) recorded yield that ranged from 6.1 to 20.1 ton ha^{-1}/year for dessert banana genotypes. Variations in yields among cultivars could be caused by genetic differences and location factors (Fonsah *et al*., 2007; Sagar *et al*., 2014), genotype being a more critical factor in determining the yield potential of a given cultivar (Njuguna *et al*., 2008). Soil characteristics could also contribute to the variation in banana yields (Kamira *et al*., 2016). Higher plant girth, more number of leaves contributes to enhanced photosynthesis and accumulation of food, number of fingers per bunch and finger weight that might led to increased yields (Sagar *et al*., 2014; 2017).

Table 3. Mean yield and yield components of ten banana cultivars across four sites and two crop cycles in Ethiopia from 2015 to 2017.

Cultivars	BWT	HPB	FPH	FWT	FL	FD	MY	TY
Chinese Dwarf	25.08bcd	11	18	159.44d	14.83abcd	4.00	37.33c	44.25c
Lady Finger	23.47cd	11	15	140.17ef	14.41d	3.89	40.75abc	46.51ab
Paracido al Rey	26.19bcd	12	17	181.88c	14.87abcd	4.13	44.48ab	49.81ab
Williams Hybrid	25.84bcd	12	15	175.55c	14.85abcd	4.00	41.32abc	46.70ab
Ambo-2	26.61bc	11	16	146.17e	14.74bcd	4.04	37.65c	43.67c
Ambo-3	23.71cd	10	18	139.18f	14.60cd	3.96	39.21bc	44.53c
Amboweha Selle-3	27.82ab	11	15	203.07b	15.44a	4.07	40.95abc	49.43ab
Dinke-1	30.38a	11	15	180.25c	15.38ab	4.10	43.33ab	51.88a
Dinke-2	23.15d	10	16	120.74g	14.33d	3.98	39.63bc	44.73b
Williams-I (check)	28.21ab	11	16	218.80a	15.09abc	4.09	45.87a	52.46a
Mean	26.05	11	16	166.40	14.85	4.03	41.05	47.40
LSD (5%)	3.22	2.10	3.03	6.52	0.65	0.19	5.63	6.15
Significance	*	Ns	ns	***	*	ns	***	***
CV(%)	21.67	16.52	17.1	3.35	7.71	8.29	24.04	22.75

Means with the same letter(s) in a column are not significantly different at 5% probability; BWT = bunch weight (kg); HPB = number of hands per bunch; FPB = number of fruits per bunch; FWT = fruit weight (g); FL = fruit length (cm); FD = fruit diameter (cm); MY = marketable yield (ton ha-1/year); TY = total yield (ton ha-1/year); * significant at $p < 0.05$; *** significant at $p < 0.001$; ns = non-significant at $p < 0.05$; LSD = least significant difference; CV(%) = coefficient of variation.

Consumer Acceptability

The results of sensory evaluation carried out to determine the acceptability of the banana cultivars to consumers are presented in Table 4. Significant differences were not observed among the ten cultivars for all sensory characteristics assessed based on the five-point scale by the panelists. The color scores ranged from 3.57 for 'Williams-I' to 4.17 for 'Ambo-2'. Though it was not statistically significant, panelists preferred all cultivars to the check in terms of color. In the case of aroma, the mean scores varied from 3.58 for 'Ambo-3' to 4.24 for 'Lady Finger'. Accordingly, the panelists preferred six cultivars to the check variety. The taste scores varied from 3.35 for 'Chinese Dwarf' to 4.21 for 'Lady Finger'. Fruits of all the cultivars except 'Chinese Dwarf' and 'Williams Hybrid' were more preferred to the check variety in taste scores. The texture scores ranged from 3.10 for 'Williams-I' to 4.20 for 'Ambo-2'. Panelists preferred all evaluated cultivars over the check variety in terms of texture. With regard to the rind peel-ability, the mean scores varied from 3.37 for 'Chinese Dwarf' to 4.28 for 'Dinke-2'. The higher the peel-ability score, the easier to peel the rind. The overall acceptability scores ranged from 3.57 for 'Chinese Dwarf' and 'Williams-I' to 4.38 for 'Lady Finger'. The general acceptability judgment of the panelists for the cultivars by considering all the perceptions concluded that all the tested banana cultivars except 'Chinese Dwarf' were better than the check variety (Table 4). Similar findings on banana and plantain cultivars were reported in Uganda (Nowakunda *et* *al*., 2000), Cote d'Ivoire (Coulibaly and Djedji, 2004), Mozambique (Uazire *et al*., 2008), Ghana (Adubofuor *et al*., 2016) and Brazil (Aquino et al., 2017). The studies by Nowakunda *et al*. (2000), Coulibaly and Djedji (2004) and Uazire *et al*. (2008) found low sensory and general acceptability scores for introduced hybrids compared to the East African highland bananas. Coulibaly and Djedji (2004) reported similar mean values of the sensory scores given by the panelists for three cultivars. In Ghana, the panelists preferred the color, aroma and aftertaste of the Medium Cavendish compared to that of the Gros Michel; while similar mouth feel and chewiness attributes were scored for both cultivars (Adubofuor *et al*., 2016). Color is a very important attribute of attractiveness to the consumer that influences the initial acceptability of a cultivar. The color differences observed among cultivars could be attributed to the differences in sugar content in the different banana cultivars (Adubofuor *et al*., 2016; Aquino *et al*., 2017). The sensory evaluation of new cultivars is decisive in the process of varietal selection since it determines the acceptability of new products by consumers (Coulibaly and Djedji, 2004).

Table 4. Sensory evaluation of ten banana cultivars

Cultivars	Color	Aroma	Taste	Texture	Peel-ability	General acceptability
Chinese Dwarf	3.72	3.64	3.35	3.29	3.37	3.57
Lady Finger	4.07	4.24	4.21	4.11	4.21	4.38
Paracido al Rey	3.77	3.83	4.04	3.94	3.51	3.96
Williams Hybrid	3.75	4.09	3.49	3.75	3.70	3.93
Ambo-2	4.17	4.21	3.92	4.20	4.01	4.25
Ambo-3	3.71	3.58	3.83	3.75	3.75	3.71
Amboweha Selle-3	3.71	3.65	3.89	3.96	3.78	3.84
Dinke -1	3.77	3.83	3.55	3.71	3.67	3.80
Dinke-2	4.10	3.88	3.67	4.06	4.28	4.01
Williams-I (check)	3.57	3.69	3.50	3.10	3.84	3.57
Mean	3.83	3.86	3.75	3.79	3.81	3.90
LSD (5%)	0.60	0.79	0.55	0.71	0.65	0.56
Significance	ns	Ns	Ns	ns	ns	Ns
CV(%)	9.12	12.00	8.61	11.00	9.94	8.31

ns = non-significant at $p < 0.05$; LSD = least significant difference; CV(%) = coefficient of variation

Fruit physicochemical characteristics

The results of the fruit physicochemical characteristics are summarized in Table 5. The cultivars exhibited significant differences in all physicochemical parameters analyzed. The mean peel thickness varied from 2.1 to 4.2 mm. 'Paracido al Rey' (4.2 mm) and 'Lady Finger' (4.1 mm) had thicker peels than the check variety (3.32 mm), whereas 'Dinke-1' had the thinnest peel. The pulp-to-peel ratio ranged from 2.21 to 3.19. 'Ambo-3' (3.19), 'Williams Hybrid' (3.0), 'Dinke-1' (2.93) and 'Ambo-2' (2.84) had higher pulp-to-peel ratios than the check variety, which indicates more pulp advantage for dessert bananas. On the hand, 'Amboweha Selle-3' (2.09) and 'Dinke-2' (2.21) had the lowest pulp-to-peel ratios. The present findings are consistent with the results reported by several authors

(Menon, 2000; Mattos *et al*., 2010; Aquino *et al*., 2017) who found significant differences among banana cultivars in peel thickness and pulp-to-peel ratio. In Brazil, Mattos *et al*. (2010) reported a peel thickness which varied from 1.3 to 4.7 mm for twenty-six banana genotypes. Menon (2000) obtained the pulp-to-peel ratios that ranged from 3.0 to 4.2 for seven banana genotypes in India. Also, Aquino *et al*. (2017) reported the pulp-to-peel ratio that ranged from 1.18 to 2.26 mm for unripe fruits of fifteen banana cultivars in Brazil. In contrast, Goncalves *et al*. (2018) found similar peel thickness and pulp-to-peel ratio among the ten plantain genotypes. Physicochemical characteristics are important quality parameters that allow for sensory acceptability by consumers. The peel thickness can be a component of resistance to transport and storage because the thicker the peel the more resistant the fruit (Goncalves *et al*., 2018). Genotype and maturation stage influence the peel thickness and pulp-to-peel ratio. The pulp-to-peel ratio increases with ripening due to the migration of water from the peel to the pulp during ripening, from the osmotic pressure gradient caused by the higher concentration of sugars in the pulp compared to the peel. Moreover, the peel loses water to the environment by transpiration process, which reduces its thickness and weight (Aquino *et al*., 2017).

The TSS, Total Titratable Acidity (TTA) and pH ranged from 20.00 to 24.47 °Brix, from 0.37 to 0.61% malic acid, and from 4.69 to 5.20 pH, respectively (Table 5). All the cultivars evaluated except 'Ambo-3' had higher TSS than the check variety. The highest and the lowest TSS values were obtained from 'Williams Hybrid' and 'Ambo-3' while 'Williams-I' (0.61%), 'Amboweha Selle-3' (0.60%) and 'Lady Finger' (0.59%) had the highest TTA values. The least TTA was obtained from 'Dinke-2' and 'Ambo-2'. All the cultivars had higher TSS: TTA ratio than the check variety, ranging from 32.70 to 63.97. 'Dinke-2' had the highest TSS: TTA ratio followed by 'Ambo-2' (59.84), while 'Williams-I' had the lowest ratio. Among the cultivars tested, the highest pulp pH was recorded from 'Dinke-1' and 'Dinke-2' followed by 'Ambo-2', whereas the lowest was from 'Amboweha Selle-3' (Table 5). Similar results were reported by Godoy *et al*. (2016) who found significant differences of physicochemical characteristics among eight banana genotypes, i.e., TSS °Brix (18.52 to 22.13), TTA% malic acid (0.34 to 0.64), TSS: TTA (33.00 to 65.05) and pH (4.59 to 5.27). Aquino *et al*. (2017) also reported similar findings in which the values of TSS ranged between 22.01 and 29.53 °Brix, TTA between 0.34 and 0.73%), and pH between 2.25 and 6.15 among fifteen banana cultivars. The TSS results are consistent with the findings of Ara *et al*. (2011) who reported significant varietal differences in the mean values of TSS that ranged from 19.2 to 23.4 °Brix for three cooking bananas in Bangladesh, and that of Mattos *et al.* (2010) who obtained the TSS which varied from 14.40 to 25.70 ºBrix for twenty-six banana genotypes in Brazil. The study is also in agreement with the findings of Siji and Nandini (2017) who reported the TSS range of 17.83 to 23.90 ºBrix for eight banana genotypes in

India. In contrast, our findings are not in harmony with the results of Dotto *et al*. (2019) who found lower mean values of the TSS (1.0 to 2.0 °Brix) and relatively higher TTA values (1.5 to 2.3%) for fifteen cooking bananas in Tanzania. Also, relatively higher TTA values (0.46 to 1.28%) than the present results were reported by Siji and Nandini (2017).

Total soluble solid (TSS), Total titratable acidity (TTA) and pH sensory attributes that had substantial effect on the consumer acceptability of bananas (Ara *et al*., 2011). The TSS levels are dependent on the cultivar and the maturation stage, which can serve as a useful index in the determination of fruit maturity and ripeness. It is an important quality attribute for many fresh fruits including bananas during ripening (Aquino *et al*., 2017; Siji and Nandini, 2017). High TSS is linked with high sucrose concentration in the fruit, and with dry matter content and some other factors. TSS influences the taste of bananas (Aquino *et al*., 2017; Dotto *et al*., 2019). Both the TTA and pH are indicators for the number of organic acids and inherent salts contained in a fruit, the higher the value of these parameters the higher the amount of acids and salts (Dotto *et al*., 2019). TTA is essential sensory attributes in bananas. High level of acidity indicates that the cultivar contains high amount of malic acid in its pulp. The TTA measures the total hydrogen ion concentration, which is more relevant to flavor than pH (Dotto *et al*., 2019). The TSS: TTA index provides information on fruit flavor (Godoy *et al*., 2016). The pH may be used as a maturity indicator for banana harvesting (Dotto *et al*., 2019). Also, the pH is an important attribute of banana juice because it influences the levels and type of contamination and therefore the kind of preservation necessary. Low pH has lower levels of microbial contamination and, therefore, need less stringent preservation methods (Nowakunda *et al*., 2000).

Moisture and ash contents

The moisture content results of the cultivars are presented in Table 5. The cultivars showed highly significant differences in their moisture content. The mean moisture content for the cultivars ranged from 71.53 to 76.56%. 'Ambo-3', 'Amboweha Selle-3', 'Ambo-2' and 'Chinese Dwarf' had notably higher moisture content than that observed in the check variety; while 'Williams Hybrid' had the lowest moisture content. Our findings are in line with the results of Dotto *et al*. (2019) for fifteen cooking bananas (65.53 to 74.44%). In contrast, lower moisture contents for banana (20.81 ± 0.72%) and plantain (20.92 ± 0.02%) were reported by Oyeyinka and Afolayan (2019). Also, Adubofuor *et al*. (2016) reported lower moisture contents for Gros Michel (20.10%) and Medium Cavendish (17.20%) bananas. The moisture content is an index for freshness and shelf-life span of fruits, with low moisture levels tending towards a longer shelf-life (Dotto *et al*., 2019; Oyeyinka and Afolayan, 2019). High moisture levels are not nutrient rich fruits, but hinder storage duration (Oyeyinka and Afolayan, 2019). The level of moisture content is greatly dependent on the genetic factors of individual variety and the site factors such as soil (Dotto *et al*., 2019). This may explain the reason of observed differences in moisture content of the studied banana cultivars.

The results of the ash contents of the cultivars are summarized in Table 5. There were significant differences in ash content among the cultivars. The ash content ranged from 2.50 to 3.36%. The lowest ash content was recorded for 'Paracido al Rey', which may indicate low mineral concentration. In contrast, 'Ambo-3' (3.36%) and 'Amboweha Selle-3' (3.31%), 'Dinke-2' (3.12%) and 'Ambo-2' (3.05%) had higher ash contents. The higher values may indicate the high mineral levels of the cultivars. This result is in agreement with the finding of Adubofuor *et al*. (2016) who reported ash contents of 3.30% for the Gros Michel and 3.00% for the Medium Cavendish bananas. However, the ash contents recorded in the present study were higher than the finding of Dotto *et al*. (2019) who reported from 0.66 to 1.45% for cooking bananas. Also, Oyeyinka and Afolayan (2019) reported lower average ash contents for banana (1.01 ± 0.00%) and plantain (0.78 ± 0.00%). The ash content increases with ripening, which explains the softening texture of banana fruits (Adeyemi and Oladiji, 2009). The ash content is essentially significant in food because the inorganic bulk is linked to mineral element composition (Adeyemi and Oladiji, 2009; Oyeyinka and Afolayan, 2019). Thus, these varietal differences might be attributed to their different ability to absorb and accumulate minerals (Dotto *et al*., 2019).

Table 5. Physicochemical characteristics and moisture and ash contents of ten banana cultivars

Cultivar	PTK (mm)	PPR	TSS	TTA	TSS:TTA	pH	Moisture (%)	Ash (%)
Chinese Dwarf	3.32b	2.46cd	21.33cd	0.40d	53.82b	4.85bc	74.82cd	2.87cd
Lady Finger	4.10a	2.25de	23.97a	0.59b	40.36d	4.72bc	71.65g	2.65de
Paracido al Rey	4.20a	2.38de	21.00cd	0.51c	40.87d	4.79bc	71.74g	2.50e
Williams Hybrid	2.31c	3.00ab	24.47a	0.50c	48.94c	4.81bc	71.53g	2.87cd
Ambo-2	3.03b	2.84ab	22.30bc	0.37d	59.84a	5.16a	75.54bc	3.05bc
Ambo-3	3.18b	3.19a	20.00d	0.49c	40.96d	5.02ab	76.56a	3.36a
Amboweha Selle-3	3.13b	2.09e	20.33d	0.60a	34.23e	4.69c	75.71b	3.31a
Dinke-1	2.10c	2.93ab	22.13bc	0.49c	44.98cd	5.20a	73.35e	2.77d
Dinke-2	3.20b	2.21de	23.70ab	0.37d	63.97a	5.20a	72.58f	3.12ab
Williams-I (check)	3.32b	2.82bc	20.00d	0.61a	32.70e	4.80bc	74.57d	2.71de
Mean	3.19	2.62	21.92	0.49	46.07	4.92	73.81	2.92
LSD (5%)	0.49	0.37	1.63	0.03	4.82	0.30	0.72	0.25
Significance	***	***	***	***	***	**	***	***
CV(%)	9.12	8.16	4.34	3.78	6.10	3.56	0.57	4.91

Means with the same letter(s) in a column are not significantly different at 5% probability; PTK = peel thickness (mm); PPR = pulp to peel ratio; TSS = total soluble solids (°Brix); TTA= total titratable acidity (%); ** significant at $p < 0.01$; *** significant at $p < 0.001$; LSD = least significant difference; CV (%) = coefficient of variation

Mineral content

The results of mineral content of the ten banana genotypes are presented in Table 6. The mineral contents varied from 41.20 to 77.89, 264.03 to 371.18 and 4.20 to 19.35 mg/100g for phosphorous, potassium and sodium, respectively. The highest and the lowest phosphorous contents were obtained from cultivars ‘Ambo-3’ and ‘Williams Hybrid’, respectively. All the cultivars except ‘Williams Hybrid’ (41.20), ‘Paracido al Rey (41.25)’ and ‘Chinese Dwarf’ (47.01) had higher phosphorous contents than the check (51.95) variety. ‘Ambo-3’ followed by ‘Dinke-1’ (74.82) and ‘Dinke-2’ (62.92) had the highest phosphorous contents. The two candidates, namely ‘Dinke-1’ and ‘Lady Finger’, had higher potassium contents than the check variety. The sodium content of all the genotypes except ‘Paracido al Rey’ and ‘Lady Finger’ was higher than the check variety. ‘Dinke-2’, ‘Ambo-3’ and ‘Ambo-2’ had more than 10 mg/100 g sodium contents; whereas the check variety had 4.63 mg/100 g sodium. Similar findings were reported by different authors (Hardisson *et al*., 2001; Ara *et al*., 2011; Adubofuor *et al*., 2016; Dotto *et al*., 2019; Oyeyinka and Afolayan, 2019) who noted variability in mineral concentrations among banana genotypes.

In the present study, potassium was generally found to be the most abundant in all the cultivars studied with the mean value of 316.42 mg/100g, which indicates the potential nutritional significance. The highest levels of potassium obtained in this study is in close agreement with the findings of Adubofuor *et al*. (2016) for Gros Michel and Cavendish bananas, Dotto *et al*. (2019) for cooking bananas, and Oyeyinka and Afolayan (2019) for banana and plantain genotypes. In contrast, Siji and Nandini (2017) obtained considerably higher potassium (261.66 to 546.66 mg/100g) and sodium (170 to 260 mg/100g) contents for banana genotypes than the present results. Mineral elements are essential components of nutrition and their functional roles involve structural, physiological, and metabolic processes in the body (Siji and Nandini, 2017; Oyeyinka and Afolayan, 2019). Banana is valued for potassium content because of its role in maintaining the body’s blood pressure (Siji and Nandini, 2017). The differences in the amounts of the mineral elements present in bananas could be attributed to several factors that include the differences in the banana genotypes, agro-climatic conditions, soil differences, and stage of fruit ripening (Hardisson *et al*., 2001; Adeyemi and Oladiji, 2009; Adubofuor *et al*., 2016).

Table 6. Mean mineral contents (mg/100g) of ten banana cultivars

Cultivars	Phosphorus	Potassium	Sodium
Chinese Dwarf	47.01	316.29	9.98
Lady Finger	52.73	324.13	4.20
Paracido al Rey	41.25	264.03	4.20
Williams Hybrid	41.20	284.10	9.44
Ambo-2	55.60	316.01	10.02
Ambo-3	77.89	301.25	15.48
Amboweha Selle-3	53.11	371.18	7. 05
Dinke-1	74.82	326.89	9.19
Dinke-2	62.92	351.23	19.35
Williams-I (check)	51.95	309.14	4.63
Mean	55.85	316.42	9.35

Genotype reaction to Fusarium wilt and black Sigatoka

The reactions of the cultivars to Fusarium wilt of bananas (also known as Panama disease), caused by *Fusarium oxysporum* f. sp. *cubense*, and black Sigatoka (black leaf streak), caused by *Mycosphaerella fijiensis*, under field conditions are presented in Figure 1. 'Amboweha Selle-3' and 'Dinke-1' hardly showed any symptom of Fusarium wilt, while the other genotypes showed little incidence of Fusarium wilt disease; which might indicate their tolerance. However, the banana cultivars evaluated showed varying degrees of tolerance to black Sigatoka disease. Tissues of all the cultivars except 'Dinke-1' developed more symptoms of black Sigatoka disease than the check variety. 'Chinese Dwarf' and 'Dinke-1' showed the highest and the least symptoms of black Sigatoka disease, respectively. Similar findings were reported by Tushemereirwe *et al*. (2000) and Arinaitwe *et al*. (2019). A study by Tushemereirwe *et al*. (2000) found five resistant banana genotypes to both Fusarium wilt and black Sigatoka diseases, while twelve other cultivars were classified either resistant or tolerant to Fusarium wilt disease. Also, Arinaitwe *et al*. (2019) observed high degree of variability among twenty-two banana accessions for their resistance to Fusarium wilt disease. Fusarium wilt was reported to cause an estimated yield loss of over 60% in dessert bananas in Uganda (Tushemereirwe *et al*., 2000). As much as 27% of the total cost of banana production was apportioned to curb the menace of black Sigatoka disease in Nigeria (Etebu and Young-Harry, 2011). Host plant resistance is an effective alternative to other methods for controlling diseases in banana (Ploetz and Pegg, 2000). Thus, the candidate banana cultivars in the present study can be grown in Ethiopia without the use of expensive and hazardous fungicides to control these diseases.

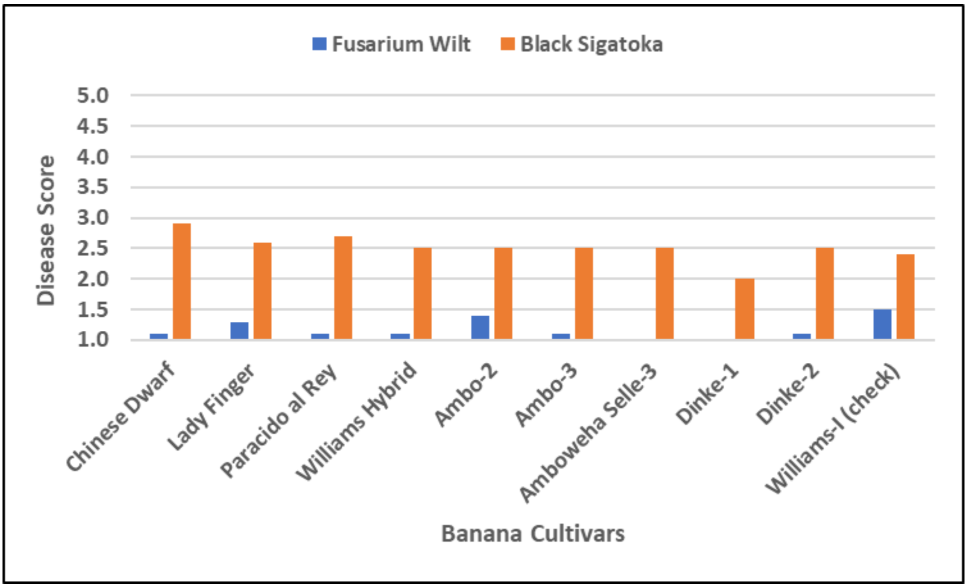

Figure 1. Fusarium wilt and black Sigatoka diseases scores on different banana cultivars.

The disease scores were recorded based on a one to five rating scales, where **Fusarium wilt:** 1=no symptom, 2=initial yellowing mainly in the lower leaves, 3=yellowing of all the lower leaves with some discoloration of younger leaves, 4=all leaves with intense yellowing, and 5=plant dead;

Black Sigatoka: 1=no symptom, 2=reddish flecks on lower and upper surface, 3=regular or irregular reddish circular spots on the lower surface, but no symptoms on the upper surface, 4=black or brown circular spots, possibly with yellow halo or chlorosis of the adjacent tissues, on the upper surface area of green tissue sometimes present, and 5=black spot with dry center of the grey color, leaf completely necrotic, sometimes hanging down.

Conclusion and Recommendation

Genetic variability was observed for most agronomic and fruit physicochemical characteristics in the ten banana cultivars evaluated. The cultivars had short to medium plant heights with generally thick pseudostems, which can be perceived as good features for harvesting and low wind damage. The candidate cultivars, namely 'Lady Finger' and 'Dinke-1' had significantly shorter crop cycle duration than the control, an important criterion for farmers in selecting cultivars. These cultivars gave comparable yields to the control. Besides genotype, experimental locations influenced yield. 'Williams-I' (control), 'Dinke-1' and 'Parecido al Rey' were found as stable and high yielding cultivars across tested environments. The cultivars exhibited significant differences in all physicochemical parameters considered. Though cultivars were not significantly different in their sensory attributes, the general acceptability scores of all the cultivars were better than the control, indicating the consumers' preference for them. 'Lady Finger' was the most preferred cultivar by panelists. The moisture and ash contents were significantly different among the cultivars. The moisture content is an indicator for fruit freshness and shelf-life. The higher ash contents obtained in this study may indicate the high mineral levels of the cultivars. Furthermore, the mineral concentration analysis showed potassium as the most abundant in all the cultivars; which indicates their potential nutritional significance. The cultivars showed varying degrees of symptoms to Fusarium wilt and black Sigatoka diseases. Although 'Parecido al Rey', 'Lady Finger', 'Dinke-1' and 'Amboweha Selle-3' were recommended for commercial production in the target areas of the country, only 'Lady Finger' and 'Dinke-1' have been registered for commercial utility hence the recommendation will also accordingly go for these two cultivars.

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Evaluation of Sweet Orange (*Citrus sinensis* L.) cultivars for Growth, Phenology, Yield and Yield Component at Raya Azebo District of Southern Tigray

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Abstract

A study was conducted to evaluate the performance and adaptability of six sweet orange cultivars for growth, phenology, and yield and yield component at Raya Azebo districts during 2014-2019 cropping season. The experiment was laid out in a randomized complete block design with three replications. The collected data were subjected to analyses. The result showed that, tree height at first harvest was highly significantly ($p<0.01$) influenced by cultivars. Regardless of the level of significance, fruit diameter, fruit length and single fruit were significantly ($p<0.05$) affected by cultivars in 2017 and 2018 harvest years. Days to maturity was also significantly ($p<0.01$) affected by cultivars. Fruit weight without rind (flesh weight) and juice weight were highly significantly ($p<0.05$) affected by cultivars. With the difference in the degree of significance, marketable yield, unmarketable yield, and total yield tree^{-1} were significantly affected by cultivars. O. Valencia matured late taking 1622 days from planting to first harvest. While, P.W.N. matured early taking an average 1104 days of from planting to first harvest. In 2017, Hamlin, gave the highest marketable fruit yield of 68.61 kg of tree^{-1} and total yield of 68.94kg tree^{-1}. Jaffa gave the maximum marketable fruit yield of 197.24 kg tree^{-1} and total yield of 198.81 kg tree^{-1} in 2018 cropping year. In 2019 harvesting year, Hamlin gave the highest marketable (63.3 kg) and total (64.02 kg) fruit yield tree^{-1}. On average Jaffa and Hamlin gave the maximum marketable fruit yield tree^{-1} across the three consecutive harvesting years with mean value of 95.38 kg and 72.24 kg, respectively. Therefore, Jaffa and Hamlin varieties are recommended for Raya Azebo and other areas having similar agro-ecologies. Further, studying the nutritional content and water requirements of these cultivars are suggested.

Introduction

The genus *Citrus* (*Citrus* spp.) belong to the angiosperm of the *Rutaceae* family, which is widely produced and consumed worldwide. Citrus is native to Southeastern Asia, having been known in China more than 4,000 years ago (Sauls, 2008) and now produced worldwide. Citrus is produced in arid, semi-arid, and even humid regions with supplemental irrigation to enhance their fruit yield (Smajstrla and Haman, 1996). It is one of the most important economic fruit crops and include oranges, lemons, limes, tangerines and grapefruit (Davies and Albrigo, 1994; Timmer *et al*., 2003; Manner *et al*., 2006). Citrus fruits in all the shapes, sizes, and colors are attractive, fragrant, and appetizing with high nutritional values (Nawaz *et al.* 2008).

Although, citrus fruits are native to Southeast Asia (Indonesia and China), now it is extensively grown almost throughout the world under tropical and sub-tropical conditions where the soil and climatic regimes are favorable for its growth and yield (Shah, 2004). Sweet orange (*Citrus sinensis* L.) is an important citrus fruit consumed all over the world. It has an excellent source of vitamin C and powerful natural antioxidant that builds the body immune system. It also contains important phytochemicals like liminoids, synephrine, hesperidin flavonoid, polyphenols, pectin, and sufficient amount of folacin, calcium, potassium, thiamine, niacin and magnesium (Tripoli *et al*, 2007; Nawaz *et al.* 2008).

In Ethiopia, citrus is one of the most economically important fruit crops grown by smallholders and commercial farmers (Seifu, 2003; Kassahun *et al*., 2006; Mohammed, 2007). It plays an important role in the national food and nutrition security, as raw materials for local agro-industries, to save hard currency by substituting imports, and to earn foreign currency by exporting fresh and processed citrus products. The development of the citrus industry also creates job opportunity (Asmare and Derbew, 2013).

Ethiopia is among the tropical countries where its vast arable land is suitable for citrus production. The total area coverage and annual production of citrus fruits in Ethiopia were estimated at 5,165 ha and 38,487 tons for small-scale farms (CSA, 2018); while 2,503 ha and 33,127 tons for large-scale farms) (CSA, 2015). The national average yields of citrus were estimated 6.8 t/ha for small-scale farms and 10.5 t/ha for large-scale plantations (CSA, 2015; CSA, 2018). Large portion of citrus fruits produced are consumed locally as fresh fruit, juice and marmalade (Seifu, 2003). Some citrus fruits such as sweet orange and lime are exported to Djibouti, Europe and the Middle East (Joosten *et al.*, 2015).

Despite its food and economic importance, citrus production in Ethiopia is at an infant stage and the national average yields of citrus fruits are far lower (8.25 t) than other citrus producing countries of the world (more than 20 t/ha) (FAO, 2017). This may be attributed to shortage of improved sweet orange varieties, lack of government and/or non-government sweet orange seedling producing organizations, poor extension service, disease and insect pest problems, and low attention given by the government as compared to other cereal crops. Some sweet orange cultivars were evaluated and registered by Melkassa Agricultural Research Center. However, the performance of these varieties vary with location, season and management practice. Further, no study done on sweet orange at around Raya valley where the fruit is highly consumed and the agro-ecology favors its production. Thus, it is important to evaluate and identify high yielding cultivar/s with good quality for this areas. This study was therefore carried to evaluate the growth, phenology, yield and yield attributes of sweet orange and recommend varieties with better performance in both yield and quality for Raya Azebo district and similar areas of Southern Tigray.

Materials and Methods

Description of the study area

The experiment was conducted at Mehoni Agricultural Research Center (MhARC) Fachagama testing site in the Raya Azebo Woreda, Southern zone of Tigray Regional State, Ethiopia. It is located at 668 Km from the capital city Addis Ababa. Geographically, the experimental site is located at 12° 41'50" North latitude and 39° 42'08" East longitude at an altitude of 1578 m.a.s.l. The area receive a mean annual rainfall of 539.32 mm with an average minimum and maximum temperature of 12.81 and 23.24°C, respectively. The soil textural class of the experimental area is clay loam with P^H of 7.9.

Experimental material

Grafted seedlings of six improved sweet orange cultivars namely P.W. N, O. Valencia, C. Valencia, Jaffa, P.A.S.O. and Hamlin were brought from Melkassa Agricultural Research Center, at July, 2014.

Field preparation, experimental design, planting and field management

Holes of 60cm x 60cm was prepared for planting at both intra and inter spacing of 6m two months ahead of planting and the subsoil and top soil were kept separately. Four plants were planted on each experimental plot for each variety. A well decomposed manure with the top soil was mixed and fill back to the prepared seedling planting holes and planting was carried in August 2014 as per the recommended agronomic practice. The experiment was laid out in a completely randomized block designs (RCBD) with each cultivar replicated three times. The gross plot size was $144m^2$ and experimental area of was $2592m^2$. All the necessary agronomic practices like, irrigating, cultivation, insecticide spray, and weeding were done following the standard recommendation for Orange crop. Special fruit orchard management practices like training at the early stage of tree growth and pruning was undertaken.

Data collection and analysis

Data on tree height, average canopy diameter, fruit diameter (cm), fruit length (cm), average fruit weight (kg), fruit flesh weight (weight without rind in kg), average juice weight (gr), marketable yield (kg $tree^{-1}$), unmarketable yield (kg $tree^{-1}$), and total fruit yield (kg $tree^{-1}$) were collected. The collected data were subjected to analysis of variance (ANOVA) using SAS software version 9.3

procedure. Comparison of treatment means was done using the Fisher's protected least significant difference (LSD) test at 1% and 5% probability.

Results and Discussion

Plant growth characters

Plant height and canopy diameter

In both 2017 and 2018 cropping seasons, plant height was significantly ($p<0.05$) affected by sweet orange cultivars (Table 2). In 2017 Jaffa gave the tallest height (3.27m); however, it is significantly different from only O. Valencia and P.W.N. varieties. P.A.S.O gave the highest plant height (3.73m) which was not different from all other varieties but O. Valencia which gave the lowest plant height (Table 1). Average of two years data indicated that Jaffa is the tallest (3.48m), while P.W.N. was the shortest (Table 1). Canopy spread was not significantly ($p \geq 0.05$) affected by sweet orange varieties in both 2017 and 2018 cropping year (Table 1). This might be attributed to the inherent genetic character of the varieties. Khan *et al*. (2015) reported similar result of significant differences in plant height among sweet orange varieties. The variation in plant height among cultivars might be attributed to the genetic differences among varieties on apical dominance and growth. Besides, plant growth and development is highly affected by mineral nutrition which affect the rate of photosynthesis thereby decrease carbohydrates production and proteins synthesis (Taiz and Zeiger, 2002).

Phenological characters

Days to first harvest

Days to first harvest (maturity) was significantly ($p<0.05$) affected by sweet orange varieties (Table 2). O. Valencia matured late taking an average of 1622 days to first harvest. All the other varieties matured early taking lower number of average days to first fruit harvesting time (Table 1). In agreement with this result, Samad *et al*. (2014) found significant variation on days to maturity. Fruit maturity is affected by genetic makeup of the cultivar, environmental condition and geographical sites (Asrey *et al*., 2008). In addition, growth and development of crops are highly affected by mineral nutrition which influence the rate of photosynthesis that decrease carbohydrates production and proteins synthesis (Taiz and Zeiger, 2002).

Table 1. Mean of Growth and phenological characters of Sweet Orange Cultivars grown at Raya Azebo district, Southern Tigray

Cultivars	PH (m)		Mean	CS (m)		Mean	DM
	Years			Years			2017
	2017	2018		2017	2018		
O. Valencia	2.87[b]	3.20[b]	3.03	3.44	3.22	3.33	1622.06[a]
C. Valencia	3.14[a]	3.65[ab]	3.40	3.46	3.64	3.56	1120.05[b]
Jaffa	3.27[a]	3.70[a]	3.48	3.45	3.74	3.59	1119.16[b]
Hamlin	3.23[a]	3.60[ab]	3.42	3.20	3.52	3.36	1116.00[b]
P.A.S.O	3.09[a]	3.73[a]	3.41	3.19	3.23	3.21	1108..04[b]
P.W.N.	2.74[b]	3.27[ab]	3.01	3.36	3.53	3.45	1104.01[b]
Mean	3.06	3.52		3.35	3.48	3.42	1198.32
LSD $_{(0.05)}$	0.18	0.46		ns	ns		201.649
CV (%)	3.2	7.1		17.6	8.2		9.2

Means within columns that are followed by different letters are statistically different at ($p < 0.05$), Least significant difference at 5%. PH = Plant height, CS = Canopy spread, DM = Days to maturity

Table 2. Mean square of Growth and phenological characters of Sweet Orange Cultivars at Raya azebo district, Southern Tigray

Source of Variation	DF	PH		CS		DM
		Years		Years		Year
		2017	2018	2017	2018	2017
Replication	2	0.17	0.17507	0.1307	0.04895	1407.4
Cultivars	5	0.13**	0.15709	0.0493	0.13750	129526
Error	10	0.01	0.06307	0.3478	0.08178	12286
CV (%)		3.2	7.1	17.6	8.2	9.2
LSD $_{(0.05)}$		0.18	0.46	ns	ns	201

ns= non-significant, *=significant, **= highly significant at P<0.05, CV = Coefficient of variation, PH = Plant height, CS = Canopy spread, DM = Days to maturity

Yield and yield related traits

Single fruit weight

Average weight of single fruit was significantly affected by sweet orange varieties in all harvesting years (Table 4). In 2017 harvest year, Hamlin gave the highest (0.49 kg) average single fruit weight, while the rest varieties had statistically similar lowest average single fruit weight. In 2018, Jaffa gave the maximum single fruit weight (0.56 kg) while Hamlin produced the lowest single fruit weight (0.12 kg) which was statistically similar with P.A.S.O. variety. The highest average single fruit weight in 2019 was observed on P.W.N. (0.27kg) which is significantly similar with C. Valencia and P.A.S.O. cultivars. Average single fruit yield across three consecutive harvests indicated the superiority of variety Jaffa with an average single fruit weight of 0.36 kg (Table 3). The result obtained from this study was higher than that reported by Nawaz *et al.* (2012) who reported highest average fruit weight of 0.2182 Kg from variety Salustiana followed by Blood Red, Hamlin, Pineapple, Valencia Late, Musambi and Succari. In another studies Ishfaq *et al.* (1999); Mohar *et al.* (2011) and Khan *et al.* (2015) recorded maximum fruit weight from Blood red and Jaffa Sweet orange varieties. This indicated that the average fruit weight which is chiefly influenced by the fruit size and juice content of the fruit differ throughout the harvest year. Therefore, fruit weight is greatly affected by not only cultivars but also the production year.

Marketable, unmarketable and total yield tree-1

Results of analysis of fruit yield per tree indicated the presence of highly significant differences ($p<0.01$) among sweet orange cultivars in marketable and total fruit yield tree^{-1} in 2017 harvest year. Similarly, cultivars showed highly significant difference ($p<0.01$) in both marketable and total fruit yield tree^{-1} during 2018 and 2019 harvest year (Table 4). The maximum marketable (68.61 kg) and total fruit yield tree^{-1} (68.94 kg) were recorded from Hamlin during 2017 harvest year though it was not significantly different from P.A.S.O, O. Valencia, and C. Valencia in both yield components. P.W.N. gave the lowest marketable and total fruit yield tree^{-1} during both 2017 and 2018 cropping year. In 2018 cropping season, Jaffa gave the maximum marketable (197.24 kg) and total fruit yield tree^{-1} (198.81 kg). Contrarily, Hamlin gave the highest marketable (63.3 kg) and total (64.02 kg) fruit yield tree^{-1} in 2019 harvesting year, which is statistically similar with O. Valencia, C. Valencia, and Jaffa cultivars. P.A.S.O and P.W.N. cultivar gave the lowest marketable and total fruit yield tree^{-1} (Table 3).

Comparison of average marketable fruit yield among varieties across the three consecutive harvest years (2017, 2018 and 2019) indicated the superiority of Jaffa and Hamlin varieties average yield of 95.38 kg and 72.24 kg fruit weight plant^{-1}, respectively. P.W.N. gave the highest unmarketable fruit yield tree^{-1} (2.10 kg) in 2017, while Hamlin produced the highest unmarketable yield tree^{-1} (1.75 kg) in 2018 cropping year (Table 3). The highest unmarketable yield tree^{-1} obtained might be attributed to heavy insect infestation and smaller fruit size. In agreement with the present finding, Chahal and Gill (2015) reported that fruit yield is affected by varieties whereby Hamlin gave the highest yield followed by Trovita and Rhode Red. Further, Samad *et al*. (2014) reported the presence of significant difference in fruit yield tree^{-1} among varieties with a highest value of 70.2 kg tree^{-1} being recorded from Sherkhana- 1 variety.

Fruit yield recorded in 2019 cropping year was lower compared to that obtained in 2017 and 2018, which is due to serious theft problem and heavy pruning done to reduce the infestation of leaf miner and cottony cushion scales insect pest. The highest marketable and total fruit yield tree^{-1} might be attributed to the large number of fruit number tree^{-1} and larger fruit size. Yearly, cultivars did not performed consistently which might be attributed to the alternate and biennial bearing habit of tree crops.

Table 3. Mean of Growth and phenological characters of Sweet Orange Cultivars grown at Raya azebo district, Southern Tigray

Cultivars	MFWtPP			Mean	UMFWtPP			Mean	TY (kg)			Mean	FWt (kg)			Mean
	Years				Years				Years				Years			
	2017	2018	2019		2017	2018	2019		2017	2018	2019		2017	2018	2019	
O.Valencia	56.27^{ab}	17.37 ^{d}	52.46^{a}	42.03	1.17^{b}	0.66^{d}	0.270^{b}	0.70	57.43^{ab}	18.04^{d}	52.73^{a}	42.73	0.26^{b}	0.16^{c}	0.19^{bc}	0.20
C. Valencia	50.77^{abc}	9.49 ^{d}	53.37^{a}	37.87	0.56^{c}	0.71^{d}	0.32^{b}	0.53	51.33^{abc}	10.20^{d}	53.68^{a}	38.40	0.29^{b}	0.17b^{c}	0.22^{ab}	0.23
Jaffa	38.87^{bc}	197.24^{a}	50.03^{a}	95.38	0.23^{c}	1.24^{b}	0.26^{b}	0.58	39.10^{bc}	198.81^{a}	50.3^{a}	96.07	0.28^{b}	0.56^{a}	0.20b^{c}	0.34
Hamlin	68.61^{a}	84.81^{b}	63.30^{a}	72.24	0.33^{c}	1.75^{a}	0.72^{a}	0.93	68.94^{a}	86.56^{b}	64.02^{a}	73.17	0.49^{a}	0.12^{d}	0.17^{c}	0.26
P.A.S.O	57.60^{ab}	91.22^{b}	15.50^{b}	54.77	1.40^{b}	1.06^{bc}	0.27^{b}	0.91	59.00^{ab}	92.28^{b}	15.77^{b}	55.68	0.25^{b}	0.14^{cd}	0.22^{abc}	0.20
P.W.N.	30.41^{c}	53.67^{c}	16.97^{b}	33.68	2.10^{a}	0.87^{cd}	0.29^{b}	1.08	32.51^{c}	54.53^{c}	17.26^{b}	34.76	0.32^{b}	0.20^{b}	0.27^{a}	0.26
Mean	50.42	75.63	41.94	55.99	0.97	1.05	0.35	0.79	51.39	76.74	42.3	56.81	0.32	0.22	0.21	0.25
LSD $_{(0.05)}$	21.69	16.05	19.3		0.44	0.32	0.23		21.61	15.97	19.22		0.14	0.03	0.055	

Means within columns for each variable followed by different letters are statistically different at ($p < 0.05$)
MFWtPP = Marketable fruit weight plant^{-1} (kg), UMFWtPP = Unmarketable fruit weight plant^{-1} (kg), TY = Total Yield (kg)

Table 4. Mean square of yield and yield data of Sweet Orange cultivars s grown at Raya azebo district, Southern Tigray

Source of Variation	DF	MFWtPP			UMFWtPP			TY (kg)			FWt		
		Years			Years			Years			Mean		
		2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019
Replication	2	623.8	28.80	131.1	0.01	0.01	0.0445	621.5	27.75	131.4	0.003	0.001	0.001
Cultivars	5	570.4*	14020.08**	1251.4	1.57**	0.49**	0.097	546.0*	14163.55**	1263**	0.024*	0.083**	0.004*
Error	10	142.1	77.82	112.4	0.06	0.03	0.152	141.2	77.08	111.6	0.006	0.0004	0.001
CV (%)		23.6	11.7	25.3	25.3	16.6	34.8	23.1	11.4	25.0	24.6	8.4	14.4

ns= non-significant, *=significant, **= highly significant at P<0.05 MFWtPP = Marketable fruit weight plant^{-1}, UMFWtPP = Unmarketable fruit weight plant^{-1}, TY = Total Yield

Fruit diameter and length

Fruit diameter and length were significantly ($p<0.05$) influenced by sweet orange varieties (Table 6). Accordingly, the maximum fruit length (8.37 cm) was recorded from variety P.W.N. which is in par with varieties C. Valencia and O. Valencia. The remaining three varieties had the lowest fruit length. In 2018 harvest year the highest fruit length (7.25 cm) was recorded from the variety P.W.N. which is at par with O. Valencia. However, P.A.S.O. and Hamlin gave the lowest fruit length in this cropping year. In 2019 harvest year, C. Valencia gave the highest (7.74 cm) fruit length. The average fruit length obtained from the consecutive three years harvesting indicated that P.W.N. had the highest (7.46 cm) fruit length (Table 5).

P.W.N. cultivar gave the highest fruit diameter of 7.96 cm and 7.03 cm, respectively in 2017 and 2018 harvest. But P.W.N.is significantly the same with C. Valencia in 2017 and C. Valencia and O Valencia in 2018. In 2019, C. Valencia gave the widest (7.73 cm) fruit diameter which is statistically the same with O. Valencia and Jaffa varieties. The mean value of the three consecutive harvesting years showed that P.W.N. is superior producing fruit with the highest diameter (Table 5). Khan *et al*. (2015) reported the presence of significant difference among sweet orange varieties their fruit diameter. Similarly, Khan *et al*. (2010) reported Tarocco-N and Salustiana gave better fruit size. The present result clearly showed the highly significant influenced of cropping year and genetic constituents on the cultivars fruit size.

Fruit size is highly influenced during floral differentiation phase prior to anthesis and development of the fruit after anthesis. During the phase prior to anthesis, the number of cells that develop in the floral parts to be incorporated in the fruit also determine fruit size (Theron, 2010). Strong positive correlation between seed number /fruit and fruit size was observed which is governed by genetic make-up of the variety. Vasilakakis *et al*. (1995) discussed the significant effect of overloading or many fruits production per tree on fruit size. Final fruit size is also determined by two distinct stages in development, i. e., the cell division stage followed by the cell enlargement stage. These stages are again influenced by climatic factors, crop load, bearing position which influenced by horticultural practices (Theron, 2010).

Fruit Quality

Flesh weight and juice content

Flesh weight (weight without rind) was not significantly ($p \geq 0.05$) affected by sweet orange varieties in 2017 but in 2018 and 2019 harvest years (Table 6). In both 2018 and 2019, the highest flesh weight was recorded from varieties P.W.N.,

C. Valencia and O. Valencia in 2018 and with P.A.S.O. and C. Valencia in 2 019 cropping year (Table 5).

The average fruit juice weight obtained from sample of ten fruits was highly significantly ($p<0.01$) affected by sweet orange variety in 2018 and 2019 harvest years (Table 6). In 2018 the highest juice weight of 90.02 g was recorded from variety P.W.N., which is statistically at par with C. Valencia and O. Valencia varieties (Table 5). C. Valencia gave the highest juice weight of 141 g which is statistically similar O. Valencia and Jaffa varieties. Conversely, the lowest juice weight was recorded from the variety Hamlin with no-statistical difference from the variety P.W.N. In average C. Valencia also gave the highest juice weight (Table 5). In agreement with this finding, Chahal and Gill (2015) and Nawaz *et al.* (2012) reported the presence of statistically significant differences among sweet orange varieties in juice percentage or content. In general, yield components and fruit quality indicators are highly influenced by season of harvest (production), cultivars and pests.

Table 5. Mean of yield and yield related characters of Sweet Orange varieties

Cultivars	FL			Mean	FD			Mean	FlWt			Mean	JWT		Mean
	Years				Years				Years				Years		
	2017	2018	2019		2017	2018	2019		2017	2018	2019		2018	2019	
O. Valencia	8.02^{a}	6.83^{ab}	7.37^{ab}	7.40	7.30^{b}	6.72^{ab}	7.40^{abc}	7.14	0.20	0.14^{ab}	0.16^{bc}	0.17	85.01^{a}	125.4^{ab}	105.2
C. Valencia	8.09^{a}	6.51^{bc}	7.74^{a}	7.44	7.50^{ab}	6.62^{abc}	7.73^{a}	7.13	0.20	0.14^{ab}	0.19^{ab}	0.17	88.71^{a}	141^{a}	114.8
Jaffa	7.21^{b}	6.15^{cd}	7.3^{ab}	6.89	6.98^{b}	6.26^{bcd}	7.41^{ab}	6.88	0.23	0.11^{bc}	0.16^{bc}	0.166	65.57^{b}	120.3^{abc}	92.9
Hamlin	6.95^{b}	5.81^{d}	6.58^{c}	6.44	7.19^{b}	5.86^{d}	6.71^{bc}	6.56	0.21	0.09^{c}	0.13^{c}	0.145	49.25^{b}	80.8^{d}	65.02
P.A.S.O	6.57^{b}	5.98^{d}	6.62^{c}	6.39	6.98^{b}	6.22^{cd}	6.94^{bc}	6.71	0.1	0.10^{c}	0.18^{abc}	0.15	54.68^{b}	107.2^{bc}	80.94
P.W.N.	8.37^{a}	7.25^{a}	6.76^{bc}	7.46	7.96^{a}	7.03^{a}	6.68^{c}	7.22	0.21	0.16^{a}	0.23^{a}	0.2	90.02^{a}	99.8^{cd}	94.91
Mean	7.54	6.42	7.07	7.01	7.32	6.45	7.14	6.97	0.21	0.12	0.17	0.17	72.21	112.41	92.31
LSD $_{(0.05)}$	0.730	0.53	0.714		0.629	0.48	0.717		ns	0.052	0.055		18.3	25.6	
CV (%)	5.3	4.5	5.6		4.7	4.1	5.5		24.8	11	17.5		13.9	12.5	

Means within columns for each variable followed by different letters are statistically different at ($p < 0.05$), FL= Fruit length (cm), FD= Fruit diameter (cm), FlWt = Flesh weight (kg), JWT = Juice weight (g)

Table 6. Mean of yield and yield related characters of Sweet Orange varieties

Source of Variation	DF	FL			FD			FLWt			JWT	
		Years			Years			Years			Years	
		2017	2018	2019	2017	2018	2019	2017	2018	2019	2018	2019
Replication	2	0.08	0.08	0.001	0.06	0.04	0.06	0.005	0.0001	0.0006	55.40	142.60
Cultivars	5	1.58**	0.90**	0.693*	0.41*	0.52**	0.55*	0.00^{ns}	0.002**	0.0036*	979.40**	1343.90**
Error	10	0.16	0.08	0.154	0.12	0.07	0.16	0.003	0.0002	0.0009	101.30	198.0
CV (%)		5.3	4.5	5.6	4.7	4.1	5.5	24.8	11	17.5	13.9	12.5

ns= non-significant, *=significant, **= highly significant at P<0.05 FL= Fruit length (cm), FD= Fruit diameter (cm), FlWt = Flesh weight (kg), JWT = Juice weight (g)

Conclusions and Recommendation

Analysis of this study indicated the presence of statistically significant difference among the sweet orange cultivars virtually in all growth, phenology and, yield and fruit related traits. Similarly, season had significant influence on all these traits and fruiting characters. Varieties Jaffa and Hamlin produced the maximum marketable fruit yield tree^{-1} (95.38 kg) during the three consecutive harvesting years with average value of and 72.24 kg. Thus, Jaffa and Hamlin varieties are recommended for the study area as well as other areas having similar agro-ecologies.

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Effect of Different Mulches on Yield and Quality of Pineapple (*Ananas comosus* (L.) Merr) in Southwest Ethiopia

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Abstract

Weeds affect the yield and quality of pineapple. In Ethiopia, there is insufficient information on different weed management practices to improve the yield and quality of pineapple fruit. To fill these gaps, a study was carried to identify best mulch materials for yield and quality of pineapple in Southwest Ethiopia. Variety Smooth Cayenne treated with different mulch materials: Soya bean straw, maize straw/stalk, black polythene/plastic, white transparent polythene, vetiver grass, frequent weed removal, coffee husk and untreated (check) were evaluated using a randomized complete block design with three replications at Jimma, Metu and Gojeb sites. Data from weed biomass yield, fruit yield, quality traits and partial budget were collected for analyses. The result revealed that mean weed biomass and its percentage of control efficacy ranged from 1.2kg to 7.8kg with 35.2% to 84.5%. At Jimma, the maximum WCE of 86.60% with minimum WBM of 1.2kg were recorded for a plot treated by black polythene. At Gojeb, frequently slashed plot followed by black polythene treated plots provided the minimum weed biomass of 1k and 2.4kg with highest percentage weed control efficacy (PWCE) of 88.10 and 81.40, respectively. But at Metu, coffee husk treated plot showed the minimum weed biomass of 1.4kg followed by frequently slashed plot (1.2 kg) with percent weed control efficiency of 76.30% and 79.70%, respectively. However, from the overall mean result, black polythene treated plot (1.8kg) showed the minimum followed by frequent slashing (1.2kg). On the other hand, in all yield and related attributes, black polythene treated plot showed the highest followed by coffee husk mulched plot. Yield of 761.20, 551.79 and 643.13 qt/ha for polythene treated and 622.30, 463.53 and 437.31 qt/ha for coffee husk mulched plots at Jimma, Metu and Gojeb, respectively. Since the area is coffee-based farming system and coffee husk is availabile , farmers who can't afford the plastic polythene can use it as alternative means of mulch material.

Introduction

Agriculture is the mainstay of livelihood and economic sources of all African countries. In order to feed the current over population, increasing the production and productivity by double or triple is the only remedy. To achieve this, producers applying different organic mulches, fertilizers and pesticides have tremendous impact to increase production (Ranjan *et al*., 2017).

Weeds are among the factors that reduce productivity by competing for all sources of crops inputs and reduce quantity and quality of products. An increase of 1kg of weeds results in a reduction of 1kg of crop growth (Abouziena and Haggag, 2016). The authors also reported that, weed scientists are now confronting other challenges like weed resistance which result from excess application of herbicides. The report indicated that worldwide consumption of herbicides approached to 48% of 2 million tons of pesticides each year (Abouziena and Haggag, 2016). The authors also portrayed that weed control is considered the major obstacle for the growers in the organic farming.

For the sake of reducing environmental problems and increasing productivity of the crop different mechanisms have been tried by researchers. Among these mechanisms, mulch is the one which is environmentally friendly and effective especially with the current global pollution problems. Mulch can be applied in production of every crop from nursery stage to field. Based on types of mulching materials used and purpose of application, mulching has tremendous importance in soil moisture retention, weed suppressing and erosion controlling (Tadesse and Tesfu, 2016).

In Ethiopia, soil degradation, insect pests and different weeds are serious crop yield reducing factors. Farmers use over dose application of inorganic chemicals which resulted in minimizing of pollinating agents, pollution and health problems. In southwestern part of Ethiopia such problems are practical. Perennial grasses, sedges and annual weeds with their fast and vigorous growth can affect the yield and quality of the crop (Meleaku *et al.* 2015) reaching up to 90% yield reduction (Spironello *et al*., 2004).

Although pineapple successfully grows in South and Southwestern Ethiopia at home stead and in large scale farms, the average yield of the crop is low, 45 tons/ha (IAR, 1996) as compared to global average fruit yield of 63 t/ha (Samuels *et al*., 1960). This low yield is attributed to lack of improved pineapple technologies for diverse environmental conditions andlow weed management practices that result in low fertility status of the soil by competing for scares resources (Hermann *et al*., 2013; Tewodros *et al*., 2018).

To solve this challenge, using mulches for weed management and reducing the application of hazardous chemicals is possible. There are different types of biodegradable mulch materials from plant parts and non-decomposable mulches such as polythene plastics. Therefore, this experiment was conducted to identify the best and environmentally friendly mulching materials for pineapple weed management.

Materials and Methods

Description of the study areas

Field experiment was conducted between 2017-2019 cropping seasons at Jimma Agricultural Research Center (JARC) horticultural research station, Gojeb

Horizon plantation state farm and Metu Research trial site of JARC which is 265 km from Jimma. ARC which is one of the national research centers found in Jimma and is located at 345 km southwest of the capital city of Ethiopia. The detail geographical description of the study areas are presented in Table 1.

Table 1. Geographical and meteorological description of the study areas

Locations	Mean altitude (m.a.s.l)	Latitude	Longitude	Temperature (°C) Max	Min.	Annual Rainfall (mm)
Jimma	1753	7° 40.00' N	36° 47'.00' E	26.2	12.1	1521.1
Metu	1650	8°18' .00' N	35°35' .00' E	28.0	12.2	1520
Gojeb	1553	7° 3' .00' N	35° 18' .00'E	29.9	15.4	1685.9

All locations have bimodal and high rainfall which is suitable for the proliferation of annual and perennial weed species competing for scarce resources.

Experimental materials and Design

The commercially known pineapple variety (Smooth cayenne) was planted in double rows planting method at the recommended 30cm x 60cm x 90cm intra and inter rows spacing, respectively. The experiment was laid out in a randomized complete block design with three replications. Different mulch materials were applied as weed controlling mechanism. The treatments used as mulches were Soya bean straw, maize straw/stalk, untreated (check), black polythene/plastic, white/transparent polythene, vetivar grass, frequent weed removal and coffee husk. These treatments were applied twice during growing seasons where the first mulch types were applied during planting and the second were after a year of the first application.

Data collected and analysis

Weed data such as biomass (kg), weed species and types were recorded using quadrant placing method of 50cm x 50cm quadrant on each plot where weed types and species counted and recorded. On the other hand, pineapple data including plant height (cm), leaf length (cm), fruit length (cm), fruit diameter (cm) and fruit weight (kg) were collected two rounds during growing period. Collected data were analyzed using SAS ver. 9.0 software and mean separation between treatments were done using least significant difference (LSD) at 5%.

Results and Discussion

Weed Types, weed biomass and treatments' weed control efficacy

The result of ANOVA for weed biomass (WBM) and the weed controlling treatment efficiency (WCE) showed significant variation among treatments (Table 2). The mean weed biomass and its percentage controlling efficacy ranged from

1.2 kg to 7.8kg with 35.2% to 84.5% controllin efficiency. At Jimma, the minimum and maximum weed biomasses were 1.2 to 9 kg, respectively. Accordingly, the plot treated with black polythene followed by frequent slashing showed the lowest WBM of 1.2 and 1.3 kg and highest WCE of 86.6 and 85.6%, respectively. On the other hand, the maximum weed biomass and least percentage WCE was recorded from the control/weedy plot (9 gk) followed by plot treated with white polythene (5.4 kg) with WCE of 40%, respectively. At Gojeb WBM of 2.4kg under black polythene next to 1kg under frequent slashing with percentage WCE of 81.4 and 88.1%, respectively. Similarly, at Metu, 1.8 kg with 70% weed efficacy under black poly next to frequent slashed plot of 1.2kg WBM with 79.70% and 1.2kg and 79.7%, respectively. The combined means results of the three locations regardless of other side effect like soil erosion, indicated that plot treated with frequent slashing and black polythene treated plot were the most efficient weed controlling mechanism with 1.2kg WBM and 85.4% , and WBM of 1.8kg and 79.4%WCE (Table 2.), respectively. under This lowest biomass result under black poly might be due to opaque nature of the plastic color and only absorbs heat that affected weed seed germination percentage decreasing emergency resulting in lower biomass. Contrary, the highest biomass result under white polythene might be as a result of light transmission nature of the poly which hastens weed germination and growth Table 3). This achievement was in agreement with the finding of Pramanick *et al*. (2006) and Sun *et al*. (2015) who reported lowest weed density and weed biomass under black polyethylene and blue-black polythene.

Treatment (mulch)	Weed biomass (weight) Kg/plot and %ge							
	Jimma		Gojeb		Metu		Mean	
	WBM	%ge	WBM	%ge	WBM	%ge	WBM	%ge
Soybean	3.6 [de]	60.0	7.7[a]	8.4	3.0[c]	50.8	4.8	39.8
Maize Stalk (MS)	4.6[bc]	49.0	5.8[b]	31.0	4.4 [b]	25.4	4.9	35.2
Black polyethylene (BP)	1.2f	86.6	2.4[d]	81.4	1.8[d]	70.0	1.8	79.4
Vetivar grass (VG)	3.9[cd]	56.7	4.0[c]	52.4	2.8[d]	52.5	3.6	53.9
White poly (WP)	5.4[ab]	40.0	3.0[d]	64.3	3.6[c]	39.0	4.0	47.8
Coffee husk (CH)	3.0[e]	66.7	3.0[d]	64.3	1.4[d]	76.3	2.5	69.1
Frequent slashing (FS)	1.3[f]	85.6	1.0[e]	88.1	1.2[d]	79.7	1.2	84.5
Weedy control (WC)	9.0 [a]	-	8.4[a]	-	5.9[a]	-	7.8	-
Mean	4	-	4.41	-	3.01	-	3.83	-
LSD (5%)	0.84		0.86		0.65			
CV (%)	12.33		11.14		8.98			

Yield and yield related traits of pineapple

There was significant variation among treatments/mulching types in all attributes at all locations (Table 3). At all locations, plots treated with black polythene effectively suppressed weed density thereby increasing yield and related traits. The yield obtained with this treatment ranged from 51.88 t/ha at Metu to 76.12 t/ha at Jimma. At Jimma and Gojeb, the highest average weights of single fruit achieved were 1.65 and 1.39 kg, respectively. At Gojeb, it gave a yield of 643.13

t/ha. Next to black polythene treatment, coffee husk treatment gave better yield though statistically similar with the result of most treatments.

The highest fruit length, fruit diameter and fruit weight obtained at Jimma were 15.20cm, 12.48cm and 1.65 kg, respectively from plot treated with black polythelyne followed by coffee husk treated plot at Jimma with 11.10cm of fruit length, 9.99 cm fruit diameter and 1.17 kg of fruit weight. At Metu, higher yield and related parameters next to black polyethylene was observed under frequent slashing with 11.40cm, 10.60cm and 1.02kg of fruit length, fruit diameter and fruit weight, respectively. However, at Gojeb the highest yield and related traits were obtained from black polyethylene treated plots with 15.07, 12.70cm and 1.39 kg of fruit length, fruit diameter and fruit weight respectively followed by a plot treated with black coffee husk with 11.23cm, 9.94cm and 0.95kg of fruit length, fruit diameter and fruit weight in that order (Table 3). Similar result was reported by Bobby *et al.* (2017) who studied effect of different color of polythene and natural mulch materials on weed control. The authors reported that black-black polythene effectively controlled weed density.

Table 3. Mean fruit yield and related traits of pineapple in tested locations as affected by different mulch types

Treatments	Jimma				Metu				Gojeb			
	FL (cm)	FD (cm)	FWt (kg)	Yield (Qt/ha)	FL (cm)	FD (cm)	FWt (kg)	Yield (Qt/ha)	FL (cm)	FD (cm)	FWt (kg)	FW (Qt/ha)
Soybean straw	10.62^{bc}	9.21^{b}	0.68^{cd}	314.24^{cd}	11.33^{b}	10.55^{ab}	0.78^{d}	425.58^{bc}	11.67^{ab}	10.88^{b}	0.63^{cd}	288.62^{cd}
Maize straw	9.57^{c}	8.75^{b}	0.58^{de}	272.00^{de}	11.50^{b}	9.95^{ab}	0.73^{d}	439.66^{b}	9.33^{e}	9.03^{cd}	0.48^{de}	220.29^{de}
Black poly	**15.20^{a}**	**12.48^{a}**	**1.65^{a}**	**761.20^{a}**	**13.90^{a}**	**11.45^{a}**	**1.26^{a}**	**581.79^{a}**	**15.07^{a}**	**12.70^{a}**	**1.39^{a}**	**643.13^{a}**
Vetiver	10.90^{b}	9.51^{bc}	0.83^{c}	377.00^{c}	11.17^{b}	9.72^{ab}	0.92^{c}	370.83^{bc}	11.00^{bcd}	9.81^{bcd}	0.72^{c}	334.18^{c}
White poly	9.99^{bc}	8.90^{b}	0.54^{de}	252.48^{de}	10.74^{b}	9.18^{ab}	0.66^{e}	383.77^{bc}	11.74^{bc}	9.38^{cd}	0.47^{de}	218.13^{de}
Slashing	10.27^{bc}	9.48^{b}	0.71^{cd}	324.85^{cd}	11.40^{b}	10.60^{ab}	1.02^{b}	339.70^{cd}	10.73^{cde}	9.55^{cd}	0.59^{cd}	272.69^{cd}
Coffee husk	**11.10^{b}**	**9.99^{b}**	**1.17^{b}**	**622.30^{b}**	**11.51^{b}**	**9.89^{ab}**	**1.05^{b}**	**463.35^{b}**	**11.23^{bcd}**	**9.94^{bc}**	**0.95^{b}**	**437.31^{b}**
Untreated	10.15^{bc}	8.75^{b}	0.46^{e}	211.42^{e}	9.97^{c}	8.48^{b}	0.56^{f}	275.85	9.80^{de}	8.65^{d}	0.3^{e}	181.67^{e}
Mean	10.98	9.63	0.84	391.94	11.44	9.99	0.89	410.06	11.43	9.99	0.70	324.50
CV	10.18	11.27	18.75	18.73	8.33	9.07	19.32	19.32	11.79	10.23	5.18	23.82
LSD (5%)	1.31	1.27	0.18	85.84	1.11	1.28	0.20	92.59	1.57	1.19	0.19	90.34

FL=fruit length, FD=fruit diameter, FWt=fruit weight

The least percentage of weed index was obtained from mulch material of black poly followed by coffee husk at all locations (Table 4). The less the values of weed index indicates the higher weed controlling effect of the materials (Bobby *et al.*, 2017). Mulching by coffee husk gave percentage weed index value of 18.25%, 32.00% and 20.36% at Jimma, Gojeb and Metu next to black polythene treated plot (0%), respectively (Table 4). Since the area is a coffee-based farming system, coffee husk is availablehenec the farmers who can't afford the plastic polythene can use it as alternative means of mulching material.

Table 4. Effect of different mulch materials on percentage weed index

Treatment	Yield index		
	Jimma	Gojeb	Metu
Soybean straw	55.17	55.12	26.85
Maize straw	64.26	65.74	24.42
Untreated	72.22	71.75	52.58
Black poly	0.00	0.00	0.00
Vetiver	50.47	48.03	36.26
White poly	66.83	66.08	34.03
Slashing	57.32	57.59	41.61
Coffee husk	18.25	32.00	20.36

The effect of polyethylene mulches on physico-chemical composition of pineapple variety smooth cayenne was presented in Table 5. The result revealed that mean fruit moisture contents ranged from 82.30 to 88.85%. The dry matter ranged from 11.50 to 17.70%, titratable acidity from 0.02 to 0.03, p^H from 3.44 to 3.95 and TSS from 12.2 to 15.10. The variability among mulches on smooth cayenne with respect to different physic-chemical character revealed wide chance to improve pineapple yield possessing desirable quality traits.

Table 5. Effect of polyethylene mulches on physico-chemical composition of pineapple variety smooth cayenne

No	Treatment type	Moisture Content %	Dry Matter Content	TA	pH	TSS
1	Soya bean straw	82.3	17.7	0.02	3.73	14.1
2	Maize	88.5	11.5	0.019	3.74	14.7
3	Check	83.55	16.45	0.02	3.58	15.1
4	Black poly	87.8	12.2	0.03	3.63	13.2
5	Vetiver grass	82.3	17.7	0.019	3.57	15.0
6	White poly	85.45	14.55	0.02	3.95	12.2
7	Slashed	88.85	12.15	0.016	3.44	12.6
8	Coffee husk	84.9	15.1	0.022	3.50	13.1
	Mean	85.46	14.67	0.02	3.64	13.75

Conclusion and Recommendation

Weeds compete with pineapple for scarce resources under no management and reduc yields in significant amount. To reduce this competition and enhance yield of pineapple, different weed management practices were studied. Among the treatments, black polyethylene was found to be the best mulch material for suppressing weed emergence, while white polyethylene was the poorest mulch material for weed control because it allows light for weed germination and growth. The current finding also showed that coffee husk was a good alternative mulch material for weed control in pineapple to growers that cannot afford to buy black polyethylene.

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Physico-Chemical and Sensory Evaluation of Pineapple (*Ananas comosus* (L.) Merr) Varieties in Southwest Ethiopia

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Abstract

Pineapple makes a significant contribution to food security and medicinal purpose in developing countries. In Ethiopia, there is insufficient scientific study on biochemical composition and sensory characteristics of pineapple fruits. To fill this knowledge gaps, this study was conducted to evaluate the physico-chemical and sensory characteristics of pineapple varieties in southwest Ethiopia. Five pineapple varieties fruit flour was prepared and run in duplicates laboratory test. Data on five physic-chemical traits and sensory characters were collected and subjected to analysis. The results revealed significant differences ($p \leq 0.01$) in physico-chemical traits of all tested varieties. The mean fruit moisture contents ranged from 83.5 to 87.1%, dry matter contents from 12.90 to 18.34%, titratable *acidity from 0.16 to 1.13%, p^H from 3.15 to 3.84 and total soluble solids from 12.20 to 14.40% with a mean value of 85.57%, 14.73%, 0.38, 3.60 and 13.55, respectively. Based on sensory evaluation, most panelists preferred all genotypes except Red Spanish. The principal component analysis grouped the variables into five components based on five physico-chemical traits, among which the first two are significant (Eigen value > 1) and explained 74.46% of the total variability. From all traits,* titratable *acidity, moisture contents and total soluble solids contributed maximally to the PCs. This variation is attributed to environmental and genetic factors. Further investigation of the existed pineapple varieties based on molecular marker analysis is vital for better assessment of genetic diversity of pineapple in Ethiopia.*

Introduction

Pineapple (*Ananas comosus* (L.) Merr) is a perennial herb in the botanical family *Bromeliaceae (*Spironello *et al.*, 2004). It is native to South America where the original species (wild) are still grown (Tewodros *et. al*, 2018). It is the second most important fruit crop after bananas and contributing for over 20% of the world tropical fruits production (Mohamed and Ahmad, 2004) and 51% of global fruit market (FAO, 2008). It is a major tropical fruit with an estimated 24.78 million metric tons of global pineapple production in 2012 (FAO, 2013). Of total production, 70% of the pineapple fruit is consumed as fresh fruit and the remaining 30% used as chunks**,** slices, juices, syrups, jams, crushed and diced pineapple in major producing countries. Moreover, wastes from processing of pineapple fruit are now further processed into sugar, wines, vinegar and animal feed during dry season. The leaves of pineapple have high quality fiber for manufacturing of luxury cloth, making rope, fishing nets and pulp in the paper industry. The fruit of pineapple have rich digestible carbohydrates, fat, vitamins

A, C and essential minerals. Besides, pineapple fruit stimulates digestion and the proper performance of the small intestine and kidneys. It also helps in detoxification, normalization of colonic flora, helps in hemorrhoid alleviation, and prevents constipation (due to the fiber content of the pulp). It has been used to heal colds, mouth, throat and bronchial infections. The suitability of pineapple as food stores on ships and medical ingredients greatly facilitated their distribution throughout the world. Currently, *Annanas* is a pan tropical genus and different species have been independently domesticated across continents.

In Ethiopia pineapple is first introduced in the 1940's by a Catholic church at Sidama and Gedeo zones of southern region (Tewodros *et al.*, 2014). Currently the crop is cultivated by small scale farmers mainly in South and South-Western parts of the country. Average yield of pineapple in Ethiopia is about 50 tons/ha (Tewodros *et. al.*, 2018), while the global average fruit yield is 63 t/ha (Spironello *et al*., 2004). In Ethiopia the crop is mainly grown to ensure food and nutrition security and income generation. According to Central Statistical Authority (CSA, 2017/18), about 104,421.81 hectares of land is covered by fruit crops and an estimated 7,774,306.92 quintals yield is produced. Of these, pineapple contributed 6090.8 (5.83%) hectares and produced 13,745.47 (0.18%) quintals yield to the total fruit production in the country. In spite of its role in food and nutrition security and medicinal importance, no efforts has so far been done to characterize the physico-chemical properties and sensory evaluation on pineapple in Ethiopia. Hence, information on the proximate and sensorial characteristics of existing pineapple varieties are lacking. Therefore, the present study was designed to assess the physico-chemical and sensory characteristics of pineapple varieties grown in Southwest Ethiopia.

Materials and Methods

Description of study area

The study was conducted at Jimma Agricultural Research Center (JARC). The center is located at latitude of 7^{o} 40.00' N and longitude of 36^{o} 47'.00' E at an altitude of 1753 m.a.s.l. The area receives mean annual rainfall of 1432 mm with the maximum and the minimum temperature of 26.5^{0}C and 12^{0}C, respectively. The soil of the study area is Eutric Nitosol (reddish brown) with p^{H} of 5.63. This environmental condition is conducive for pineapple production.

Soil sampling and analysis

Fifteen core soil samples were randomly collected from 0 to 30cm top soil and bulked to form a composite sample. The collected samples were air dried, crushed and allowed to pass through a 2 mm sieve. Particle size distribution analysis was carried out by the hydrometer method, while soil p^{H} in soil solution ratio of 1:2 in 0.01M C_aCl_2. Soil organic carbon was determined by the Walkey and Black method and total N by the micro-Kjeldahl digestion method (Bremmer and Mulraney, 1982). Available P was determined by Bremmer and Mulroney (1982) extraction method. Exchangeable bases were extracted with neutral 1M NH_4OAC at soil solution ratio of 1:10 and measured by flame photometry. Exchangeable acidity was determined by titration of 1M KCL extract against 0.05M NaOH to a pink end point using phenolphthalein as indicated by Maclean (1982). The soil sample analysis was conducted at JARC soil and plant tissue laboratory.

Experimental materials, design and management

Five pineapple varieties, namely Smooth cayenne, Red-Spanish, Queens, MD-2 and Sugarloaf, grown at JARC, in Southwest Ethiopia was used for this study. Slips of the same size and age from each variety was planted in a randomized complete block design (RCBD) with three replications with double row planting pattern of 30 x 60 x 90 cm between plants, paired rows and between rows, respectively. The gross plot size for each treatment was $9m^2$ (3 m x 3 m). One month after planting, seedlings were earthed up, followed by frequent weeding. All other agronomic practices were carried according to the recommendation.

Samples collection and preparation

Samples were collected from five plants of each pineapple variety. Pineapple fruits were weighed, peeled, cut into small pieces and dried at 65°C for 72 hours until constant weight was obtained (10%). The dried chips were then milled using an electric grinder to obtain fine powder pineapple flour. The flour was sieved through 1 mm sieve, measured and packed into airtight plastic bag and kept at room temperature until analysis. The quality analysis was conducted at Jimma University College of Agriculture and Veterinary Medicine (JUCAVM) post-harvest and nutrition laboratory.

Physico-chemical and sensory analysis

The fruit moisture content, dry matter, titratable acidity, p^H, and total soluble solids (TSS) were determined in accordance with the standard methods of AOAC (2000). The fruit flour moisture content was determined by the standard analytical method AOAC (1984). Duplicate fruit samples (100 g) were weighed in aluminum dishes and oven dried at 65°C for three days. The dried samples were cooled in a desiccator's at room temperature and weighed. The fruit moisture content was determined by loss of weight due to drying and converted to percent flour moisture content as follows: Fruit moisture %= (weight of fresh fruit sample-weight of dried fruit) x 100. The fruit dry matter content of pineapple was calculated by taking a representative duplicate sample of about 100 g (W1) prepared by thoroughly mixing sliced pieces and drying it in an oven set at 65°C for 72 hours and weighed (W2). Then the dry matter percent of the fruit is determined by (W2/W1) x 100 (Cozzolino and Labandera, 2002). Or % Dry matter=100 - % moisture content. Titratable acidity was assessed as outlined by

AOAC 962.12 method. The pineapple peel extract contains a number of organic acids, which are readily neutralized by strong bases and can be titrated against standard bases such as sodium hydroxide. A 10ml sample of pineapple peel extract was weighed. Then, the sample was transferred in to a 500 ml Erlenmeyer flask. The sample was diluted to 250 ml with deionized water. Using a standard solution of 0.1 N sodium hydroxide, the sample was titrated to the end point. The end point was determined using a phenolphthalein indicator. One ml of phenolphthalein indicator was added to the sample and titrated until faint pink end point was observed. The volume of 0.1 N sodium hydroxide used was recorded. The total acidity can be calculated using equation and expressed as concentration of citric acid (g/l). The measurement was repeated at least three times. The percentage of citric acid was calculated according to the following expression: % Acid (as anhydrous citric acid) = Volume of 0.1 N NaOH (ml) × 0.64 / 10. The pH of the pineapple peel extract was determined using a pH meter (pH 211 Microprocessor pH meter Hanna) at room temperature. Total soluble solids were determined using a refractometer (Digital ABBE Refractometer, Kruss Optronic) by following AOAC 932.12; 1990. A drop of the solution was squinted on the prism of refractometer. The percentage of TSS was obtained from direct reading of the instrument (Amador, 2008). The samples were run in duplicates and the mean value was used. The sensory characteristics of the genotypes were determined to establish their quality profile. The sensory attributes and consumer acceptability of fruits including color, aroma, taste, texture and market acceptability were scored by panelists based on a five-point hedonic scale with 1=poor and 5=excellent of a given attribute.

Data analysis

The collected data were subjected to analysis of variances and treatment means for significant difference is separated by Least Significant Difference (LSD) by using Statistical Analysis System (SAS) package (SAS, 2000).

Results and Discussion

Soil physico-chemical property

The result of the soil physico-chemical properties of the study area is presented in Table 1. The result revealed, the soil of study area is sandy clay with low N and available P, p^H of 5.65 in water, 0.539 g kg^{-1} N, 3.27 g kg-1 organic C. 0.691 ppm available P, 1.969 meq/100g K, 5.636 % organic matter, 0.120 meq/100g exchangeable acidity and 22.76 meq/100g CEC. Particle size distributions were 52% sand, 36% clay and 12% silt.

Table 1. Physico-chmemical properties of experimental field top soil (0-30 cm) in JARC.

No.	Physico-chemical composition	
1	% Sand	52
2	% Silt	12
3	% Clay	36
4	Textural class	Sandy clay
5	pH (H_2O)(1:2:5)	5.65
6	Organic carbon (g)	3.269
7	Available P (ppm)	0.691
8	Total N (g/kg)	0.539
9	Available K (meq/100g)	1.969
10	%Organic matter	5.636
11	Exchangeable acidity (meq/100g)	0.120
12	CEC (meq/100g)	22.76
13	Exchangeable AL^{+++} (meq/100g)	Trace

Physicochemical properties of pineapple varieties

Analysis of variance

The result of analysis of variance of the physicochemical and sensory attributes of the pineapple varieties was presented in Table 2. The result on the analysis of variance indicated, mean squares due to variety were non-significant ($p \geq 0.05$) difference for all tested physico-chemical traits considered in this study.

Table 2: Analysis of variance of different quality traits of pineapple varieties from Southwest Ethiopia

Quality triat	Mean square		CV%	R^2
	Variety	Error		
Moisture content (%)	288.41	196.3	17.6	0.57
Dry matter (%)	1.51	0.76	6.1	0.60
Total acidity (%)	0.004	0.0008	193	0.56
pH	0.98	0.34	13.5	0.73
TSS (%)	2.20	0.34	4.16	0.83
	NS			

Mean performance quality traits

The mean performance of the physico-chemical traits and pineapple varieties indicated significant variation ($p \leq 0.01$) among varieties (Table 3). TSS is an important quality factor for many fruits during ripening and can be used as an indicator of fruit maturity and quality. Senescence is enhanced by increasing sugar content in fruits. Soluble solids are also known to affect sweetness index than does the total sugars (Wardy *et al.*, 2009). With 14.4 and 14.2% of TSS, variety MD-2 and Smooth cayenne were the best performed varieties, respectively while variety queens recorded was the lowest (12.20%) in TSS value. The variability among pineapple varieties with respect to TSS also revealed wide chance of developing pineapple varieties possessing desirable quality traits. The other varieties sugar loaf and red Spanish had moderate TSS value. The result obtained from this study was similar with the report of Nadya *et al*. (2012).

The pH of pineapple fruit extract on different varieties are presented in Table 3. There was significant difference among pH values for all tested varieties. The mean pH value ranged from 3.15 (Red Spanish) to 3.84 (Sugar loaf). This result was consistent with the report of Nadzirah *et al*. (2012) who reported pH value of 36 pineapple varieties that ranged from 3.0 to 6.5. The low pH value of variety Red Spanish may be attributed to high weak acids like citric acid and malic acid and sodium, potassium and calcium salts concentration in the fruit. Furthermore, maturity stage of the fruit decreased the concentration hydrogen ion of the fruit. As the fruit matured, pH was increased and contributed less acidity to the pineapple fruit. When concentration increased, the acidity increased due to the increase in hydrogen ions present in the solution. Hydrogen ions determined the degree of acidity. As the concentration of hydrogen ions reduced, pH value is expected to increase. Fruit pH increases at the high rate of respiration by accelerated acid metabolism and accumulation of cations (Fernando and De Silva, 2000). Further, the pH values obtained also reflect significant extent to the microbial stability of the various varieties (Wardy *et al*., 2009).

Significant difference among pineapple varieties was also observed in their TA contents. Red Spanish contained the maximum (1.13%) total TA while the minimum value was observed from Sugarloaf (0.16%). TA was evaluated to determine the citric acid in pineapple fruit extract and it is a good indicator of sourness. In pineapple, TA is reported as citric acid, not malic acid (Spironello *et al.,* 2004). It varies primarily with fruit developmental stages but does not relatively respond to short term environmental changes, while the malic acid varies with environmental changes especially the light (Chuenboonngarm *et al*., 2007). Different scientific studies indicate that during storage periods, fruits utilize organic acids for metabolic activities and leads to decrease in the TA content. These report further explained the decrease in acidity coincided with an increase in sugar concentration in the pomegranate fruits (Chuenboonngarm *et al*., 2007).

Table 3: Physico-chemical characteristics of pineapple varieties grown at JARC

Variety	MC	DM	TA	pH	TSS
Smooth cayanne	85.86[b]	14.20[b]	0.26[b]	3.51[d]	14.20[b]
MD-2	87.10[a]	12.90[d]	0.19[c]	3.77[b]	14.40[a]
Queens	86.83[a]	13.06[d]	0.18[d]	3.75[c]	12.20[e]
Sugarloaf	84.60[c]	15.13[b]	0.16[e]	3.84[a]	13.30[c]
Red spanish	83.50[c]	18.34[a]	1.13[a]	3.15[e]	13.64[d]
Mean± Se	85.57±3.74	14.73±0.93	0.38±0.09	3.60±0.76	13.55±0.76
CV (%)	0.49	0.62	4.55	0.10	0.11
LSD (5%)	0.85	0.32	0.22	0.010	0.012

MC= Moisture content (%),DM= Dry matter (%), TA= Titratable acidity, TSS= Total soluble solids (%)

Further, Joomwong (2006) and Tehrani *et al*. (2011) reported the slow decrease in acidity, concomitant with increased TSS and total sugar content, is an intrinsic process during ripening of fruits to impart the flavor. During ripening, organic acids are respired or converted to sugars and acid levels decline (Fernando *et al*., 2000). The TSS and acid content are the factors influencing consumption quality (Joomwong, 2006). From all varieties studied, MD2 and Queens had high moisture contents with value of 87.10 and 86.83%, respectively. However, Red Spanish and sugar loaf had lowest moisture content.

Sensory characteristics

The results of sensory evaluation carried out to determine the acceptability of the pineapple genotypes to consumers are presented in Table 4. This results revealed that there was no significant differences among the five genotypes for all sensory characteristics assessed based on the five point scale by the panelists. The color scores ranged from 3.21 for Red Spanish to 4.16 for MD-2 with a mean value of 3.61. Nevertheless, it was not statistically significant and panelists preferred all genotypes based fruit color. In terms aroma, the mean scores varied from 3.12 for Sugarloaf to 4.36 for MD-2 with a mean of 3.69. Similarly, the taste scores varied from 3.80 for Sugarloaf to 4.84 for Queens.

Table 4. Sensory evaluation of five pineapple genotypes at JARC

Genotype	Color	Aroma	Taste	Texture	Acceptability
Smooth Cayane	3.32	4.14	4.35	4.18	4.25
MD-2	4.16	4.36	4.42	3.21	4.28
Queens	3.50	3.51	4.84	3.64	3.89
Sugarloaf	3.85	3.12	3.80	3.80	3.63
Red Spanish	3.21	3.32	3.92	3.60	3.10
Mean	3.61	3.69	4.27	3.70	3.83
LSD 5%	1.13	1.19	0.45	0.60	0.79
CV%	7.10	10.90	6.40	9.00	6.40

LSD = least significant difference; CV(%) = coefficient of variation

The texture scores ranged from 3.60 for Red Spanish to 4.18 for Smooth Cayanne. Although, there is no statistically significant textural difference, most panelists preferred Smooth Cayenne and Sugarloaf genotypes from the rest of genotypes. The overall consumer acceptability scores ranged from 3.10 for Red Spanish to 4.18 for 'MD-2. The general acceptability on the final judgment of the panelists for the genotypes computed by summing up all the perceptions indicated that all the tested pineapple genotypes were better than the Red Spanish (Table 4).

Similar findings were reported in Sri Lanka (Fernando and De Silva, 2000), Malaysia (Mohamed and Ahmad, 2004), and in Ghana (Wardy *et al*., 2009). Spironello *et al.* (2004) also reported similar mean values of sensory scores given by the panelists for the three pineapple genotypes. In Ghana, the panelists preferred the color, aroma and texture of pineapple varieties (Wardy *et al*., 2009). Color is a very important attribute related to attractiveness of the fruit to the consumer and influences the initial acceptability of a product by consumers. The color differences observed among genotypes could be due to the different sugar content in the different fruits (Aquino *et al*., 2017). The sensory evaluation of new genotypes is decisive in the process of varietal selection. Therefore, the analysis of sensory characteristics is useful for determining the acceptability of new products by consumers (Coulibaly and Djedji, 2004).

Principal component analysis

The patterns of variation and the relative importance of each quality trait in explaining the observed variability was assessed through principal component analysis (PCA). The result of PCA grouped the variables into five components based on five quality traits, among which the first two are significant (Eigen value > 1) and explained 74.46% of the total variability (Table 5).

Table 5: Eigen values, proportion, cumulative variance and component scores of the first five principal components for quality traits in five varieties of pineapple

Variables	PC-1	PC-2	PC-3	PC-4	PC-5
Eigen value	2.113	1.639	0.806	0.263	0.207
Proportion	42.27	32.19	16.13	5.27	4.14
Cumulative	0.422	0.744	0.905	0.958	1.00
Moisture Contents%	-0.074	**0.669**	0.482	**0.494**	-0.261
Dry matter %	0.408	-0.510	0.391	0.550	0.340
TA	**0.635**	-0.125	-0.053	-0.081	-0.755
P^H	0.395	0.375	-0.695	0.376	0.278
TSS (%)	0.517	0.366	0.357	-0.550	0.408

The first principal component (PC-1) accounted for 42.27% of the total variation and was correlated positively with dry matter (0.408), titratable acidity (0.635), pH (0.395) and total soluble solids (0.517), while only moisture contents (-0.074) contributed negatively. The second principal component (PC-2) accounted for 32.19% of the total variability and mainly correlated with moisture contents (0.669), pH (0.597), and total soluble solids (0.366) and negatively with the titratable acidity (-0.125) and dry matter (-0.510). The third principal component (PC-3) had 16.13% contribution to the total variation. Moisture content contributed (0.482), dry matter (0.391) and total soluble solids (0.357), while PC-

4 accounted for 5.27% of the variation and correlated positively with moisture content (0.494), dry matter (0.550) and pH (0.376). Finally, PC-5 had 4.14% of the variation and negatively correlated with moisture content (-0.261) and titratable acidity (-0.755).

Conclusion and Recommendation

The mean performance of quality attributes and pineapple varieties indicated significant variation ($p \leq 0.01$) among all traits considered. For total soluble solids, variety MD-2 and Smooth cayenne were best performed varieties due to highest value of total soluble solids with its value of 14.4 and 14.2%, respectively. The variability among pineapple varieties in respect to TSS also revealed wide chance of developing pineapple varieties possessing desirable quality traits. The principal component analysis grouped the variables into five components based on five traits among which the first two are significant (Eigen value > 1) and explained 74.46% of the total variability. From all traits, titratable acidity, moisture contents and total soluble solids contributed maximally to the PCs. This variation is attributed to environmental and genetic factors. The results obtained from this study will help to pineapple processors, breeders and producers to develop pineapple variety with good quality. Accordingly, the study makes a significant contribution to food and nutritional security to the society in the country.

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Adaptability of True Seed Shallot Varieties around Fogera, Dera and Libokemkem Districts of South Gondar Zone

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Abstract

Shallot (Allium cepa L. cv aggregatum group) is among the most popular Allium in Ethiopia which is preferred for its pungency and unique flavor. Shallots are more pungent with good storability than onions. Pungency is a desired trait for most Ethiopians prefer hot spicy dishes. Shallot production is getting declined mainly due to vegetative (bulb) propagation. Major challenges of shallot production include short shelf life of bulbs and the need for several quintals of bulbs to plant a hectare of land. In an attempt to alleviate the major bottlenecks of the production practice, true seed propagated shallot varieties were recently developed and released from DZARC and MARC. Adaptability of improved true seed shallot varieties, namely DZSHT-157-1B, and DZSHT-91-2B from Debere Zeit Agricultural Research Center (DZARC) and Yeras and onion variety as a check (Nasik red) from Melkassa Agricultural Research Center (MARC) were evaluated in the dry seasons of 2017/18 and 2018/19 in Fogera, Libo kemkem and Dera districts of South Gondar zone of North Western Ethiopia. Varieties Dzsht-157-1B and Dzsht-91-2B had good vegetative growth and a bit late in maturity. The earliest varieties in maturity were Years and Nasik red. Variety Dzsht-157-1B produced the highest cured marketable bulb yield both in 2018 and 2019 dry seasons. Feedback from farmers and agricultural experts further indicated that varieties Dzsht-157-1B and Dzsht-91-2B are preferred to Years because of good vegetative growth, leaf and bulb color and number of bulb splits. Variety Years rarely produced splits more than two and even the majority of bulbs are single ones with no splits. Furthermore, bulb color of this variety is light red. Farmers are therefore requesting for the supply of seed of true seed shallot varieties Dzsht-157-1B and Dzsht-91-2B, which have a typical characteristic similar to traditionally bulb propagated shallot varieties. It is therefore planned to multiply seeds for pre-extension demonstration activity and to distribute to farmers.

Introduction

Shallot (*Allium cepa* L. cv aggregatum group) is one of the most preferred *Allium* in Ethiopia. The use of shallot as a condiment for flavoring many local dishes such as '*Wot*' (a spiced stew) has significant importance and is preferred to onion for its pungent culinary purposes. Furthermore, unlike '*Wot'* prepared with onion, it is believed that '*Wot*' of shallot can be kept overnight or more without being spoiled. The advantage of keeping quality of '*Wot*' cannot be overlooked for many Ethiopian's residing in rural areas do not afford buying refrigerators.

Among other merits of shallot over onion in Ethiopia is the relative tolerance of the plant to foliar diseases and insect pests. It has a short growing cycle suiting to double harvest in a plot- shallot grown as a first and an early cash crop planted at the onset of the small rain *(Belg)*, and other food crops immediately planted following shallot harvested during the main rainy period. It has also wide soil and climatic adaptation and is suitable for cultivation both under irrigation and rain-fed conditions.

Shallot (*Allium cepa cv aggregatum, ascalonicum*) is among the most popular *Allium* in Dera, Fogera and Libokemkem Districts of South Gondar zone of Amhara region in Ethiopia. Despite the preference for shallot bulbs to onion by growers for it fetches good price, production of shallot is decreasing from time to time. This is solely due to vegetative propagation which is costly and has other many disadvantages as compared to propagation by true seeds.

Shallot is commonly propagated from bulb splits and this has been the major bottle neck for large scale production of shallot. Because of the inherent nature of poor storability of shallot bulbs due to rotting, sprouting and loss in weight, bulbs used for planting materials need to be handled with maximum care. It was therefore difficult to keep bulbs for planting material from season to season or year to year. Consequently, farmers are compelled to sell their own produce with low price right after harvesting and buy expensive planting materials during planting time. Furthermore, large quantities of bulbs are required to plant a hectare (more than ten quintals) which is costly leading to rise in cost of production and ultimately reducing return or net profit per unit area. Furthermore, bulbs could serve as good media for growth and carryover of pathogens from season to season and from place to place. Soegianto, *et al* (2011) indicated that continued cultivation using a bulb of shallot variety as planting material can cause yield reduction and quality deterioration mainly due to accumulation of pest and disease from preceding cultivation. Though shallots are widely consumed in various countries, Getahun, *et al* (2003) elaborated that the main constraints to commercial production are the high cost and scarcity of shallot planting material emanated from storage problem. Vegetative propagation is therefore one of the major bottlenecks to large scale shallot cultivation in Ethiopia. These disadvantages could however be overcome through the use of true seed propagation.

Propagation by true seeds can, on the other hand, help towards alleviating several problems associated with bulb propagation. Propagation using true seeds avoids storage and transportation challenges emanating from bulky bulb propagation methods. Few kilograms of true seeds are sufficient for production of shallot in many hectares of land, which otherwise tons of bulbs are required using bulb propagation. Risk of disease transmission is minimal using true seeds. True seed production, however, depends on the potential of varieties to produce flower stalk and flower in the presence of a favorable environment particularly cold temperature for flower stalk induction. According to Getahun and Zelleke (2006), the night temperature around Debre Zeit is cold between October and January going down to 5-15^0 C, which is necessary to expose young growing plants to cold period so as to induce bolting and flowering. It was further reported that shallot variety 'Hurruta' (DZ-SHT-91) is bolting tolerant and high bulb yielding while DZ-SHT-OP-S5 is a semi bolter. Recently, true seed propagated shallot varieties were developed and released by Debere Zeit and Melkassa Agricultural Research Centers. The objectives of this experiment were therefore to evaluate performance of true seed shallot varieties and demonstrate and popularize best performing varieties around Fogera, Dera and Libokemkem districts of South Gondar Zone in Amhara region, Ethiopia.

Material and Methods

True seed shallot variety adaptation and demonstration trials were conducted in the dry seasons of 2017/18 and 2018/19 in Fogera, Libokemkem and Dera districts of South Gondar zone of North Western Ethiopia. Performance of three true seed shallot varieties and one onion variety as a check were evaluated in these field experimentations.

Seeds of true seed shallot varieties, namely DZSHT-157-1B, and DZSHT-91-2B were obtained from Debre Zeit Agricultural Research Center (DZARC) whereas seeds of shallot variety named Yeras and onion variety named Nasik red were obtained from Melkassa Agricultural Research Center (MARC).

Seedlings were raised at the Fogera center following recommended nursery management practices. Seed beds were thoroughly prepared, and seeds of these three true seed shallot varieties and one onion variety were separately sown on 5m x 1m adjacent beds, 5 cm raised from the surface. Seeds were drilled on rows with ten cm inter-row spacing and it was covered lightly with fine soil and mulched with eucalyptus leaves until emergence. Grass or straw mulching is not advised because it aggravates seedling damage by termites around the study area. Weeding was accomplished as deemed necessary. Water was regularly applied to seedling beds (seeds till emergence and thereafter seedlings) using watering can. Seedlings were thinned at first true leaf stage to allow 1-2cm distance within plants (intra-raw spacing). This seedling raising was done on average six weeks ahead of the transplanting date in the main field. Seedlings generally attained transplantable size in six weeks. Healthy, vigorous and uniform seedlings of pencil size were transplanted in the field.

Treatment and design

Three released true seed shallot varieties (Dzsht-157-1B, Dzsht-91-2B and Years) together with one onion variety (Nasik red) as a check were evaluated in a randomized complete block with three replications for adaptation trials at Fogera and Libokemkem districts while single plots were used for demonstration efforts of varieties on farmers plots' in Fogera, Dera and Libokemkem districts. These variety adaptation and demonstration trials during dry seasons using irrigation was carried out on total plot sizes of 12m2 (4m*3m) and 50m2 (10m*5m), respectively, for adaptation and demonstration trials of each treatment. The experimental field was thoroughly plowed and leveled, and ridges were then prepared on sides of which transplanting was done. The pacing used was 40cm*20cm*10cm between furrows, rows and plants, respectively. Inorganic fertilizers in the form of Urea (46:0:0) (100kg/ha) and Nitrate phosphate sulfur (NPS) (19:38:7) (242kg/ha) were applied. NPS was applied at transplanting while urea is applied in two splits, the first at seedling establishment (1-2 weeks after transplanting) and the second one and half months after transplanting. Weeding & cultivation were performed as deemed essential during the growing season following standard field management practices. Furrow irrigation once in a week starting at transplanting until two to three weeks before harvesting was practiced for these true seed shallot variety adaptation trial and demonstrations during dry seasons of 2017/18 and 2018/19.

Data collection

Feedbacks from farmers and development agents were collected during farmers' field days organized to evaluate field performances of varieties in Fogera, Dera and Libokmekm districts. Both male and female farmers, development agents and agricultural experts of the Woreda agriculture in the three districts and researchers and other stakeholders participated in the farmers' field days. Criteria considered in evaluating varieties were vegetative growth (leaf color, thickness, shoot number and plot cover), tolerance/ resistance to disease and insect attack, earliness in maturity, split number, bulb color, size, pungency and firmness.

Data was collected on disease and insect attack, plant height, leaf number, neck thickness, bolting and days to maturity. Disease and insect attacks were regularly observed and recorded using one to five score where five refers to 100% attack, all leaves and plants developing severe symptoms. Onion bulbs were harvested at 50% foliage fall over. Harvested bulbs with foliage were cured for ten to fifteen days before neck cutting (foliage removal). Drying and curing of onion bulbs was done on wire-mesh and wooden made shelves in a simple ventilated storage constructed from poles, wire meshes and sheets of corrugated iron roofing. Bulb splits per plant was counted since shallots, unlike onion, produce two or more bulb splits per plant. Bulbs were then categorized into marketable and nonmarketable based on size, visible damages on bulbs and rotting. Marketable bulbs are those with average size and above, and are free from visible damages due to diseases, rotting and bruise. Marketable bulbs were counted and weighed whereas non marketable bulbs were counted and sorted out based on their respective causes, i.e., disease, rotting, bruise or undersized bulbs. Data was subjected to analysis of variance using SAS software version 9.2 and least significance difference (LSD) was used to compare treatment means when there was statistically significant difference ($P<0.05$).

Result and Discussions

Adaptation and demonstration trials of true seed shallot varieties were undertaken in Fogera, Dera and Libokemkem districts of South Gondar zone during the dry seasons of 2018 (1^{st} year) and 2019 (2^{nd} year). Seeds of true seed shallot varieties were sown on thoroughly prepared beds on 1^{st} November 2017 and 10^{th} December 2018 for the 2018 and 2019 dry season field trials, respectively. Seedlings took on average six weeks from sowing to transplanting. Seedling transplanting on experimental fields were undertaken from 13-15 December in 2017 while harvesting was accomplished from April 18- 30, 2018 for the trial in the first year, whereas seedlings transplanted on the main field from 23-25 January in 2019, harvesting accomplished from 16-24 May 2019 for the 2^{nd} year trial.

Variety Dzsht-157-1B produced the highest cured marketable bulb yield both in 2018 and 2019 dry seasons (Table 1 and 2). The earliest varieties in maturity are however Years and Nasik red.

Farmers, agricultural experts and Development agents of Fogera, Dera and Libokmkem districts witnessed during farmers' field days that varieties Dzsht-157-1B and Dzsht-91-2B had good vegetative growth and a bit late in maturity period when compared with variety Years. Evaluation of varieties by female and male farmers, and agricultural experts also indicated that varieties Dzsht-157-1B and Dzsht-91-2B are preferred to Years because of good vegetative growth, leaf and bulb color and number of bulb splits (Table 3). Furthermore, it was reiterated that shallots are more pungent with good storability than onions. Pungency is a desired trait for most Ethiopians prefer hot spicy dishes. Farmers thus requested for seed supply of true seed shallot varieties. Farmers in Ethiopia are also unable to keep planting materials from their own harvest for the next planting season or year. As a result, they buy planting materials during planting time, which are expensive. Vegetative propagation is, however, one of the major bottlenecks to large scale shallot cultivation in Ethiopia. Wiles and Midmove (1994) reported that disease incidence (primarily *Alternaria porri)* and short storage life of existing cultivars are the main constraints to shallot production in Papua New Guinea.

Varieties Dzsht-157-1B and Dzsht-91-2B were selected as best varieties followed by Years. Variety Years rarely produced splits more than two and eventhough the majority of bulbs are single ones with no splits. Furthermore, bulb color of this variety is light red (Table 3). It is therefore not the first choice of both farmers and agricultural experts, despite its earliness in maturity and good yield.

Conclusion and Recommendation

Variety Dzsht-157-1B gave the highest cured marketable bulb yield. Farmers preferred varieties Dzsht-157-1B and Dzsht-91-2B for their good vegetative growth, disease tolerance, split number, dark red bulb color and pungency, although they showed a bit lateness in maturity period than variety Years. Since shallots are the preferred bulb crops as a condiment for flavoring many local dishes with pungent culinary purposes to onions, the access to true seed shallot varieties were very much appreciated by both stakeholders including male and female farmers and agricultural experts. Farmers are therefore requesting for seed supply of true seed shallot varieties Dzsht-157-1B and Dzsht-91-2B, which have typical characteristics similar to traditionally bulb propagated shallot varieties. These attributes are more than one bulb split, unlike onion, per plant, pungency, bulb color and good vegetative growth. Seeds of varieties Dzsht-157-1B and Dzsht-91-2B will therefore be multiplied for pre-extension demonstration activity and to distribute to farmers.

Table 1. Cured marketable bulb yield in tone per hectare and days to maturity of adaptation trials of true seed shallot varieties in 2018 and 2019.

Variety	2019 Fogera1	2019 Fogera 2	2018 Adis zemene	Combined	Days to maturity 2019 Fogera 1
DZsht-91-2B	24.329	24.394	22.361b	23.695b	127b
DZsht- 157-1B	27.101	27.419	31.875a	28.799a	127b
Yeras	26.150	28.442	22.986b	25.859ab	124a
Nasik red	26.847	24.975	27.292ab	26.371ab	125a
LSD0.05	6.809	7.779	7.859	3.859	1.73
CV%	13.055	14.80	15.055	15.078	0.689

Table 2. Cured marketable bulb yield in tone per hectare and days to maturity of demonstration trials of true seed shallot varieties in 2019

	Yield		Days to maturity	
Variety	Fogera	Libokmkem	Fogera	Libokmkem
DZsht-91-2B	18.394	23.65	120	122
DZsht- 157-1B	22.089	27.15	120	122
Yeras	21.322	25.15	116	115
Nasik red	22.896	25.20	114	115

Table 3. Number of bulb splits, color and tolerance to diseases of varieties

	Number of bulb splits				Disease
Variety	Fogera	Libokemkem	Dera	Bulb color	Score (1= least & 5= severe attack)
DZsht-91-2B	4	4	3	Dark red	1.5
DZsht- 157-1B	4	3	3	Red	1.0
Yeras	2	2	2	Light red	1.0
Nasik red	1	1	1	Dark red	1.5




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True Seed Shallot Variety Adaptation for Yield and Yield Components in Arsi, Ethiopia

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Abstract

Shallot (Allium cepa var. ascalonicum Backer) is an important vegetable crop cultivated by smallholder farmers for home consumption and income generation in Ethiopia. However, absence of true-seed based propagated and high yielding shallot varieties have seriously constrained the productivity of the crop for many years. A study was initiated to evaluate adaptation true seed shallot varieties in the country and select well adapted varieties with better yield and yield components in Arsi highlands. To this end an experiment was conducted to evaluate the adaptability of two shallot varieties propagated by seed (DZ-SHT-157-1B and DZ-SHT-91-2B) and one bulb-propagated shallot variety (Minjar) as control during the rainy season of two consecutive years (2018 and 2019) at Kulumsa Agricultural Research Center. The experiment was laid out in a completely randomized block design with four replications. Results of the analysis of variance showed that main factor genotype and year, as well as their interaction, genotype x year, had significant ($p<0.05$) effect on marketable bulb yield. The total bulb yield of the varieties ranged from 171.49 to 256.56 qha^{-1} with mean of 207.49 qha^{-1} in which Minjar gave better yield (256.56 qha^{-1}) than DZ-SHT-157-1B (194.44 qha^{-1}) and DZ-SHT-91-2B (171.49 qha^{-1}). However, the average number of bulb splits per plant ranged from 4.72 to 8 in which Minjar scored the highest number (8) compared to DZ-SHT-91-2B (5.48) and DZ-SHT-157-1B (4.72). Although Minjar gave superior bulb yield over the two shallot varieties in bulb yield and bulb split, the two varieties have several advantages over Minjar considering the amount of seed required and ease of post-harvest handling of seed and minimum risk of keeping seed for extended period without loss among others. However, the experiment could be repeated across multi locations and additional years to come up with conclusive recommendation.

Introduction

Shallot (*Allium cepa var ascalonicum* Baker) is an important vegetable crop cultivated in many tropical countries as a substitute for bulb onions (*Allium cepa L. var cepa*) (Wassu *et al*., 2018). Farmers in tropical countries prefer shallots to onion for its ability to propagate vegetatively, shorter growth cycle, better tolerance to disease and drought stresses and longer storage life than the common onion and for their distinct flavor that persists after cooking (Tiru *et al*., 2015; AskariKhorasgani and Pessarakli, 2019)**.** In Ethiopia, shallot is produced mostly in highland areas under rain-fed conditions by smallholder farmers as an income generating spice crop mainly used as condiment in Ethiopian traditional food

(Shimeles, 2014; Wassu *et al*., 2018). Besides that, the crop is widely adapted to different climatic and edaphic conditions and is cultivated both under rain-fed and irrigated conditions (Kebede, 2003).

According to Kebede (2003) the crop is produced traditionally by small farmers in Hararge, Showa, Arsi, Gojjam, etc. as cash and income generating spice crop for flavoring local dishes. Shallot (*Allium cepa* L. aggregatum group) is the favorite and widely grown condimental crop in Ethiopia. It is used daily in almost every house as a seasoning spice in the preparation of local dishes such as Wot (a stew) eaten with Injera (Ethiopian fluffy bread) (Dessie, 2016**)**. In Ethiopia, the production of shallot is estimated to be about 132,424.68 ton produced on 14,758.51 ha of land with an average yield of 8.97 t ha^{-1} (CSA, 2017) which is lower as compared to the world average of 18.8 tons ha^{-1} (FAOSTAT, 2017).

In Ethiopia, Shallot is cultivated vegetatively from sprouted bulbs until the release of new varieties propagated from true-seed (MoANR, 2016). Planted under suitable environmental conditions and agricultural management, high- quality true shallot seeds (TSS) have a high potential as alternative planting material. The advantages of using TSS include, reduced bulkiness, less expensive planting materials, easier transportation, long-term storage capacity, production of healthy bulbs free of pathogens and larger bulbs, a shorter period between planting to harvesting time (depending on variety, and environmental conditions (Agung and Diara, 2017*;* Triharyanto *et al*., 2018a).

However, scarcity of high yielding varieties, as well as lack of superior planting material, seriously constrained the productivity of the crop. Moreover, use of bulbs as planting material is exposed to degeneration due to accumulation of disease causing pathogens and may lose its yield potential easily. The perishability of the fleshy planting material and its sheer bulkiness and predisposition to fungal and viral disease create difficulties in handling the material. Moreover, large quantities of bulbs are required to plant a relatively small area of land, which exacerbates the problem of shortage of planting material. Also it is the edible part of the plant that is used for planting, which compromises the potential for consumption and marketing. Therefore, a research project was initiated aiming at studying the adaptation of true seed shallot varieties for bulb production in an area where shallot is important.

Materials and Methods

Description of the study area

The experiment was carried out under rain fed condition at Kulumsa Agricultural Research Center (KARC) during the rainy season of two consecutive years (2018 and 2019) (Table 1).

Table 1: Description of the study area

Descriptions	Measurement
Altitude (m)	2,200
Latitude	08^0 01' 10"N
Longitude	39^0 09' 11"E
Rainfall(mm)	820
Tmin(°c)	10.5
Tmax(°c)	22.8
Soil type	Clay soil (Luvisols)
Soil p^H	6

Experimental materials, treatments and design

The experiment was conducted using 2 true-seed shallot varieties and 1 bulb-propagated shallot variety as a control (Table 2). Seedlings were prepared for the two shallot varieties (DZ-SHT-157-1B and DZ-SHT-91-2B) on raised seed bed and transplanted to experimental plots at 8-10cm length after 60 days of sowing while well sprouted bulbs were planted for Minjar variety. NPS was applied at 242kgha^{-1} during transplanting and 100kgha^{-1} Urea in splits half 2 weeks after transplanting and the rest half 45 days after transplanting.

Table 2: List of experimental materials used in the study

Treatments(varieties)	Year of release and owner*	Remark
DZ-SHT-157-1B	2016/EAIR-DZARC	True-seed-propagated
DZ-SHT-91-2B	2016/EAIR-DZARC	True-seed-propagated
Minjar (control)	2009/EAIR-DZARC	Bulb propagated

*MoANR (Ministry of Agriculture and Natural Resources):- Plant Variety Release, Protection and Seed Quality Control Directorate Report (2009 and 2016).

The experiment was composed of the three shallot varieties as treatments which was laid out in a completely randomized block design with four replications. The experimental plot size was 7.2 m^2 in which seedlings/bulbs were planted in double rows using a spacing of 40cmx20cmx10cm.

Data Collection and Measurement

Number of bulb splits plant^{-1}, marketable bulb yield per plot (kg plot^{-1}), unmarketable bulb yield per plot (kg plot^{-1}), total bulb yield per plot (kg plot^{-1}) and total bulb yield per hectare (qt ha^{-1}) were the parameters for which data were collected for the study. Number of bulb splits plant^{-1} was measured as the average of bulb split numbers counted from five plants per plot. Only bulb splits that had directly grown from the mother tuber/seedling were considered in the data.

Marketable bulb yield was calculated by weighing all bulbs free from defects, disease, crack, and other physiological disorders while unmarketable bulb yield was calculated by weighing bulbs other than marketable bulbs. Total bulb yield per plot was calculated as the sum of the weights of marketable and unmarketable bulbs per plot while the total bulb yield per hectare was computed as the sum of the weights of marketable and unmarketable bulb per plot and transformed to quintals per hectare.

Data Analysis

All data were subjected to analysis of variance (ANOVA) combined over years using SAS software version 9.3 (SAS Institute 2010) using a general linear model (GLM) (Gomez and Gomez 1984). Mean comparison of the varieties was conducted based on pooled mean performance over the years using Least Significant Difference at 5% level of significance. Analysis of variance in completely randomized block design was computed using the model: $Y_{ij} = \mu + r_j + g_i + \varepsilon_{ij}$, where Y_{ij}=the response of trait Y in the i^{th} genotype and the j^{th} replication, μ = the grand mean of trait Y, r_j = the effect of the j^{th} replication, g_i = the effect of the i^{th} genotype and ε_{ij} = experimental error effect.

Results and Discussion

Results of the combined analysis of variance for marketable bulb yield, unmarketable bulb yield, total bulb yield and bulb splits are shown in Table 3. The results showed that the main effects of genotype and year as well as interaction of genotype x year were significant ($p<0.05$) for marketable bulb yield. However, the main effect of genotype (variety) was significant on all the parameters except for unmarketable bulb yield while the year effect was observed on all parameters except for number of bulb splits per plant($p>0.05$).

The highest total bulb yield (256.56qt ha^{-1}) was obtained from variety Minjar followed by DZ-SHT-157-1B (194.44qt ha^{-}1) and DZ-SHT-91-2B (171.49qt ha^{-1}) with mean yield of 207.49qt ha $^{-1}$ (Table 4). However, variety DZ-SHT-157-1B was not statistically different from Minjar in bulb yield ha^{-1}. Besides, Minjar was superior over the two true-seed shallot varieties in bulb splits plant $^{-1}$ ranged from 4.72 (DZ.SHT157-1B) to 8 (Minjar) with mean value of 6.1. The superiority of Minjar over the two shallot varieties in total bulb yield performance could be accounted for the high number of big sized bulb splits it produced per plant. However, the differences between the two shallot varieties was not significant in either of the two parameters measured (bulb yield and bulb splits per plant). Highly significant difference was obtained between the years in all the parameters measured except bulb splits plant^{-1} (Table 4).These differences between the two years were for the reason that in 2018 rain fall was short and quitted early before plants reached at physiological maturity and hence small sized bulbs were developed and significantly reduced bulbs yield. However in 2019 sufficient rainfall was experienced during the experimental period and the mean performance of the parameters were higher than what was obtained in 2018. The overall results of this study is in agreement with the findings of Shimeles and Lemma (2015) in that Shallot, as a plant belonging to the *Aggregatum* Group when grown from bulbs can produce clusters with a large number of daughter bulbs, whereas when it is grown from seeds or seedlings clusters contain on average 1–3 bulb lets or plants produce only a single bulb like onion.

Table 3:- Mean squares of the combined analysis for marketable bulb yield (kgplot^{-1}), unmarketable bulb yield (kgplot^{-1}), total bulb yield (kgplot^{-1}) and total bulb yield (qtha^{-1}) over two years (2018 and 2019).

Source Variation	DF	MBYPP(kg)	UBYPP(kg)	TBYPP(kg)	TBYPH(qt)	NBSPP
Rep	3	3.1	1.1	4.78	2563.61	5.25
Year	1	494.55**	7.86*	627.17**	336060.82**	5.5
Variety	2	28.1*	2.6	21.68*	11621.93*	17.70*
Year*Variety	2	10.64*	3.32	2.12	1164.2	11.38
Error	10	2.3	1.1	4.76	2552.53	3.36
Mean		6.8	2.2	8.96	207.49	6.1
LSD		1.95	1.32	2.81	64.99	2.36
CV		22.3	47.43	24.35	24.35	30.2
R^2		96.2	67.59	93.49	93.49	68.85

DF= Degrees of freedom**, CV=** Coefficient of variation**, LSD**= Least significant difference**, R^2=** Coefficient of determination**, MBYPP**= Marketable bulb yield per plot, **UBYPP=** Unmarketable bulb yield per plot, **TBYPP=**Total bulb yield per plot, **TBYPH**=Total bulb yield per hectare, **NBSPP**=Number of bulb splits per plant.

Table 4:- Mean results for marketable bulb yield (kgplot^{-1}), unmarketable bulb yield (kgplot^{-1}), total bulb yield (kgplot^{-1}) and total bulb yield (qtha^{-1}) over two years (2018 and 2019) and performances over varieties.

Treatment	MBYPP(kg)	UBYPP(kg)	TBYPP(kg)	NBSPP	TBYPH(qt)
			Variety		
DZ-SHT157-1B	6.90b	1.5a	8.4ab	4.72b	194.44ab
DZ-SHT91-2B	4.60c	2.82a	7.41b	5.48b	171.49b
Minjar	8.92a	2.20a	11.1a	8.00a	256.56a
			Year		
2018	1.56b	1.5b	3.01b	5.51a	70.86b
2019	12.04a	2.82a	14.87a	6.62a	344.14a

MBYPP= Marketable bulb yield per plot, **UBYPP=** Unmarketable bulb yield per plot, **TBYPP=**Total bulb yield per plot, **TBYPH**=Total bulb yield per hectare, **NBSPP**=Number of bulb splits per plant.

Conclusion

Three shallot varieties were compared at Kulumsa Agricultural Research Center in an experiment using completely randomized block design with three replications. Analysis of variance was computed for bulb yield and number of splits per plant over years. The results showed that the main effects of genotype (variety) and year, as well as its interaction, were significant for marketable bulb yield. The total bulb yield range of the shallot varieties was from 171.49 to 256.56 qt ha^{-1} and the average number of splits per plant was from 4.72 to 8. Although variety Minjar showed its superiority in both bulb yield as well as bulb splits per plant over the two varieties, bulb yield obtained from variety DZ-SHT-157-1B (194.44$qtha^{-1}$) was not statistically different from Minjar (256.56$qtha^{-1}$). Although the two shallot varieties performed below Minjar in terms of bulb yield, because of the many advantages they have (eg. Easiness of propagation by seed, pathogen free planting material, less bulkiness, low degeneration rate, etc.), they need to be promoted and produced by farmers. However, the experiment could be repeated across multi locations and additional years to come up with conclusive recommendation.

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Evaluation of Onion (*Allium cepa* L.) Varieties Performance of Seed Production and Quality at Kulumsa in Arsi Zone

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Abstract

A field level evaluation experiment was carried out at Kulumsa Agricultural Research Center under irrigated condition of 2018 to 2019 using five improved onion (Allium cepa L.) varieties to identify the best performing variety for seed production to the target areas of Arsi Zone. The onion varieties included in the field experiment were Nafis, Robaf, Nasik Red, Bombe Red and Adama Red. The field experiment was laid out in randomized complete block design (RCBD) with three replications. Phenological and growth parameters, seed yield and yield components were studied. The result of this study showed the significant effect variety on most of phonological and growth attributes as well as on yield attributes. Number of days to flowering and vigorosity were significantly affected by variety; while plant height, days to bolting and stalk number was not significantly influenced by variety. Flower stalks height and diameter, number of umbel per plant and umbel diameter also significantly affected by variety. Seed yield per umbel and mean seed yield per hectare also showed a significance difference among varieties. The highest seed yield per hectare (1415.89 kg/ha) and good germination percentage (85%) was recorded from Adama Red followed by Nafis variety. Therefore, it can be concluded that use of the improved onion varieties Adama red and Nafis that have good germination percentage is advisable and could be appropriate for onion seed production in the test area.

Introduction

Onion (*Allium cepa* L.) is one of the most important vegetable crops commercially grown in the world. In Ethiopia, onion is one of the most important cash crops, which contributes to commercialization of the rural economy and creates many off-farm jobs (Lemma and Shimeles, 2003; Nikus and Fikre, 2010). Onion seeds are well known to be highly perishable and poor in keeping quality and lose viability within a year (Currah and Proctor, 1990). Therefore, it is essential to produce fresh seed every year and use the same for bulb production. One of the problems of onion production in the tropics is lack of seed which is true to type with high germination and vigor (Griffiths *et al.*, 2002). Onion is produced in many regions of Ethiopia. During the 2017/18 production year, the Oromia Region's onion production coverage was estimated about 13,669.5 ha from which 1,033,485.45 tons of onion bulbs were produced with an average productivity of 7.56 tons ha^{-1}. Arsi Zone is one of the potential areas in Oromia regional state

(CSA, 2017). In addition to bulb production, the area is suitable for onion seed production.

In Ethiopia the productivity of onion seed is much lower than other African countries (Olani Nikus and Fikre Mulugeta, 2010). The yield of onion seed in the country varies from 1000 to 1300 kg ha^{-1} (Lemma *et al.,* 2006), 75.15 to 1155.75 kg ha^{-1} (Teshome *et al.,* 2014, Tamrat, 2006) and 748.9 to 879.4 kg ha^{-1} (Getachew, 2014) and other countries ranged 828 - 1446 kg ha^{-1} (Aminpour and Mortzavi, 2004). The area coverage and production across the country are increasing from time to time and large area of these are planted with most of the recently released varieties (Ahmed and Abdella, 2006). Despite increasing trend in area coverage, the productivity of onion variety in Ethiopia is much lower than the expected production level. The low productivity among the others could be attributed to the limited availability of quality seeds and associated production technologies used. Onion cultivars vary in their susceptibility to flower stalk development, depending on climatic conditions and their genetic background (Shimeles *et al*, 2000).

The seed production potential of these released onion varieties as a means of curbing the overriding oninon productivity associated problem were not studied for Arsi areas except the little information available on onion seed production potential of Nafis variety with najor target on the effects of fertilizer rates on seed production and quality (Limeneh *et al.,* 2019). Therefore, the presented study was designed to evaluate seed production potential of different varieties to come up with relevant recommendations that will help farmers produce better onion seed in the area.

Materials and Methods

Description of the Study Area

The study was conducted at Kulumsa Agricultural Research Center (KARC) which is located at 8°00' to 8o02'N and 39°07‟ to 39°10'E and an altitude of 2210 m a.s.l. in Oromia, Ethiopia. KARC has a low relief difference with altitude ranging from 1980 to 2230 m. The agro- climatic condition of the area is wet with an average of 811mm mean annual rain fall and it is a uni-modal rainfall pattern with extended rainy season from March to September. However, the peak rainy season is from July to August. The mean annual maximum and minimum temperatures are 23.1 and 9.9°C, respectively. The coldest month is December whereas; May is the hottest month (Abayneh *et al.,* 2003).

Experimental materials and bulb production

Five released varieties of Onion; namely, Nafis, Robaf, Nasik Red, Bombe Red and Adama Red were used in this experiment. The seedlings were raised on seed bed at nursery site. After 45 days of planting, seedlings were transplanted to the field for bulb production. Seedlings were transplanted with a recommended double row spacing of 40 cm × 20 cm × 5 cm (Lemma and Shimeles, 2003). All the agronomic and crop protection practices such as cultivation, fertilization, weeding and fungicide/pesticide application were applied according to the national recommendations for onion. A bulb to seed method we used for this experiment. The bulb was grown from February to June, following this, typical mother bulbs were selected and stored for one to two months, and the bulbs were planted in the cooler period (end of August to first September).

Experimental design and procedure

The experiment was conducted under irrigation condition during the off- season using randomized complete block design (RCBD) with three replications. The sprouted onion bulbs were planted in double rows with spacing of 60, 40 and 20 cm between water furrows, rows and plants in rows, respectively (Lemma and Shimeles, 2003). Distances of 1 and 1.5 m were maintained between plots and blocks, respectively. A plot size of 3.2 m × 2.8 m (8.96 m2) was used for each variety. Each plot had four rows (ridges) which consisted of 112 plants. The middle double rows were considered for recording of data. Recommended amount of fertilizer (200kg/ha DAP and 100kg/ha Urea) were used, Urea as nitrogen source and NPS as phosphorous for each plot. The site was irrigated at the interval of three days during the first phase of active growth of the plant. Later, the irrigation interval increased to every seven days (Lemma and Shimelis, 2003).

Data collection

Days to bolting: This was recorded as the number of days from date of planting up to when 50% of the plants in a plot produced flower stalk.

Days to 50% flowering: This was recorded as the number of days from date of planting up to when 50% of the flower stalks in each plot produced flowers.

Days to maturity: This was recorded as the number of days from date of planting up to when 50% of the plants in each plot matured or ready for harvest (when the seed colour changed to black or the capsule turned brown and started splitting).

Vigorousity(1-9 scale): this parameter was taken subjectively by scale (1-9 scale)

Plant height (cm): This refers to the mean height of five randomly selected plants from the central rows from each plot. It was measured from the soil surface to the tip of the plant after development of umbels of the plant.

Flower stalk diameter (cm): This was measured for five randomly selected plants from the central rows from each plot at flowering stage and the average was calculated to record the parameter.

Flower stalk height (cm): measured for five randomly selected plants from the central rows from each plot at flowering stage and the average was calculated to record the parameter.

Number of flower stalks per plant: Numbers of flower stalks of the five randomly selected plants per plot from 4 double central rows was counted and the average calculated and recorded as the number of flower stalks per plant.

Number of umbels per plant: Numbers of umbels from the five randomly selected plants was `counted and the average calculated and expressed as the number of umbels per plant.

Umbel diameter (cm): This was taken by measuring umbel diameter of five randomly selected plants in each plot. The diameter was measured using a ruler or a caliper two times measuring in two opposite direction (north-south and east to west).

Number of seeds per umbel: Five umbels were randomly taken from the five randomly selected plants in each plot, dried, threshed and then counted to obtain number of seeds per umbel.

Seed yield per umbel (g): Five randomly selected umbels were harvested, dried, threshed to determine seeds weight per umbel and adjusted to a moisture content of 8%; the average weight of seed per umbel was calculated by dividing the total weight of seeds to number of the umbels.

Seed yield per plant (g): Five randomly selected plants were harvested, dried, threshed to determine seeds weight per plant and adjusted to a moisture content of 8%; the average weight of seed per plant was calculated by dividing the total weight of seeds to number of the plants.

Seed yield (kg ha^{-1}): The yield was estimated from seed yield per plot. Then converted to hectares in kilograms.

1000 seeds weight (g): Sample of seeds from the bulk in each plot was taken and 1000 seeds were counted in seed counter machine and weighed using a sensitive balance and then adjusted to the moisture content of 8%.

Germination (%): One hundred seeds were placed on Petri dishes covered with filter paper and allowed to imbibe distilled water which was kept at room temperature until 15 days. The percent of germination has three replications using the total of 48 Petri dishes. A seed was considered germinated when the radicle protrusion attained approximately 1mm. Then percent germination was determined from counts of normal seedlings and the total seeds placed on Petri dishes. Percent of seed germination were done after harvest.

$$\text{Germination (\%)} = \frac{\text{Number of germinated seed}}{\text{Total seed}} * 100$$

Data analysis

The collected data were subjected to Analysis of Variance (ANOVA) using statistical analysis Software (SAS Version 9.2, 2008). The mean separation was done using (LSD) test at 5% probability level and simple correlation was made to determine association of parameters by using Pearson analysis.

Results and Discussion

Phenology and growth parameters

Table 1. The mean values of phenology and growth parameters of five onion varieties evaluated for seed production at Kulumsa in 2018 to 2019 using irrigation.

Treatments	Days to Bolting	Stalk formation date	50% flowering date	Vigourisity	Plant height	Seed maturity date	Number of flower Stalks per plant	Flower Stalk height (cm)
Nafis	65	56.33	84.33a	7.33a	88.6	167	6.4	68.6bc
Robaf	64	52.67	85a	5.67bc	83.83	172.67	7.47	65.47c
Nasic Red	58.33	54.67	80ab	6.5ab	89.47	167.33	6.8	73.93a
Bombe Red	54	47.67	74b	5c	83.2	155.67	7.4	68.47bc
Adama Red	59	53.33	77b	5.5bc	82.8	175	7.73	69.3b
LSD5%	8.167	12.609	6.6613	1.3202	7.365	16.627	1.2385	3.657
CV	7.22	12.65	4.42	11.69	4.57	5.27	9.19	3.31
Significance Level	NS	NS	*	*	NS	NS	NS	*

Means with no superscript letter within a column are not significantly different at 5% level of significance; * = significant at $P < 0.05$ probability level; Ns =non-significant at $P < 0.05$ probability level; LSD = least significant difference; and CV = Coefficient of Variation

Days to bolting

Days to bolting was not-significantly (P>0.05) affected by the variety. Bombay Red onion variety bolted early (about 5 to 8 days earlier) compared to the Nafis variety (65 days) (Table 1). Those onion varieties have no significant difference among varieties; however can vary in their liability to bolting, depending on climatic conditions and their genetic backgrounds,.

Stalk formation date

Days to stalk formation was not significantly (P>0.05) affected by the variety. Bombay Red onion variety formed flower stalk early (about 4 to 3 days earlier) compared to others variety (Table 1). There was no significant difference among varieties hence varieties donot vary in their stalk formation date depending on climatic conditions and their genetic backgrounds to the area.

Days to 50% flowering

Varieties showed significant difference on days to flowering. The longest (85) and earliest (74, 77) days to flowering was shown in Nafis and Adama red and Bombe red, respectively (Table1). This indicated that Nafis took longer days to flower while Bombe red and Adama red flowered earlier. Earliness or lateness in the days to 50% flowering might have been due to the inherited characters, like early acclimatization to the growing area to enhance their growth and developments. This result was in agreement with the finding of Seleshi *et al*. (2014) who reported that days to flowering was significantly affected by the interaction effect of variety and location which could be due to the temperature of the growing area.

Vigourisity (1-9 scale)

Varieties showed significant (P<0.05) difference on vigoursity. Nafis variety was more vigorous (7.33) than Bombe red variety which was the lowest, while others varieties were statistically non- significant difference among them (Table1).

Plant height (cm)

Plant height has no-significantly (P<0.05) influence due to varieties for onion seed production. The mean plant height of the onion varieties (55.23 cm) among the evaluated varieties at the locations (Table1). There was no significant difference among varieties, this mean that varieties cannot produce significant difference on plant height depending on climatic conditions and their genetic backgrounds to the area.

Seed maturity days

Days to maturity were other growth parameters of seed onion. As indicated in Table 1, non-significant (P>0.05) difference was observed on seed maturity days of different onion varieties for onion seed production. The longest and the earlier seed maturity days were observed on Adama red and Bombe red which is 175 days and 155.67 days respectively. The results indicate that, the traits are not affected by both genotype and environment.

Number of flower stalks per plant and height (cm)

The number of flower stalks per plant did not showed statistically significant ($P>0.05$) difference between the varieties, hence varieties were not affected by the environment and genotypes to produce flower stalk per plant. Varieties showed significant ($P<0.05$) difference on flower stalk height. Nasik red variety was the longest (73.93cm) and Robaf variety produce the shortest flower stalk (65.47cm) (Table 1). This result was in agreement with Tamrat (2006) and Debashis *et al.* (2017) who found stalk heights for other cultivar of onion in the range of 76 to 93 cm which was similar to height recorded in the present study.

Table 2. The mean values of some growth and seed yield parameters of five onion varieties evaluated for seed production at Kulumsa in 2018 to 2019 using irrigation.

Treatments	Flower Stalk Diameter (cm)	Number of Umbel per plant	Umbel Diameter (cm)	Number of seed per umbel	Seed Yield per umbel (g)	Seed Yield per plant(g)	Seed yield per hectare (kg ha^{-1})	1000 seed weight (g)	Germination rates %
Nafis	2.35a	8b	4.77b	724.7	1.76b	6.137	1157.17b	4.2	85.67
Robaf	2.33a	7.87b	4.98ab	601.7	1.45b	6.4	912.54c	4.06	84.67
Nasic Red	2.34a	7.73b	5.56a	653.3	1.21b	7.04	1136.11b	4.49	85
Bombe Red	2.02b	7.47b	4.58b	663	0.75b	8.627	1056.33bc	4.1	84
Adama Red	2.01b	10.93a	5.18ab	763.5	2.82a	8.87	1415.89a	4.54	85.33
LSD5%	0.3132	2.4107	0.6407	161.81	1.0121	3.0474	223.04	0.692	10.232
CV	7	15.24	6.81	19.43	33.65	21.83	10.43	8.64	7.45
Significance Level	*	*	*	NS	**	NS	*	NS	NS

Means followed by the same letter or with no superscript letter within a column are not significantly different at 5% level of significance; * = significant at P < 0.05 probability level; Ns =non-significant at P < 0.05 probability level; LSD = least significant difference; and CV = Coefficient of Variation

Flower stalk diameter (cm)

Flower stalk diameter was significantly (P<0.01) influenced by varieties. Nafis, Robaf and Nasic had the highest (2.3 cm) flower stalk diameter without statistically significant difference between them, while Bombay Red and Adama Red onion variety had the lowest in flow stack diameter (Table 2).

Number of umbel per Plant

Varieties shoed statistically significant (P<0.05) difference in the number of umbel per plant. Adama Red onion variety had the highest (10.39) number of umbel per plant than other varieties, all without statistically siginificant difference amongst each other in the number of umbel per plant (Table 2).

Umbel diameter (cm)

Umbel diameter was significantly *P*(<0.05) affected by varieties. Nasic red gave the highest umbel diameter (5.56cm) followed by the Adama red variety (5.18cm) with no significant difference between the two means. The lowest umbel diameter was recorded from Bombe red variety (4.58cm) (Table 2).

Number of seed per umbels

The highest number of seed per umbel was recorded from Adama red (763.5) and Nafis (744.70) variety and this was statistically similar with other varieties, hence the varieties showed non-significant (P>0.05) differences in number of seed per umbels. Number of seed per umbels can directly affect the total seed production (Table 2). Results on the number of umbels per umbel also followed similar trend to the number of flower stalk per plant.

Seed yield per umbel (g)

Seed yield per umbel showed significant (P<0.05) difference between the varieties. The highest significant seed yield per umbel was obtained from Adama Red variety (2.82g). This mean that other varieties as Nafis, Robaf, Nasic red and Bombe red had statistically the same seed yield per umbel (Table 2).

Seed yield per plant (g)

The effect of varieties was non- significantl (P>0.05) on seed yield per plant hence there was no significant difference in seed yield per plant among varieties. The lowest seed yield per hectare was obtained from the variety Robaf (Table 5).

Seed yield per hectare (kg ha^{-1})

The seed yield is significantly (P<0.05) affected by varieties. The significantly highest seed yield (1416.31 kg ha^{-1}) was recorded from Adama Red variety. The least seed yield was obtained from Robaf variety, but statistically similar with other varieties except Adama red variety (Table 2). Some of these parameters are directly correlated with the finding of Shimeles *et al,* 2000 who reported that seed yield were related with flowering characters like bolting period, umbel size, number of flower stalks/plant, flower stalk diameter and thousand seed weight had a direct positive influences on seed yield. These parameters are therefore recommended for selecting cultivars for high seed yield potential under Kulumsa conditions.

Thousand seed weight

The highest 1000 seed weight was recorded from Adama red variety but statistically non-significant with other varieties. The lowest thousand seed weight was recorded from Nasik (Table 2).

Germination Percentage

Germination percentage was not significantly affected by varieties. Bombe red variety gave the highest germination percentage of seeds (85.67%) followed by Adama red (85.33%) with no significant difference between the two means. The lowest germination percentage (64.67) was obtained from Nasik red (Table 2).

Conclusion and Recommendation

The results of this experiment indicated that variety had significant effect on most of yield and yield related traits as flowering date, flower stalk height and diameter, number of umbel per plant, umbel diameter, seed yield per umbel and seed yield per hectare. The highest seed yield per plant (8.87 g) and per hectare (1415.89 kg/ha) was obtained from Adama red variety which was followed by Nafis variety (1157.17kg/ha). This result had direct relation with number of umbel per plant and also seed yield per umbel thus, Adama red variety was significantly different from yield increasing parameters. On the other hand, the highest 1000 seeds weight (4.54 g) was also recorded from Adama red variety. Therefore, it can be concluded that use of the improved onion varieties Adama red is appropriate for onion seed production in the test area followed by Nasfis variety which have high germination percentage with former variety.

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Evaluation of Summer Squash (*Cucurbita pepo)* Genotypes for Immature Green Fruit Yield and Yield Components

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Abstract

Evaluation of three squash (Cucurbita pepo L.) genotypes, two summer squash genotypes 'ZK-15' and 'JP-10' and a standard check 'black beauty', was conducted at Melkassa, Kulumsa, Holeta and Debre Ziet Agricultural Research Centres during 2018 and 2019 to examine their yield and yield components over several harvests under open field conditions. The experiment was conducted in a small replicated plot experiment using Randomized Complete Block Design (RCBD) with four replications. Plants were grown using irrigation water and rain following standard production practices for the crop. Plants were harvested 15-20 times during each growing cycle at two days interval. Vegetative and quality data of the evaluated genotypes were taken. The yields of evaluated summers squash genotypes were 199, 169 and 159 q/ha in their order for 'black beauty', 'JP-10'and 'ZK-15', respectively. The yield for the 'ZK-15' was significantly lower. Owing to its short maturity, high yield per plant, healthy and attractive fruits color, gentoype'JP-10' was released as new variety for production in the country by the National Variety Release Committee.

Introduction

Summer squash, members of the Cucurbitaceae family and relatives of both the melon and the cucumber, come in many different varieties. While each type varies in shape, color, size and flavor, they all share some common characteristics (Srivastava *et. al*, 2001). The entire vegetable, including its flesh, seeds and skin, is edible. In addition, some varieties of the squashes produce edible flowers. Unlike winter squash, summers squash is more fragile and cannot be stored for long period of time. Summer squash have a very mild, nutty taste, sometimes resembling fresh corn.

Cucurbita pepo is native to North America and can be found growing wild in Northeastern Mexico and Southern, Southeastern, and Central USA. As yet undiscovered wild populations might still exist in Central or Southern Mexico and the wild range might have extended to what is now the Northeastern USA (Paris, 2008). Nearly all summer squashes are varieties of Cucurbita pepo, though not all Cucurbita pepo are considered summer squashes.

Summer squash is a tender, warm-season vegetable that can be grown easily in-home garden anytime during the warm, frost-free growing season. It grows on bush-type plants that do not spread like the plants of fall and winter squash and pumpkin. A few healthy and well-maintained plants produce abundant yields.

Well-drained garden soils produce excellent yields of summer squash. Use of a mulch will keep the shallow roots moist and cool and will allow for early harvest and increased yields. Since summer squash develops very rapidly after pollination, they are often picked when they are not too large and over matured. They should be harvested when small and tender for best quality. Most elongated varieties are picked when they are 2 inches or less in diameter and 6 to 8 inches long.

Squash is used generally as a cooked food item, but is sometimes eaten raw as a fresh salad ingredient. The fruit is usually harvested when immature and it is 20 cm (8 in) or less in length while seeds are still soft, palatable and the rind is still tender and edible. It can be prepared in many ways, including boiled, baked, steamed, stir fried or grilled. Zucchini squash grated over mixed vegetable green salad. Sliced zucchini can last for a long time, if frozen and stored properly. For value addition, yellow zucchini slices can be added to a mixed vegetable package and sold as a frozen food item by local farmers. Very tasty breads can be made using zucchini squash (Richardson VA Kenneth, 2016).

Summer squash varieties neither released nor registered for production in Ethiopia (Variety Release Booklet, 2019). However, seeds of the commercial 'black beauty' summer squash variety has been introduced and produced by farmers with the recommendation of Ministry of Agriculture since 1970. However, the productions and consumptions of summer squash have been increased in recent years around large cities due to population increase and the demand of nutritional diversification. Hence, this study was conducted to evaluate the performance of summer squash genotypes and recommend better quality variety for production.

Material and Methods

Description of Experimental Sites

The study was conducted at Melkassa, Kulumsa, Holeta and Debre Zeit Agricultural Research Centers. Melkassa Agricltural Researtch Center (MARC) is located in the Central Rift Valley of Ethiopia at 8°24′N latitude, 39°21′E longitude, and altitude of 1,550 m.a.s.l. The average annual rainfall is 768 mm and the mean maximum and minimum temperatures are 28.5°C and 12.6°C, respectively. The soil physico-chemical properties is clay sandy loam which suits for summer squash. Kulumsa Agricultural Research Center (KARC) is located at 8°2' N and 39°10' E and an altitude of 2200 m. a. s. l. The agro-climatic condition of the area is wet with 811 mm mean annual rain fall and it has a uni-modal rainfall pattern with extended rainy season from March to September. However, the peak rainy season is from July to August. The mean annual maximum and minimum temperatures are 23.1 and 9.9°C, respectively. The dominant soil type in the center is Vertic Luvisol (Abayeneh *et.al*, 2006). Debre Zeit Agricultural Research Center (DZARC) is located 8°44' N latitude and 38°58' E longitude at an altitude of 1900 m.a.s.l. The area is characterized by monomodal rainfall pattern. The mean annual rainfall recorded at the center is 660 mm and the average annual minimum and maximum temperatures are 12^oC and 27.4^oC, respectively. Holeta Agricultural Research Center (HARC) is found in the Central highlands of Ethiopia at $9^0$00′N latitude and $38^0$30′E and altitude of 2400 m.a.s.l. The mean annual rainfall is 1144 mm and the minimum and maximum temperatures is 6ºC and 22ºC, respectively.

Experimental materials and procedures

The summer squash genotypes were ZK-15 and JP-10 that were introduced from America. The commercially available black beauty variety was brought from the market and used as a standard check for comparison. These genotypes were evaluated at the three different locations during 2018 and 2019.

The experiments were conducted at Melkassa, Kulumsa and Holeta ARC while the variety verification experiments were carried out at Melkassa, Kulumsa and Debre ziet both on research station and on farmers' field. The evaluation was conducted during rainy season however there was also evaluation of the variety trial by irrigation at Melkassa ARC for two seasons.

The experimental genotypes were planted in a Randomized Complete Block Design (RCBD) with four replications in the variety evaluation trial while on a single large plot size ($100m^2$ per variety) was used for variety verification trial.
The immature green fruit yield was harvested 15 to 20 times for one growth cycle of the plant and the yield and related components were subjected to ANOVA. The ANOVA was carried out using the General Linear Model of the GenStat 15th Edition procedure of version 15.1. For factors showing significant effects, mean comparisons were made using the least significant difference (LSD) test at 5% level of significance.

Results and Discussions

Fruit yield and yield components

ANOVA results of marketable yields of evaluated summer squash genotypes showed significant difference at Melkassa during 2018. Genotype JP-10 produced significantly highest yield (264.7 Q/ha) followed by black beauty (254 Q/ha) and genotype ZK-15 (165.7 Q/ha). The yield obtained at Kulumsa and the combined mean of the two location were not statistically significant among genotypes during 2018 (Table 1). Similar kind of study carried in USA on different summer squash variety showed statistically significant variations among varieties evaluated (Goldy and Wendzel, 2016).

During 2019 production season, black beauty gave significantly higher yield at Kulumsa while at Melkassa, Holeta and the combined yield were not statistically significant. Similarly, there was no statistically significant difference in mean yield of genotypes among the tested genotypes during irrigation season. When the overall mean yield of summer squash genotypes across locations, seasons and years are observed, black beauty gave significantly the highest yield followed by JP-10 and ZK-15 i.e. 199.5, 169.2 and 157.4 Q/ha, respectively (Table 1).

As indicated in Table 2 of the variety verification data of 2019, the candidate variety JP-10 gave 247.5 q/ha and 289.51 q/ha marketable and total average yield, respectively; while ZK-15 gave 215.87 q/ha and 248.61 q/ha marketable and total average yield, respectively. The yield performance of both varieties was low at Debre Zeit Research Center due to disease and insect pest damage. In terms of unmarketable yield, JP-10 produced about 18% while ZK-15 produced 16% unmarketable yield. Both varieties had comparable average fruit thickness, fruit length and average fruit weight. Besides, the varieties had similar inner color, shape, internal structure and texture. However, in terms of days to maturity, ZK-15 is earlier than JP-10 by 5 days but yielded less.

Table 1. Marketable (Qt/ha) of summer squash genotypes at Melkassa, Kulumsa and Holeta under rain fed and irrigated conditions in 2018 and 2019.

Genotypes	2018			2019				Irrigation (Melkassa)			Over all
	Melkassa	Kulumsa	Combined	Melkassa	Kulumsa	Holeta	Combined	2018	2019	Combined	
Black beauty	253.0	242.0	210.0	203.0	239.8	132.5	191.6	135.0	191.0	163.0	199.5
JP-10	264.7	135.3	174.0	264.7	143.7	106.8	165.6	122.1	147.1	134.6	169.2
ZK-15	165.7	177.9	155.4	190.7	209.7	94.4	159.0	122.5	141.1	131.8	157.4
Mean	227.8	185.1	179.8	219.5	197.8	111.2	172	126.5	159.7	143.1	175.4
F-test (5%)	**	NS	NS	NS	**	NS	NS	**	NS	NS	*
CV	23.8	24	24.5	32	8.8	29.8	38.5	2.6	22.9	22.8	39.9

Table 2. Yield performance of summer squash genotypes across locations (VVT), 2019.

Cultivars	Locations	Marketable Yield (Qt/ha)	Unmarketable yield (Qt/ha)	Total Yield (Qt/ha)
ZK-15	Melkassa on station	357.08	121.88	478.96
	Wonji on farm	171.78	24.56	196.34
	Kulumsa on station	260.19	0.64	260.83
	Debre zeit on station	79.97	16.62	96.59
	Debre zeit on farm	210.32		210.32
	Average	**215.87**	**40.93**	**248.61**
JP-10	Melkassa on station	356.25	157.87	514.12
	Wonji on farm	153.99	35.56	189.55
	Kulumsa on station	179.12	0.71	179.83
	Debre zeit on station	142.11	16.16	158.27
	Debre zeit on farm	405.80		405.80
	Average	**247.45**	**52.57**	**289.51**
Black beauty	Melkassa on station	408.77	53.56	462.33
	Wonji on farm	200.59	5.93	206.53
	Kulumsa on station	308.72	0.19	308.92
	Debrezeit on station	133.80	142.43	142.43
	Debrezeit on farm	222.22		222.22
	Average	**254.82**	**50.53**	**268.48**

Mean values for single fruit length and single fruit weight are shown in Table 3. Size of fruit and fruit weight fluctuated over time. Some of the matured fruit were not acceptable size for market, as they were considered too large for sale (USDA-AMS, 1997). The size of fruit is influenced by genetics, environment, and plant conditions during development of the pistillate flower and fruit as reported by Maynard (2007). Conditions that reduce the amount of assimilate available tend to decrease the size of individual fruit. Increased plant density, greater numbers of fruit per plant, and reduced water supply tend to decrease fruit size. If fruit is too large, seed may be too hard, rendering it in edible. Harvesting was done at two to three days interval and there was no significant difference in fruit size, both fruit length and width. But fruit weight of 'Black beauty' was significantly higher than the others. Significant difference was also observed in average fruit number per plant. Genotype ‘ZK-15’ gave higher number of fruits per plant followed by ‘Black beauty’ and ‘JP-10’. All the three genotypes had non-significant vine lengths. The genotypes have different maturity days but statistically non-significant. However, genotype ‘ZK-15’ was earlier to mature by five days than ‘JP-15’ and ‘Black beauty’ (Table 3).

Table 3. Vegetative response of Summer squash genotypes at Melkassa, Kulumsa and Holeta under rain fed and irrigated conditions in 2018 and 2019.

Genotypes	Days to Maturity	Fruit length (cm)	Fruit width (mm)	Average fruit weight (gm)	Fruit number per plant	Plant height (cm)
Black beauty (check)	52.9	24.7	64.8	566.4	11.2	62.2
JP-10	52.6	24.6	61.6	495.5	8.7	62.9
ZK-15	48.1	25.8	62.8	449.9	11.6	62.5
Mean	51.2	25	63.1	504	10.5	62.6
CV	23.6	17.8	16	31.4	66.3	12.36
F-test (5%)	NS	NS	NS	*	*	NS

Table 4: Quality characteristics of summer squash genotypes

Genotypes	Fruit color	Fruit surface	Flush color	Growth habit
Black beauty (check)	Dark green	smooth	White	Bushy
JP-10	Light green	smooth	White	Short vine
ZK-15	Green	smooth	White	Short Vine

Conclusion and Recommendation

Thus far there is no summer squash variety released in the country except one commercially recommended variety (Black beauty) that was includedf in this trial. The candidate genotype ‘JP-10” had good fruit yield, early with frequent harvest and good quality (taste) of fruits. Farmers are using imported commercial seeds, which are expensive. These two genotypes were healthy and produce quality and higher yield with whitish yellow inner color and acceptable fruit size. The genotypes could be produced in areas with altitude that range from 1500 to 2400 m. a. s. l throughout the year under both rain fed and irrigation conditions. The genotypes successfully produce seed which can ensure the sustainabile production of summer squash without importation of expensive seed like in other vegetable crops. Hence, from the present result it can be concluded that summer squash variety ‘JP-10’ is recommended for release based on its superior fruit weight, fruit length and best yield potential. So, it should be multiplied, demonstrated and popularized to both small holder to large scale beneficiaries.

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Morphological Characterization and Evaluation of Garlic (*Allium sativum L.*) Accessions Collected from Northern Highlands of Ethiopia

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Abstract

Seventy five garlic germplasm collected from the highland of Northern Ethiopia, three standard checks and three promising genotypes were evaluated for six quantitative characters using simple lattice square design at Chefe Donsa and Debre Zeit, Central part of Ethiopia. The main objective of the study was to select and advance better genotypes with high yield, quality and pest tolerance to the next steps. Analysis of variance showed significant difference among the tested accessions for most of the quantitative traits considered in the study except weight of clove. The better performed accessions with superior yield over the checks were GOG-018/18 and GOG-067/18. These were followed by GOG-073/18, GOG-069/18, GOG-058/18, GOG-057/18, GOG-072/18, GOG-074/18, GOG-075/18, GOG-061/18, GOG-064/18, GOG-059/18, GOG-047/18, GOG-056/18, GOG-055/18, GOG-001/18, GOG-063/18, GOG-045/18, GOG-049/18, GOG-068/18, GOG-011/18, GOG-051/18, GOG-070/18, GOG-025/18 and GOG-046/18 genotypes. Hence, these accessions will be promoted to the next breeding step of variety development. Based on the variations in the traits used, the accessions were grouped into five clusters in which cluster- IV and V were constituted most important garlic accessions characterized by high bulb yield over the other clusters. All morphological traits including plant vigor, maturity date, plant height, number of clove per bulb and bulb weight were positively and significantly correlated with bulb yield. The results of this study depicted that variability of garlic germplasm in the collections should be properly conserved so that it could serve as sources of genetic material for the future genetic improvement program.

Introduction

In Ethiopia, the Alliums group (onion, garlic, and shallot) are important bulb crops produced by small and commercial growers (Yohannes, 1987; Metasebia, and Shimelis, 1998). Garlic (*Allium sativum* L.) is one of the important vegetable crops in Ethiopia for local market and export. It is also the most ancient cultivated herbs. It is propagated vegetatively by cloves and widely cultivated spice crops used for food as well as medicinal purposes (Diriba *et al*., 2013). These crops are produced for home consumption and as a source of income to many farmers, especially for those who have limited cultivated land or smallholder farmers in many parts of the country (Metasebia and Shimelis, 1998; Getachew and Asfaw, 2000).

Garlic is widely cultivated around home gardens, but nowadays, its production is practiced in some large farms. In addition to its importance for home consumption and income generation to many farmers, it is one of the most important vegetables produced for flavoring the local stew called ‘wot’. In Ethiopia above 1.78 million quintals of garlic was harvested from an estimated 19 412.49 hectares of land during 2017/18 cropping season (CSA, 2017/18). The average yield per hectare was 9.18 tons. Economic significance of garlic in Ethiopia is quite considerable; it is grown as a spice and used for flavoring local dishes, and also contributes to the national economy as an export commodity (Fekadu and Dandena, 2006). Garlic is produced mainly in the mid and high lands of the country (Getachew and Asfaw, 2000; CACC, 2002) and the bulk of garlic for the domestic market is produced around homestead gardens of subsistence farmers and produced mainly for income generation.

Garlic is one of the main Allium vegetable crops known worldwide with respect to its production and economic value which requires good production and management practices. It is used as a flavoring in many foods worldwide and without garlic; many of our popular dishes would lack the flavor and character that make them favorable. However, the quality and yield garlic production is influenced by production and management practices on both field and after harvested (Diriba, 2016).

In spite of its importance (increasing of garlic production and productivity), garlic yield is low in many parts of the world, due to genetic and environmental factors affecting its yield and yield related traits (Nonnecke, 1989). To overcome such production problems, great effort should have to be made in the selection and breeding of high yielding cultivars (Rabinowitch and Brewster, 1990).

So far, garlic germplasm have been collected from different sources, maintained, and an attempt was also made to characterize and select which was resulted in the release of six varieties for users in Ethiopia (Getachew *et al*, 2016). This might be due to the fact that including bulb size, shape, maturity date, the percentage of thick-necked and double bulbs are affected by the environment (Rabinowitch and Brewster, 1990). Since then, continuous efforts have continued to develop high yielding and disease tolerant garlic varieties from the collection of genotypes (eco-types) from different parts of the country. For the development of suitable varieties of garlic, it is essential to evaluate the characters of available germplasm properly for selection (Alam *et al*., 2010). This study was therefore, conducted as part of the variety development effort to select and advance better garlic genotypes with high yield, quality and pest tolerance to the next stage of breeding.

Materials and Methods

The experiment was conducted at Debre Zeit Agricultural Research Center (DZARC) and Chefe Donsa research sub-station during 2019/20 main season. Seventy-five garlic germplasm collected from the highlands of Northern Ethiopia, three standard checks and three promising genotypes were included in the study (Table 1). The experiment was laid out in simple lattice square design (9 x 9). The plot size was 2m x 1.2m = 2.4m^2 and the spacing between double rows, rows and plants was 60 cm, 40 cm and 20 cm, respectively. All agronomic management practices such as weeding, watering, and hoeing were carried out at the same time to all treatments. Fertilizers were applied at the rate of 243 kg/ha NPS during planting and 130 kg/ha Urea in split application once during planting and the second application 45 days after emergence. Pesticides including Tilt at 0.5 lit/ha, Karate at 0.3 lit/ha and Ridiomil Gold at 2.5 lit/ha were applied to manage disease and insect pests as per manufacturer recommendations.

Pertinent morphological traits were measured at various growth stages according to descriptors developed for garlic by International Plant Genetic Resources Institute (IPGRI, 2001). These were plant vigor, plant height, maturity date, number of clove/bulb, weight of clove, and bulb yield. Statistical analysis was done using SAS version 9.00 (SAS, 2002) in which the Analysis of variance (ANOVA) was performed and mean results were compared using least significant difference (LSD) test at 5% probability. Besides, simple correlation analysis was done for the inter-relations between the measured traits and cluster analysis was also performed using the unweighted pair-group method with arithmetic average (UPGMA) (Fielding, 2007).

Results and Discussion

Bulb yield

Significant differences ($P<0.05$) were obtained between the tested genotypes for garlic bulb yield (Table 2). The variability between accessions was statistically significant for the morphological characters indicating the presence of wide variability among the local garlic accessions (Bahadur, 2016; Yebirzaf *et al.*, 2017; Chadha *et al.*, 2019).

Table1. Garlic accessions and their source of collection

Accessions	Region	Zone	Woreda	Accessions	Region	Zone	Woreda
GOG-001/18	Amhara	S. Gonder	Libokemkme	GOG-041/18	Amhara	N. Gonder	Debarke
GOG-002/18	Amhara	S. Gonder	Libokemkme	GOG-042/18	Amhara	N. Gonder	Debarke
GOG-003/18	Amhara	S. Gonder	Libokemkme	GOG-043/18	Amhara	N. Gonder	Debarke
GOG-004/18	Amhara	S. Gonder	Libokemkme	GOG-044/18	Amhara	N. Gonder	Janamora
GOG-005/18	Amhara	S. Gonder	Libokemkme	GOG-045/18	Amhara	N. Gonder	Debarke
GOG-006/18	Amhara	S. Gonder	Libokemkme	GOG-046/18	Amhara	N. Gonder	Debarke
GOG-007/18	Amhara	S. Gonder	Libokemkme	GOG-047/18	Amhara	C. Gonder	Taqussa
GOG-008/18	Amhara	S. Gonder	Libokemkme	GOG-048/18	Amhara	C. Gonder	Taqussa
GOG-009/18	Amhara	S. Gonder	Libokemkme	GOG-049/18	Amhara	C. Gonder	Taqussa
GOG-010/18	Amhara	S. Gonder	Libokemkme	GOG-050/18	Amhara	C. Gonder	Taqussa
GOG-011/18	Amhara	S. Gonder	Libokemkme	GOG-051/18	Amhara	C. Gonder	Taqussa
GOG-012/18	Amhara	S. Gonder	Libokemkme	GOG-052/18	Amhara	C. Gonder	Taqussa
GOG-013/18	Amhara	S. Gonder	Libokemkme	GOG-053/18	Amhara	C. Gonder	Taqussa
GOG-014/18	Amhara	S. Gonder	Libokemkme	GOG-054/18	Amhara	C. Gonder	Taqussa
GOG-015/18	Amhara	S. Gonder	Libokemkme	GOG-055/18	Amhara	C. Gonder	Taqussa
GOG-016/18	Amhara	S. Gonder	Libokemkme	GOG-056/18	Amhara	C. Gonder	Taqussa
GOG-017/18	Amhara	S. Gonder	Libokemkme	GOG-057/18	Amhara	C. Gonder	Taqussa
GOG-018/18	Amhara	S. Gonder	Libokemkme	GOG-058/18	Amhara	C. Gonder	Taqussa
GOG-019/18	Amhara	S. Gonder	Libokemkme	GOG-059/18	Amhara	C. Gonder	Taqussa
GOG-020/18	Amhara	S. Gonder	Libokemkme	GOG-060/18	Amhara	C. Gonder	Taqussa
GOG-021/18	Amhara	S. Gonder	Libokemkme	GOG-061/18	Amhara	C. Gonder	Taqussa
GOG-022/18	Amhara	S. Gonder	Libokemkme	GOG-062/18	Amhara	C. Gonder	Taqussa
GOG-023/18	Amhara	S. Gonder	Libokemkme	GOG-063/18	Amhara	C. Gonder	Taqussa
GOG-024/18	Amhara	S. Gonder	Libokemkme	GOG-064/18	Amhara	C. Gonder	E. Dembia
GOG-025/18	Amhara	S. Gonder	Libokemkme	GOG-065/18	Amhara	C. Gonder	E. Dembia
GOG-026/18	Amhara	S. Gonder	Libokemkme	GOG-066/18	Amhara	C. Gonder	E. Dembia
GOG-027/18	Amhara	S. Gonder	Libokemkme	GOG-067/18	Amhara	C. Gonder	E. Dembia
GOG-028/18	Amhara	S. Gonder	Libokemkme	GOG-068/18	Amhara	C. Gonder	E. Dembia
GOG-029/18	Amhara	S. Gonder	Libokemkme	GOG-069/18	Amhara	C. Gonder	E. Dembia
GOG-030/18	Amhara	S. Gonder	Libokemkme	GOG-070/18	Amhara	C. Gonder	E. Dembia
GOG-031/18	Amhara	S. Gonder	Libokemkme	GOG-071/18	Amhara	C. Gonder	E. Dembia
G0G-032/18	Amhara	S. Gonder	Libokemkme	GOG-072/18	Amhara	C. Gonder	E. Dembia
GOG-033/18	Amhara	S. Gonder	Libokemkme	GOG-073/18	Amhara	C. Gonder	E. Dembia
GOG-034/18	Amhara	S. Gonder	Libokemkme	GOG-074/18	Amhara	C. Gonder	E. Dembia
GOG-035/18	Amhara	S. Gonder	Libokemkme	GOG-075/18	Amhara	C. Gonder	E. Dembia
GOG-036/18	Amhara	N. Gonder	Debarke	Tsedaye	Check		
GOG-037/18	Amhara	N. Gonder	Debarke	G-009/03	Promising		
GOG-038/18	Amhara	N. Gonder	Debarke	Kuriftu	check		
GOG-039/18	Amhara	N. Gonder	Debarke	HL	check		
GOG-040/18	Amhara	N. Gonder	Debarke	G-020/03	Promising		
				G-054/03	Promising		

Table 2. Mean Bulb yield for 81 garlic accessions from two locations (Chefe Donsa and Debre Zeit)

SN	Accessions	CHD	DZ	Combined Mean	SN	Accessions	CHD	DZ	Combined Mean
		BIY	BIY				BIY	BIY	
1	GOG-001/18	6535.40	3638.50	5086.95	26	GOG-026/18	4142.90	1215.50	2679.20
2	GOG-002/18	6036.00	3034.40	4535.20	27	GOG-027/18	5002.70	2743.50	3873.10
3	GOG-003/18	3753.40	2947.70	3350.55	28	GOG-028/18	4658.60	2662.70	3660.65
4	GOG-004/18	6609.00	2374.40	4491.70	29	GOG-029/18	5896.40	1687.40	3791.90
5	GOG-005/18	3407.00	1814.70	2610.85	30	GOG-030/18	6557.60	1338.80	3948.20
6	GOG-006/18	3120.70	2743.00	2931.85	31	GOG-031/18	4658.10	1663.10	3160.60
7	GOG-007/18	4805.10	2273.10	3539.10	32	G0G-032/18	4513.10	2172.60	3342.85
8	GOG-008/18	5491.80	3146.70	4319.25	33	GOG-033/18	4215.50	2567.40	3391.45
9	GOG-009/18	5542.80	1561.60	3552.20	34	GOG-034/18	5123.80	2773.70	3948.75
10	GOG-010/18	3279.00	2036.60	2657.80	35	GOG-035/18	3855.50	1482.00	2668.75
11	GOG-011/18	7305.20	2427.10	4866.15	36	GOG-036/18	4149.00	1826.70	2987.85
12	GOG-012/18	2644.60	2099.40	2372.00	37	GOG-037/18	4280.90	1557.70	2919.30
13	GOG-013/18	3580.20	2473.30	3026.75	38	GOG-038/18	3987.00	2463.10	3225.05
14	GOG-014/18	5500.10	3367.70	4433.90	39	GOG-039/18	4769.40	2115.50	3442.45
15	GOG-015/18	6779.40	2393.30	4586.35	40	GOG-040/18	5654.00	2368.50	4011.25
16	GOG-016/18	4231.10	2169.70	3200.40	41	GOG-041/18	5216.40	2482.90	3849.65
17	GOG-017/18	5844.10	3392.70	4618.40	42	GOG-042/18	4789.10	1504.00	3146.55
18	GOG-018/18	7990.50	5320.80	6655.65	43	GOG-043/18	4689.50	1722.00	3205.75
19	GOG-019/18	4547.40	1793.80	3170.60	44	GOG-044/18	4802.30	1472.20	3137.25
20	GOG-020/18	3089.80	1399.20	2244.50	45	GOG-045/18	6979.50	2993.10	4986.30
21	GOG-021/18	4461.20	1635.60	3048.40	46	GOG-046/18	4975.80	4417.90	4696.85
22	GOG-022/18	6210.90	2341.50	4276.20	47	GOG-047/18	7139.20	3243.80	5191.50
23	GOG-023/18	4799.00	1675.50	3237.25	48	GOG-048/18	4495.00	3323.10	3909.05
24	GOG-024/18	5262.60	3129.20	4195.90	49	GOG-049/18	6570.40	3216.50	4893.45
25	GOG-025/18	6539.10	2956.70	4747.90	50	GOG-050/18	5548.70	1837.90	3693.30

Continued…Table 2. Mean Bulb yield for 81 Gonder garlic accessions from two locations (Chefe Donsa and Debre Zeit) continue

SN	Accessions	CHD	DZ	Combined Mean	SN	Accessions	CHD	DZ	Combined Mean
		BlY	BlY				BlY	BlY	
51	GOG-051/18	6574.60	3056.30	4815.45	68	GOG-068/18	7215.30	2566.90	4891.10
52	GOG-052/18	4692.70	2928.80	3810.75	69	GOG-069/18	8423.10	3609.40	6016.25
53	GOG-053/18	6372.30	2513.50	4442.90	70	GOG-070/18	6950.30	2619.10	4784.70
54	GOG-054/18	6084.20	1450.70	3767.45	71	GOG-071/18	6038.70	3182.10	4610.40
55	GOG-055/18	7170.40	3124.50	5147.45	72	GOG-072/18	7645.60	3810.80	5728.20
56	GOG-056/18	6890.50	3445.00	5167.75	73	GOG-073/18	8953.20	4150.30	6551.75
57	GOG-057/18	7512.20	4146.70	5829.45	74	GOG-074/18	7953.10	3340.80	5646.95
58	GOG-058/18	8241.40	3459.40	5850.40	75	GOG-075/18	6831.30	4039.40	5435.35
59	GOG-059/18	6657.40	3862.70	5260.05	76	Tsedaye	2912.90	1092.50	2002.70
60	GOG-060/18	6588.50	2430.60	4509.55	77	G-009/03	2970.40	1516.30	2243.35
61	GOG-061/18	7592.20	2975.60	5283.90	78	Kuriftu	6258.50	2582.40	4420.45
62	GOG-062/18	4612.80	4035.00	4323.90	79	HL	5651.40	3676.40	4663.90
63	GOG-063/18	6084.20	3990.40	5037.30	80	G-020/03	3817.80	1655.80	2736.80
64	GOG-064/18	6610.40	3952.90	5281.65	81	G-054/03	4941.50	1854.30	3397.90
65	GOG-065/18	8682.00	5973.10	7327.55		Mean	5634.62	2701.22	4168.18
66	GOG-066/18	6481.60	2528.10	4504.85		CV (%)	17.13	33.17	21.58
67	GOG-067/18	9000.40	4231.60	6616.00		LSD (5%)	1928.10	1789.80	1257.33

CHD=Chefe Donsa, DZ=Debre Zeit, BlY=Bulb yield (Kg/ha), CV = coefficient of variation, LSD= least significant difference

There were garlic accessions that surpassed the standard checks and promising genotypes in terms of yield. Although the Holetta Local (HL) is one of the highest yielding garlic variety used as a check in the present study; combined mean bulb yield over locations revealed that about 26 (32%) of the garlic accessions were found to be the top yielders. GOG-065/18 (7327.55 kg/ha) was superior among the accessions whereas HL yielded 4663.90 kg/ha. Other accessions which were superior to the best checks are GOG-018/18, GOG-067/18, GOG-073/18, GOG-069/18, GOG-058/18, GOG-057/18, GOG-072/18, GOG-074/18, GOG-075/18, GOG-061/18, GOG-064/18, GOG-059/18, GOG-047/18, GOG-056/18, GOG-055/18, GOG-001/18, GOG-063/18, GOG-045/18, GOG-049/18, GOG-068/18, GOG-011/18, GOG-051/18, GOG-070/18, GOG-025/18 and GOG-046/18. This shows the possibility of screening high yielding genotypes among the accessions from the Northern highlands of Ethiopia where the collection was conducted.

Growth and Bulb yield related traits

Growth and yield related traits data are presented in Table 3. The tested garlic accessions significantly differed ($P<0.05$) in terms of plant height, plant vigor, maturity date, number of cloves per bulb, but not for weight of clove. Among different genotypes evaluated, GOG-065/18 was the tallest in plant height (64.90 cm) followed by GOG-072/18 (64.65 cm) and GOG-069/18 (62.90 cm) whereas, genotype GOG-008/18 (44.25 cm) was the shortest. Among all the evaluated accessions, GOG-008/18 matured early taking only 116.50 days followed by GOG-006/18 (117.00 days) and GOG-006/18 (117.25 days) while, the maximum days to maturity were recorded in GOG-072/18 and GOG-079/18 (135.25 days) followed by GOG-065/18 (135.00 days). However, the remaining genotypes took between 117.25 days to 134.50 days with a mean of 128.08 days to maturity which could be regarded as medium maturing. Thus, in addition to bulb yield evaluation and characterization of collected germplasm, growth and yield related traits helps to get useful information that can help exploit genetic variability and enhance the utilization of germplasm.

Table 3. Some growth and yield related traits combined mean of 81 garlic accessions from two locations (Chefe Donsa and Debre Zeit)

Accessions	VI	MAD	PH	NOC	WOC	Accessions	VI	MAD	PH	NOC	WOC
GOG-001/18	2.75	131.00	62.60	15.15	3.34	GOG-043/18	2.75	130.25	53.80	13.50	2.55
GOG-002/18	3.00	129.75	56.85	12.55	2.97	GOG-044/18	2.88	129.25	55.10	15.25	3.37
GOG-003/18	2.75	119.75	51.15	12.50	3.21	GOG-045/18	3.38	130.25	52.40	17.30	4.18
GOG-004/18	3.13	131.50	58.25	15.20	3.37	GOG-046/18	2.88	130.00	56.80	14.90	3.04
GOG-005/18	2.50	121.00	48.55	10.80	3.24	GOG-047/18	3.25	133.75	55.30	14.00	3.37
GOG-006/18	2.75	117.00	55.40	12.50	3.09	GOG-048/18	3.00	130.75	54.10	17.50	3.57
GOG-007/18	2.88	127.25	55.25	13.35	3.00	GOG-049/18	3.38	130.75	51.95	14.05	3.18
GOG-008/18	2.63	116.50	44.25	11.65	3.43	GOG-050/18	3.13	131.50	53.80	14.95	4.49
GOG-009/18	3.00	121.75	57.30	14.05	3.39	GOG-051/18	3.38	133.25	57.80	17.90	3.66
GOG-010/18	2.38	122.25	61.70	14.90	3.64	GOG-052/18	3.13	131.75	55.05	18.45	2.78
GOG-011/18	3.13	126.75	53.65	15.45	3.86	GOG-053/18	3.00	126.50	47.90	16.35	3.18
GOG-012/18	2.63	123.50	45.30	13.45	3.11	GOG-054/18	2.50	132.75	58.10	14.40	3.49
GOG-013/18	2.75	122.00	51.65	14.30	4.02	GOG-055/18	3.25	132.00	59.45	15.30	3.41
GOG-014/18	2.88	123.50	49.90	13.15	2.97	GOG-056/18	3.38	132.50	55.75	17.35	3.77
GOG-015/18	2.63	117.25	56.20	14.55	3.70	GOG-057/18	3.75	128.00	52.05	14.35	3.92
GOG-016/18	2.75	125.50	47.60	12.40	2.98	GOG-058/18	3.38	131.25	59.15	13.90	3.49
GOG-017/18	2.50	133.50	60.05	16.95	4.03	GOG-059/18	3.38	131.25	51.05	14.80	3.10
GOG-018/18	3.25	131.00	61.15	15.90	3.86	GOG-060/18	3.38	132.75	54.85	14.45	3.28
GOG-019/18	2.75	120.00	53.50	14.10	3.97	GOG-061/18	3.25	130.25	51.90	13.75	3.54
GOG-020/18	2.50	119.00	46.10	15.10	3.83	GOG-062/18	3.13	131.75	59.00	16.95	4.46
GOG-021/18	2.63	122.75	47.00	12.85	3.46	GOG-063/18	3.38	130.75	59.35	15.30	3.55
GOG-022/18	2.88	132.75	57.05	17.85	4.25	GOG-064/18	4.00	129.75	62.30	15.65	4.15
GOG-023/18	2.63	120.00	47.20	11.35	2.61	GOG-065/18	3.88	135.00	64.90	15.50	3.92
GOG-024/18	3.00	127.50	55.85	14.20	3.92	GOG-066/18	3.38	128.25	61.90	15.00	3.79
GOG-025/18	2.75	131.50	57.30	14.55	3.84	GOG-067/18	3.38	131.75	60.70	14.05	3.50
GOG-026/18	2.00	119.00	50.35	13.95	3.23	GOG-068/18	3.38	131.75	61.30	13.90	3.37
GOG-027/18	2.63	124.00	58.85	15.40	3.98	GOG-069/18	3.88	132.25	62.90	16.50	3.97
GOG-028/18	2.88	123.25	56.90	15.30	3.48	GOG-070/18	3.38	132.50	61.10	16.65	3.59
GOG-029/18	3.00	126.75	58.70	16.15	4.12	GOG-071/18	3.50	132.50	61.65	15.30	3.06
GOG-030/18	2.63	118.75	49.30	16.60	4.50	GOG-072/18	3.13	135.25	64.65	15.40	3.31
GOG-031/18	2.75	123.50	54.90	16.20	3.77	GOG-073/18	3.88	130.50	58.15	16.10	4.16
G0G-032/18	2.63	124.50	54.40	16.60	3.60	GOG-074/18	3.25	129.25	62.55	15.65	3.42
GOG-033/18	3.13	120.75	46.10	14.10	3.37	GOG-075/18	3.38	128.50	60.45	13.90	3.15

GOG-034/18	3.38	130.75	55.90	16.95	3.72	Tsedaye	2.13	131.75	52.15	15.55	3.14
GOG-035/18	2.75	119.25	45.70	10.80	3.18	G-009/03	2.25	128.50	51.90	13.15	3.41
GOG-036/18	2.88	133.25	54.20	18.80	3.44	Kuriftu	3.25	134.50	61.85	14.35	2.79
GOG-037/18	3.00	132.25	53.60	15.55	3.51	HL	3.13	135.25	59.10	15.90	3.91
GOG-038/18	2.63	125.25	59.05	13.75	2.91	G-020/03	2.50	130.50	57.00	14.20	2.75
GOG-039/18	2.25	129.50	56.20	17.70	3.42	G-054/03	2.38	132.75	60.10	13.10	3.33
GOG-040/18	2.88	129.00	52.55	18.95	3.73	Mean	2.98	128.08	55.57	14.95	3.50
GOG-041/18	3.00	127.75	57.25	14.90	3.29	CV (%)	16.83	4.84	10.15	17.56	22.95
GOG-042/18	2.63	131.25	57.05	15.80	3.23	LSD (5%)	0.70	8.66	7.88	3.67	NS

VI; Plat vigor rate: 1 to 2 = poor (weak plant with little foliar growth), 3 = average (acceptable foliar growth), and 4 to 5 = high (excessive amounts of foliar growth), MAD= Maturity date (No.), PH= Plant Height (cm), NOC= Number of cloves per bulb (No.), WOC= Weight of clove (g), CV = coefficient of variation, LSD= least significant different

Mean performance and Associations of characters for garlic accessions

The ranges and means of bulb yield and its related traits are indicated in Table 4. The results of analysis showed that there was wide range of variation for most of the traits such as bulb yield (2003 kg/ha to 7328.00 kg/ha) with a mean value of 4168.00 kg/ha. The maximum value of plant height was 64.90cm and the minimum value was 44.25cm. Number of cloves per bulb ranged between 10.80 and 18.95 and clove weight from 2.55 to 4.50 g. The range and mean values in this study indicated the existence of variability among the tested accessions for the major characters studied and there is considerable potential for garlic improvement program in the future. The present findings is in agreement with the findings of Bahadur (2016), Yebirzaf *et al.* (2017), Asiya *et al*. (2017) and Chadha *et al.* (2019), who reported wide range of variations for bulb yield and yield related characters of garlic genotypes.

Table 4. Range and mean of quantitative characters for the 81 garlic germplasm accessions studied

No.	Characters	Minimum Value	Maximum Value	Range unit	Mean
1	Bulb yield (Kg/ha)	2003.00	7328.00	5325.00	4168.00
2	Plant Vigor (scale 1 to 5)	2.00	4.00	2.00	2.98
3	Maturity date (Days)	116.50	135.25	18.75	128.08
4	Plant height (cm)	44.25	64.90	20.65	55.56
5	No of cloves per bulb (Number)	10.80	18.95	8.15	14.94
6	Weight of clove (g)	2.55	4.50	1.95	3.50

In addition to analysis of variance, correlation analysis was applied to understand the relationship existing between yield and its components. Significant positive correlation of bulb yield per hectare was observed with plant vigor, maturity date, plant height, number of clove per bulb and bulb weight (Table 5). Choosing genotypes with high levels of these characteristics, and application of appropriate agronomical techniques will guaranty higher yield (Chadha *et al.*, 2019). The highest and positive correlation was found between bulb yield and plant vigor (r = 0.788) and plant height (r = 0.543), respectively. On the other hand, there was a relatively strong positive correlation (r = 0.606) between plant height and maturity date.

Table 5. Simple correlation between values of the garlic germplasm accessions for different traits

Characters	BIY	VI	MAD	PH	NOC	WOC
BIY	1					
VI	0.788***	1				
MAD	0.499***	0.473***	1			
PH	0.543***	0.413***	0.606***	1		
NOC	0.232*	0.247*	0.479***	0.354**	1	
WOC	0.281*	0.247*	0.060NS	0.179NS	0.466***	1

BIY=Bulb yield (Kg/ha), VI; Plat vigor rate: 1 to 2 = poor (weak plant with little foliar growth), 3 = average (acceptable foliar growth), and 4 to 5 = high (excessive amounts of foliar growth), MAD= Maturity date (No.), PH= Plant height (cm), NOC= Number of cloves per bulb (No.), WOC= Weight of clove (g)

Clusters analysis of garlic accessions

The cluster analysis based on six morphological traits was shown as a dendrogram of dissimilarity representing the closest accessions in homogeneous groups with distantly related in different clusters. It grouped the 81 garlic accessions into five main groups (Fig. 1). Cluster analysis confirmed the presence some variation among genotypes in which they were grouped into Cluster I, which comprised of the largest number of accessions (32 accessions) (39.50%) followed by cluster II with 31 accessions (38.27%), cluster III with 9 accessions (11.11%), cluster IV with 5 accessions (6.17%) and cluster V with 4 accessions (4.94%) (Table 6). The clustering indicated that garlic accessions of the same cluster group were at least morphologically similar. The clusters- IV and V constituted the most important garlic accessions that are characterized by higher bulb yield than the other clusters. The clustering pattern of the accessions revealed the existence of genetic diversity in the garlic accessions for the characters studied.

Table 6. Clustering patterns of 81 garlic accessions based on six quantitative traits

Cluster	No. of accessions in each cluster	% of accessions in cluster	Serial number	Name of accessions in each cluster
I	32	39.50	1,2,4,8,11,14,15,17,22,24,25,45,46,47,49,51,53,55,56,59,60,61,62,63,64,66,68,70,71,75,78,79	GOG-001/18, GOG-002/18, GOG-004/18, GOG-008/18, GOG-011/18, GOG-014/18, GOG-015/18, GOG-017/18, GOG-022/18, GOG-024/18, GOG-025/18, GOG-045/18, GOG-046/18, GOG-047/18, GOG-049/18, GOG-051/18, GOG-053/18, GOG-055/18, GOG-056/18, GOG-059/18, GOG-060/18, GOG-061/18. GOG-062/18, GOG-063/18, GOG-064/18, GOG-066/18, GOG-068/18, GOG-070/18, GOG-071/18, GOG-075/18, Kuriftu, HL
II	31	38.27	3,6,7,9,13,16,19,21,23,27,28,29,30,31,32,33,34,36,37,38,39,40,41,42,43,44,48,50,52,54,81	GOG-003/18, GOG-006/18, GOG-007/18, GOG-009/18, GOG-013/18, GOG-016/18, GOG-019/18, GOG-021/18, GOG-023/18, GOG-027/18, GOG-028/18, GOG-029/18, GOG-030/18, GOG-031/18, GOG-032/18, GOG-033/18, GOG-034/18, GOG-036/18, GOG-037/18, GOG-038/18, GOG-039/18, GOG-040/18, GOG-041/18, GOG-042/18, GOG-043/18, GOG-044/18, GOG-048/18, GOG-050/18, GOG-052/18, GOG-054/18, G-054/03
III	9	11.11	5,10,12,20,26,35,76,77,80	GOG-005/18, GOG-010/18, GOG-012/18, GOG-020/18, GOG-026/18, GOG-035/18, Tsedaye, G-009/03, G-020/03
IV	5	6.17	57,58,69,72,74	GOG-057/18, GOG-058/18, GOG-069/18, GOG-072/18, GOG-074/18
V	4	4.94	18,65,67,73	GOG-018/18, GOG-065/18, GOG-067/18, GOG-073/18

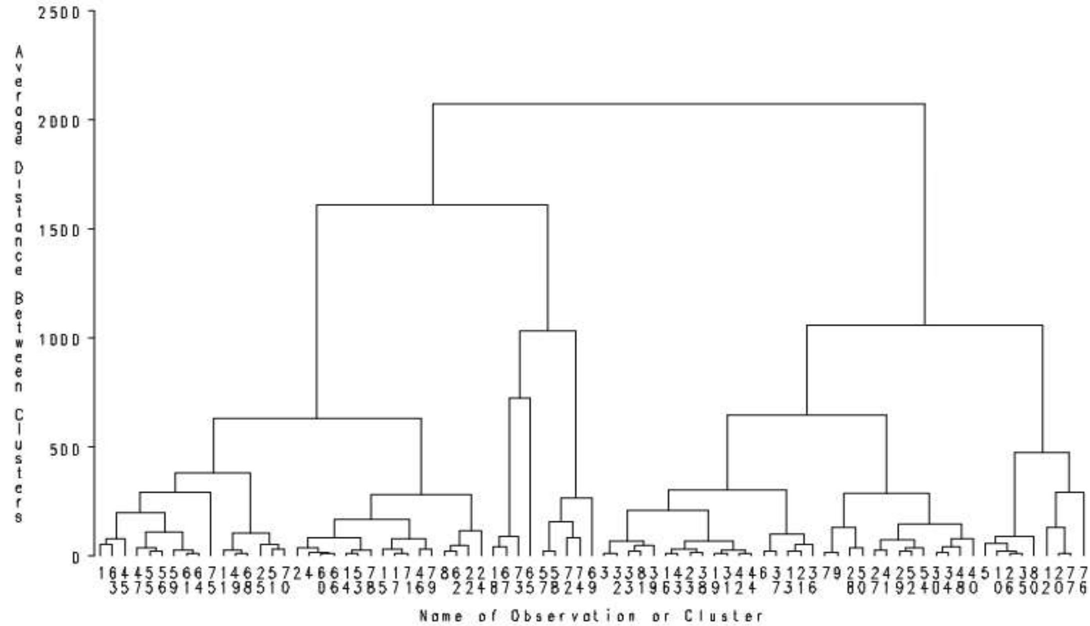

Figure 1. Dendrogram showing hierarchical clustering patterns of 81 garlic accessions for six traits

Conclusion

The result this characterization study showed the presence of significant difference among the garlic genotypes for almost all the traits. Among the collections, genotypes GOG-065/18 , GOG-018/18, GOG-067/18, GOG-073/18, GOG-069/18, GOG-058/18, GOG-057/18, GOG-072/18, GOG-074/18, GOG-075/18, GOG-061/18, GOG-064/18, GOG-059/18, GOG-047/18, GOG-056/18, GOG-055/18, GOG-001/18, GOG-063/18, GOG-045/18, GOG-049/18, GOG-068/18, GOG-011/18, GOG-051/18, GOG-070/18, GOG-025/18 and GOG-046/18 were found promising for yield and yield related traits compared to the check varieties. The genotypes were grouped into several clusters indicating the existence of sufficient variations among the studied genotypes. In addition, the traits considered in the present study had positive correlations among traits and exhibited positive and significant correlation between bulb yield and plant vigor, maturity date, plant height, number of clove per bulb and bulb weight.

This results is helpful for researchers to comprehensively understand the genetic background of the garlic collection and more easily select the genotypes with desired characters, especially those with high bulb yield and best quality characteristics. Hence, these useful garlic germplasm in the collections should be properly conserved and used for future genetic improvement program.

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Performance Evaluation of Okra Genotypes at Different Ago-ecologies for Variety Development

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Abstracts

Ethiopia is considered as the likely origin and center of diversity for Okra, however, variety improvement and related technology developments of on this crop are very limited. Okra genotypes introduced from AVRDC-World Vegetable Center evaluation were carried in a multi-location variety trials at Melkassa, Pawe, and Werer to develop high yielding Okra variety for different agro-ecologies. The variety trials were carried out during 2017 and 2018. The genotypes were evaluated in RCB design of three replications. Significant and wide variations were observed among the evaluated different genotypes in their vegetative traits, immature green pod yield, and fruit characteristics. Genotypes ML-OK-16 (155 Q/ha) and Spinless (119 Q/ha) gave significantly high yield over the rest genotypes across the tested years and locations. These prominent genotypes wer selected and promoted to a variety verification trial and verified with a check-in single plot. Following the candidates' performance in the verification trial, the NVRC approved the release of these two varieties for wider production in the country.

Introduction

Okra (*Abelmoschus esculentus* (L) Moench) belongs to the family Malvaceae. It is known in many English-speaking countries as ladies' fingers, is a flowering plant. The geographical origin of okra is disputed, with supporters of West African, Ethiopian, and South Asian origins. The plant is cultivated in tropical, subtropical, and warm temperate regions around the world.

It is an important vegetable crop cultivated in the tropics and sub-tropics for its immature tender edible green fruits. According to FAOSTAT 2019, the annual world production of okra reached 9,953,537 tonnes from an area of 2,729,811 ha of land. India is the largest okra producer in the world with 6,176,000 tonnes production per year. Nigeria stands second with 1,819,018 tonnes of yearly production (FAO, 2021). There is no clear record of the production area and productivity of the crop under the Ethiopian condition. However, okra has great diversity and is a tranditional vegetable in different parts of the country particularly in the Western lowland (550-1600 masl) regions (Tesfa and Yosef, 2016).

The fruit is an elongated, conical or cylindrical capsule, comprising, for the most part, five cavities containing ovules. The fruit is long pod and generally ribbed, developing in the leaf axil and spinelesss in cultivated kinds. The fruit is normally yellowish-green to green, but is sometimes purple or whitish green. The pods are the edible portion, which is harvested while still tender and immature. They grow rapidly into long (10-30 cm) and narrow (1-4 cm) pod with a tip that is either pointed like a beak or blunt (Tripathi *et.al.*, 2011).

Okra has nutritional as well as medicinal value. The immature fruits are used as a boiled or fried vegetable, they are particularly popular for adding to soups and stews; they may also be dried and powdered for use as a flavoring. Mature pods contain a mucilaginous substance. Young shoots and leaves are also edible; the mature seeds contain about 20% of edible oil. The green tender pod contains oxalic acid, thiamine, riboflavin, nicotinic acid and also vitamin A, B and C. Calcium content is very high as compared to other vegetables, which is about 66 mg per 100 g. Okra provides an important source of vitamins, calcium, potassium, and other minerals which are often lacking in the diet in developing countries (IBPGR, 1990).

Although okra has many importance and utilization, development of high yielding and quality improved variety are very limited in Ethiopia. Ethiopian Institute of Biodiversity (IBC) has collected okra germplasms from Western Ethiopia. There is also an attempt of collection and evaluation by Humera, Pawe, Gambella, and Assosa Agricultural Research Centers. However, little has been attempted by breeders in improving the crop in terms of variety develoment. Thus far only one variety has been released by Humera ARC.

In this study, an attempt was made to develop a suitable high yielder variety for different agro-ecologies with acceptable immature green pod yield and quality.

Material and Methods

Descriptions of Experimental Sites

The study was conducted at Melkassa, Pawe, and Werer Agricultural Research Centers in 2018 and 2019 during the main cropping season (rainy season). Supplementary irrigation was applied at Melkassa and Werer but not at Pawe. Melkassa is located $8^0$24’59.20” N latitude and $39^0$19’15.19” E at an altitude of 1550 m.a.s.l. The area is characterized by low and erratic rainfall with a mean annual rainfall of 796 mm with peaks in July and August. The dominant soil type of the center is Andosol of volcanic origin with pH that ranges from 7 to 8.2. The mean annual temperature is 21.2^0C with a minimum of 14^0C and a maximum of 28.4^0C (MARC, 2008). Pawe has hot to warm moist environment and situated at a latitude of 11°19’N and longitude of 36°24'E, and an altitude of 1120 m.a.s.l. The area is characterized by a unimodal rainfall pattern receiving average annual rainfall of 1586.4 mm. The minimum and maximum temperatures of the area are 16.4 and 32.6 °C, respectively with an average relative humidity of 55%. Werer is located at a latitudes of 9^0 60’ N and 40^0 9’ E longitude and an altitude of 70 masl. The soil type of the study area is chromic Aertisols (clay to silty clay). The pH of the soil is slightly alkaline and ranges from 7.5 to 8.5. The mean annual rainfall is 540 mm and the mean minimum and maximum temperatures are 19^0C and 34^0C, respectively.

Experimental Design, Treatment and Analysis

Okra genotypes were introduced from AVRDC-The World Vegetable Center, through the project “Improving Nutrition and Income in Eastern and Southern Africa by Enhancing Vegetable-based Farming and Food systems in Peri-urban Corridors” (VINESA) in 2014. These materials were characterized and evaluated at Melkassa Agricultural Research Center. Five okra genotypes were promoted from a preliminary evaluation to multilocation variety trial with one released variety included, Bamaya-Humera, as a check. These genotypes were evaluated at Melkassa, Werer and Pawe in 2017 and 2018 in a Randomized Complete Block Design with four replications. The immature green fruit yield was harvested 15 to 17 times within four days interval for one growth cycle of the plant, fruit number per plant, days to maturity, plant height, quality and related components were recorded and subjected to ANOVA. Consequently, these genoypes were found to be high fruit yielders and had good quality of immature green pod. Based on the performance of the genotypes, two best performing genotypse in terms of fruit yield and quality, ML-OK-16 and Spinless, were selected and promoted to verification trial for release.

The variety verification experiments were also carried out at the same research centers both on research station and on farmers’ fields in 2019 cropping season. Two selected okra genotyeps ‘**ML-OK-16’** and ‘**Spinless’** with one check ‘**Bamya Humera’** were put under verification trials on a single large plot size of 100 m^2 per variety were used for a variety verification trial. The experiment was conducted from early June 2019 to October 2019. The trial wsa evaluated by national variety release technical committee.

Result and Discussions

Green Pod Yield

The okra genotype yield varied significantly ($p<0.05$) at different locations over years as displayed below in Table 1. There were significaant difference among the genotypes during both years at all locations. ML-OK-16 produced significantly higher yield, followed by Spinless, ML-OK-10 and TZSMN which produced i.e., 155, 119, 112, and 108 q/ha, respectively. The cultivar RCA1(42 q/ha) and the check variety Bamya-Humera (55 q/ha) were low yielders among the genotypes under evaluation.

There was also large yield gap between the years 2017 and 2018. The combined mean of all the genotypes in 2017 was 133 q/ha. This yield reduced to 74 q/ha in 2018. The reduction in yield might be caused by rainfall distribution and pest prevalence. In general, there were supplementary irrigation at Melkassa and Werer while at Pawe rain fall were the solely source of water for production. However, those superior genotypes were sustainably high yielders across location and years (Table 1).

Table 1. Marketable pod yield (q/ha) at Melkassa, Pawe and Werer in 2017 and 2018 under rainfed and irrigated conditions

Genotypes	**2017**				**2018**				**2018**	**Over all**
	Melkassa	**Pawe**	**Werer**	**Combined**	**Melkassa**	**Pawe**	**Werer**	**Combined**	**Melkassa Irrigation**	
Bamya-Humera	60	45	58	54	32	25	83	47	81	54.9
ML-OK-10	158	79	154	145	140	22	118	93	71	106.0
ML-Ok-16	**246**	**179**	**198**	**244**	**121**	**55**	**119**	**99**	**79**	**142.4**
RCA1	61	19	81	53	16	13	88	36	39	45.3
Spinless	**151**	**157**	**163**	**157**	**76**	**30**	**162**	**90**	**91**	**118.7**
TZSMN	140	64	137	147	122	12	106	80	75	93.7
Mean	**136**	**91**	**132**	**133**	**85**	**26**	**113**	**74**	**73**	93.5
F-test	**	**	**	**	**	*	*	**	*	**
$LSD_{0.05}$	46.9	47.5	63.8	31	36.6	23	52.5	20.9	24.8	38.1
CV (%)	19	28.9	20.2	24.3	23.9	52	25.5	29.6	18.8	63.3

During verification, both candidate varieties gave higher yield over the check. The candidate variety ML-OK-16 gave 138.16 q/ha and 139.61q/ha marketable and total yields, respectively; whereas, Spinless gave 114.12 q/ha and 115.55 q/ha marketable and total yields, respectively (Table 2). The yield of candidate varieties was significantly higher than the standard check Bamya-Humera (72.66 q/ha). Similarly these varieties were superior in all tested locations. The proportion of unmarketable yield is very small and not significant in all the varieties.

Table 2. Yield performance of okra varieties verification, 2019

Varieties	Locations	Marketable Yield (q/ha)	Unmarketable yield (q/ha)	Total Yield (qt/ha)
ML-Ok-16	Melkassa on station	130.75	0.11	130.87
	Wonji on farm	141.07	2.7	143.77
	Pawe on station	150.5	1.3	151.8
	Pawe on farm	143	1.5	144.5
	Werer on station	125.5	1.6	127.1
	Average	138.16	1.44	139.61
Spinless	Melkassa on station	120.14	0.81	120.95
	Wonji on farm	89.36	1.08	90.44
	Pawe on station	130.57	1.1	131.67
	Pawe on farm	115.5	1	116.5
	Werer on station	117	1.2	118.2
	Average	114.52	1.04	115.55
Bamya-Humera	Melkassa on station	77.14	0.31	77.45
	Wonji on farm	67.33	0.64	67.97
	Pawe on station	80.6	0.9	81.5
	Pawe on farm	75	0.78	75.78
	Werer on station	60	0.6	60.6
	Average	72.01	0.64	72.66

Yield compenenets

There was highly significant ($p<0.01$) variation among okra genotypes in commercial immature green pod harvest. Bamya-Humera, RCA1 and Spinless were early, ready to commercial harvest after 71 days of sowing. TZSMN and ML-OK-10 were significantly late to mature. They took 84 days to harvest after sowing while while ML-Ok-16 was harvested at 78 days after sowing. Variation of okra genotypes to days to maturity was reported by Tesfa and Yosef (2016).

Fruit length and diameter varied significantly among the studied cultivars (Table 3). The longest fruit length (20 cm) was noted in Spinless, while the shortest was found in Bamya-Humera (14 cm). Variation in fruit length among different genotypes of okra was also recorded by Islam (1997); Halim (2008) and Saifullah *et al*. (2009). The highest fruit diameter (2.6 cm) was recorded from Spinless and the lowest (1.7 cm) was from Bamya-Humera, ML-OK-10 and RCA1 (Table 3. Islam (1997) and Saifullah *et al*. (2009) also found significant variations in fruit diameter in different genotypes of okra.

Candidate variety ML-OK-16 was characterized by higher number of primarily branches (8) and tall plant height (213 cm). It has whitish, non-ridged and downy fruits. Spineless is medium tall plant (137 cm) with an average of five primarily branches. It has downy and green fruits with an average of nine ridges per fruit (Table 3 and 4).

Table 3. Vegetative and pod characteristics of okra genotypes at Melkassa, Pawe and Werer, 2019

Genotypes	Day to maturity	Pod number per plant	Pod length (cm)	Fruit width (mm)	Plant height (cm)	Average fruit weight (g)	Ridge number per pod
Bamya-Humera	71	25.7	14	17	165	14.4	5
ML-OK-10	84	26.8	20	23	172	37	8
ML-Ok-16	78	49.7	16	17	213	31.4	0
RCA1	71	15.6	17	17	123	24.3	5
Spinless	71	24.8	19	26	137	37.8	9
TZSMN	84	33.6	17	18	184	26.1	5
Mean	76.5	29.4	17	20	166	28.5	5
F-test	**	**	**	**	**	**	**
$LSD_{0.05}$	3.86	11.07	1.1	5.6	36.7	3.41	0.9
CV(%)	2.8	20.7	3.5	2	12.6	6.6	9.7

Table 4. Vegetative and quality characteristics of okra genotypes, 2019

Genotypes	Pod color	Pod surface	Growth habit	Pod Pubescence	Primary Branch per plant
ML-Ok-16	**Whitish green**	**Smooth**	**Erect**	**Downy**	**8**
Spinless	**Green**	**Ridge**	**Erect**	**Downy**	**5**
ML-OK-10	Green	Ridge	Erect	Downy	4
Bamya-Humera	Green	Ridge	Erect	Downy	7
TZSMN	Green	Ridge	Erect	Slightly rough	4
RCA1	Green	Ridge	Erect	Slightly rough	3

Conclusion and Recommendation

Yield and quality variation was found among the okra genotypes studied. ML-OK-16 and Spinless showed greater potential in terms of yield and quality attributes as they outperformed the other genotypes, indicating their usefulness as promising varieties. Based on their on-farm verification performance, the NVRC decided both genotypes to be released as new varieties to be produced in Ethiopia. Further technology package development such as population density, fertilizer requirement, and other crop management techniques should be studied. Seed multiplication, pre-extension demonstration and popularization of the released varieties for producers from small scale home garden up to potential producers are recommended.

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Performance of Hot Pepper (*Capsicum annuum* L.) Genotypes for Green and Dry Pod Yield and Quality in Ethiopia

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Abstract

Hot pepper (Capsicum annum L) is a dominant vegetable crop grown in different parts of Ethiopia playing an important role for nutrition, income generation and foreign currency earnings. The production of this crop, however, is constrained by pre- and post-harvest-pests and limited improved varieties with important traits such as disease resistance.Therefore, a field experiment was conducted at Melkassa and Mehoni Agricultural Research Centers during the main and off-seasons in 2017 and 2018 to develop hot pepper varieties with high green and/dry pod yield and acceptable pod quality. The experiment was carried out using seven hot pepper genotypes (PBC-731, ICPN-9#16, PBC-602, Rivival, PGRC-80021, Melka Awaze, and Marko Fana) that were laid out in Randomized Complete Block Design with three replications. They were evaluated for yield and physical pod characterstics at the two locations. The overall combined total green pod yield across locations/season and years showed non-significant difference among genotypes. However, genotypes ICPN 9#16 (262 q/ha), Rivival (249 q/ha), and PBC 602(208 q/ha) gave higher total green pod yield than standard check varieties in that order. Similarly, though there was no significant difference among genotypes over the combined analysis of variance, total dry pod, PBC 602 (30.8 q/ha), Rivival (29.4 q/ha) and ICPN 9#16 (29.3 q/ha) gave higher yield compared to the check varieties. The per location and combined analysis of variance showed significant (P<0.01) differences in marketable and total green and dry pod yields at Melkassa and Mehoni during the rainfed seasons, but only at Melkassa under irrigation condition. Significant differences were also observed among the genotypes in plant height, pod number per plant, pod length, and pod wall thickness. Moreover, PBC-602 had elongate pod shape, green pod color, smooth pod surface, and highly pungent which are preferred by consumers in green pod markets. Similarly, Rivival had elongate pod shape, dark green pod color, brown dry pod color, smooth pod surface and medium pungency which could be used for both dry pod and green pod markets. Consequently, Rivival named as Gebaba (for green and dry pod), and PBC-602 named as Chala (for green pod) purposes were released for production in agro-ecologies of Ethiopia similar to that of Melkassa and Mehoni. The released varieties thus should be promoted for production under wider recommendation domain areas of hot pepper.

Introduction

Hot pepper (*Capsicum annuum* L.) is one of the most important vegetable crops that belong to the Solanaceae family (Kumar *et al.,* 2011). It is the second most economically important vegetable crop of the family after tomato in the world

(Rubatzky and Yamaguchi, 1997; Berhanu *et al*., 2011). It is important for pungency and oleoresin extraction that attributes in food products as a spice and in pharmaceutical applications. It is used as spice for flavoring and coloring of foods, providing essential vitamins and minerals (Bosland and Votava, 2012).

The world total area coverage of hot pepper for dry and green pod is estimated to be 1,989,664 and 1,914,685 hectares in 2012 with a total production of 3,352,163 and 31,171,567 tones, respectively. In Ethiopia total area coverage for dry and green pod of hot pepper, respectively is 172,142.2 and 10,473.07 hectares in 2018/19 with a total production of 307,457.1 and 62,247.5 tones, respectively (CSA, 2018/19). The top five leading hot pepper producing countries in the world are India, China, Peru, Bangladesh, and Pakistan. In Ethiopia, central (Eastern and Southern Shoa), western, north-western (Wellega, Gojjam), and the northern parts of the country are the major hot pepper producing areas in the country (Girma *et al*., 2001).

The national average productivity of the crop is 0.286 t/ha for dry pepper and 2.734 t/ha for green pod which is far below the world average productivity of 1.685 t/ha for dry pod and 16.28 t/ha for green pod (FAOSTAT, 2012). The major production constrains attributed to the low productivity of the crop in the country among others include pre and post harvest pests, limited improved varieties (disease resistant) and quality seed of released varieties (Vicente *et al*., 2007 and Topuz and Ozdemir, 2007).

In order to solve these problems, the National Warm Season Vegetable Research Program considered hot papper as high priority crop in the research program and has been focusing on its breeding. In an effort to improving the yield of hot pepper in the country, germplasm have been collected from major producing areas, the Ethiopian Institute of Biodiversity (EIB) and introduced from World Vegetable Center, the Asian Vegetable Research and Development Center (AVRDC, Taiwan). The present study was conducted to evaluate and identify hot pepper vareties with high green/dry pod yield and quality for wider production and consumption in the country.

Material and Methods

Experimental materials and procedures

Five hot pepper genotypes (PBC-731, ICPN-9#16, PBC-602, Rivival, and PGRC-80021) introduced from World Vegetable Center, the Asian Vegetable Research and Development Center (AVRDC, Taiwan) were evaluated along with two locally released standard check varieties (Melka Awaze and Marko Fana). The experiment was laid out in Randomized Complete Block Design with three replications in a plot size of 8.4 m^2 having four rows with the spacing of 70 cm and 30 cm between rows and plants, respectively. Fertilizers, NPS (242 kg/ha) was applied just before transplanting, while urea (79 kg/ha) was applied in two splits, 50% two weeks after transplanting and the remaining 50% one and half month after transplanting. Fungicides Ridomil gold and Bylaton were applied at the rate of (3.5 kg/ha) to control the different leaf diseases; bacterial leaf spot and powdery mildew, respectivly and Karate 5% (2.5 l/ha) was also applied against insect pests (African boll worm and aphids). Other necessary cultural practices were applied to all plots uniformly as needed. Data were collected from the central two rows. Data on days to 50% flowering, plant height, growth habit, green and dry marketable and total yields, pod characters (pod length, pod diameter, pod number per plant, pod wall thickness, pod color, pod shape, pod surface and pungency) were collected. Quantitative data were subjected to environment wise analysis of variance followed by pooled analysis of variance. GENES software package was used to compute the pooled ANOVA, while statistix 10 was used for mean separation (Cruz, 2013).The genotypes were evaluated in 2017 and 2018 cropping season at Melkassa and Mehoni Agricultural Research Centers.

Description of the study areas

Melkassa Agricltural Researtch Center (MARC) is located in the Central Rift Valley of Ethiopia at 8°24′N latitude, 39°21′E longitude, and altitude of 1,550 m.a.s.l. The average annual rainfall at MARC is 768 mm and the mean maximum and minimum temperatures are 28.5°C and 12.6°C, respectively. Mehoni Agricultural Research Center (MeARC) is located in the Raya Valley, Northern Ethiopia at 12° 41'50N" Latitude and 39° 42'08E" Longitude and an altitude of 1578 m.a.s.l. The site receives a mean annual rainfall of 300 mm and has an average minimum and maximum temperature of 22 and 32°C, respectively. The soil textural class of the experimental area is clay loam with pH of 7.9-8.1(MeARC, 2015). The field trials in both years were conducted in the rainy season with supplementary irrigation and in the dry season using full irrigation.

Result and Discussions

Marketable and Total Green Pod Yield

The combined analysis of variance for marketable and total green pod yield of hot pepper genotypes were highly significant *($P<0.01$)* under rainfed condition (Tables 1 and 2) at both locations. It ranged from 153.6 to 257 q/ha and 161 to 270.2 q/ha for marketable and total green pod yields, respectively. ICPN- 9#16 (257.2 q/ha), Rivival (226.3 q/aha) and PBC 602 (201.4 q/ha) produced higher green marketable yield. Similar trend was observed for total green pod yield. The individual location analysis of variance during these seasons showed a significant difference among genotypes at Mehonni while only for marketable yield alone at Melkassa, but was significant at both locations for the total yield. During 2017 rainfed trial, Rivival (317.5 q/ha), PGRC 80021 (269 q/ha), ICPN 9#16 (268.6 q/ha), and PBC 602 (23.02 q/ha) gave higher yield at Mehonni, while Rivival

(179.9 q/ha), ICPN 9#16 (145 q/ha), PBC 731 (143 q/ha) and PBC 602 (101.4 q/ha) in 2018. At Melkassa ICPN 9#16 (357.2 q/ha), PBC 602 (300.4 q/ha) and Rivival (229.1 q/ha) were the highest in 2017.

The combined analysis of variance across years/locations under irrigated condition showed non-significant difference among genotypes for marketable and total yield. The variability among genotypes, however, ranged from 272.7 q/ha for variety Mareko fana to 250 q/ha for ICPN 9#16. Similarly, the total yield ranged from 170.3 q/ha to 262 q/ha for the same genotypes. The individual location/years analysis of variance for marketable yield during these seasons showed significant difference at Melkassa. ICPN 9#16 (250 q/ha), Rivival (226.3 q/ha), and PBC731 (178.9 q/ha) gave higher yielde. Similar trend was observed for the total yield which is significant at Melkassa, but at Mehonni. ICPN 9#16, Rivival and PBC 602 were the highest yielder.

The overall analysis of variance across seasons, location and years showed non-significant difference among genotypes for marketable and total yield. However, ICPN 9#16, PBC 602 and Rivival gave higher marketable and total green pod yield than the standard check varieties (table 1 and 2).

Table 1. Marketable green pod yield (q/ha) at Melkassa and Mehoni in 2017 and 2018 under rainfed and irrigated conditions

Genotypes	2017*		2018*	Combined	2017**	2018**	Combined	Overall
	Melkasa	Mehoni	Mehoni		Mehoni	Melkasa		
PBC-731	232.4	213.0[c]	143.0[abc]	196.4[bc]	196.5	178.9[bc]	187.7	190.0
ICPN-9#16	357.2	268.6[b]	145.2[ab]	257.0[a]	-	250.0[a]	250.0	249.9
PBC-602	300.4	230.2[bc]	101.4[cde]	201.4[bc]	251.9	159.3[c]	205.6	219.9
Rivival	229.1	317.5[a]	179.9[a]	226.3[ab]	274.9	226.6[ab]	250.7	245.6
PGRC-80021	212.1	269.8[b]	68.9[e]	199.5[bc]	237.7	89.5[de]	163.6	175.6
Melka Awaze	244.9	204.3[c]	94.1[de]	181.0[bc]	241.3	130.3[cd]	185.8	182.9
Marko Fana	131.7	208.1[c]	120.9[bcd]	153.6[c]	293.8	51.8[e]	293.8	172.7
F-test	NS	**	**	**	NS	**	NS	NS
Mean	244.1	244.6	121.9	202.2	249.4	155.2	219.6	205.3
CV	3.0	6.7	19.2	25.0	33.2	21.1	26.0	25.2

Means followed by the same letter are not significantly different at $p < 0.05$ and 0.01
Note: * Rainfed; ** Irrigated

Table 2. Total green pod yield (q/ha) at Melkassa and Mehonni in 2017 and 2018 under rainfed and irrigated conditions

Genotypes	2017*		2018*	Combined	2017**	2018**	Combined	Overall
	Melkasa	Mehoni	Mehoni		Mehoni	Melkasa		
PBC-731	233.2	217.0^{c}	158.0^{b}	203.0^{bc}	203.2	180.5^{bc}	191.8	197.4
ICPN-9#16	259.8	278.0^{c}	172.3^{ab}	270.2^{a}	-	253.7^{a}	253.7	262.0
PBC-602	302.2	233.0^{bc}	107.7^{cd}	204.9^{bc}	260.2	161.1^{c}	210.6	207.8
Rivival	212.5	325.3^{a}	203.6^{a}	236.0^{ab}	283.0	228.2^{ab}	255.6	245.8
PGRC-80021	230.0	274.5^{b}	83.2^{d}	207.0^{ab}	251.3	90.7^{cd}	171.	189.0
Melka Awaze	245.8	209.3^{c}	108.9^{cd}	188.0^{bc}	249.3	134.2^{cd}	191.	189.9
Marko Fana	132.4	213.9^{c}	136.1^{bc}	161.0^{c}	305.3	53.8^{e}	179.5	170.3
F-test	245.1	250.3	138.5	210.0	258.7	157.5	207.7	209
Mean	NS	**	**	**	NS	**	NS	NS
CV	29.8	6.41	18.5	24.3	32.3	21.0	26.5	25.4

Means followed by the same letter are not significantly different at p < 0.05 and 0.01
Note: * Rainfed; ** Irrigated

Marketable and Total Dry Pod Yield

The combined analysis of variance for marketable and total dry pod yield of hot pepper genotypes were highly significant *(P<0.01*) under rainfed condition (Tables 3 and 4) at both locations. It ranged from 18.2 to 30.2 q/ha and 20.4 to 32.7 q/ha for marketable and total dry pod yields, respectively. PBC (30.2 q/ha), Melka awaze (29.3 q/ha) and Rivival (25.6 q/ha) gave higher dry marketable yield. Similar trend was observed for total dry pod yield.

The individual location analysis of variance during each season showed significant difference among genotypes at both Melkassa and Mehonni for marketable and total dry pod yield. PBC 602 (34.9 q/ha and 39.7 q/ha), Melka awaze (34.6 q/ha and 35.7 q/ha) and Rivival (33.3 q/ha and 35.5 q/ha) were top for marketable and total dry pod yield at Melkassa during 2017 under rain fed. At Mehoni genotype PGRC- 80021(39.5 q/ha and 42.6 q/ha), PBC-602 (36.6 q/ha and 38.3 q/ha) and Markofana (35.8 q/ha and 38.9 q/ha) were top yielder for marketable and total dry pod yield during 2017 under rainfed condtions. In 2018 genotypes Rivival followed by Melka awaze standard check gave higher marketable and total dry pod yield at Mehoni under rainfed.

The combined analysis of variance across years/locations under irrigated condition showed non-significant difference among genotypes for marketable and total dry pod yield. It ranged from 17.3 to 30.2 q/ha and 23 to 33 q/ha for marketable and total dry pod yield, respectively. The individual location/years analysis of variance for marketable dry pod yield in each season showed significant difference at Melkassa, but not at Mehoni. ICPN 9#16 (30.2 q/ha), PBC-602 (24.6 q/ha) and PBC-731 (23.5 q/ha) were the top yielder. Similar trend was observed for the total yield with significant difference at Melkassa during 2018.

The overall analysis of variance across seasons, location and years showed non-significant difference among genotypes forboth marketable and total dry pod yield. However, genotype PBC-602 (27.6 and 30.85 q/ha) gave the highest marketable and total dry pods yield, respectively followed Melka Awaze (check) and Rivival (Table 3 and 4).

Table 3. Marketable dry pod yield (q/ha) at Melkassa and Mehoni in 2017 and 2018 under rainfed and irrigated conditions

Genotypes	2017*		2018*	Combined	2017**	2018**	Combined	Overall
	Melkasa	Mehoni	Mehoni		Mehoni	Melkasa		
PBC-731	18.4[bc]	29.6[bc]	17.8[ab]	21.9[bc]	31.5	23.5[ab]	27.5	24.7
ICPN-9#16	27.9[ab]	23.0[c]	17.0[ab]	22.6[bc]	-	30.2[a]	30.2	26.4
PBC-602	34.9[a]	36.6[ab]	19.0[ab]	30.2[a]	25.6	24.6[ab]	25.1	27.6
Rivival	33.3[a]	25.8[c]	22.6[a]	25.6[ab]	28.0	23.2[ab]	25.6	25.6
PGRC-80021	27.2[ab]	39.5[a]	4.0[c]	25.2[ab]	21.2	13.5[bc]	17.3	21.3
Melka Awaze	34.6[a]	34.0[ab]	19.2[a]	29.3[a]	32.9	13.5[bc]	23.2	26.2
Marko Fana	9.0[c]	35.8[ab]	10.0[bc]	18.2[c]	28.2	8.3[c]	18.25	18.2
F-test	26.5	32.0	15.6	24.7	27.9	19.5	23.7	24.2
Mean	**	**	**	**	NS	**	NS	NS
CV	26.5	13.0	32.9	24.8	20.1	32.5	26.2	25.5

Means followed by the same letter are not significantly different at p < 0.05 and 0.01
Note: * Rainfed; ** Irrigated

Table 4. Total dry pod yield (q/ha) at Melkassa and Mehoni in 2017 and 2018 under rainfed and irrigated conditions

Genotypes	2017*		2018*	Combined	2017**	2018**	Combined	Overall
	Melkasa	Mehoni	Mehoni		Mehoni	Melkasa		
PBC-731	19.9[bc]	32.0[bcd]	19.0[ab]	23.9[bc]	41.4	25[ab]	33	28.45
ICPN-9#16	29.8[ab]	26.5[d]	23.4[a]	26.6[abc]	-	32[a]	32	29.3
PBC-602	39.7[a]	38.3[ab]	20.1[ab]	32.7[a]	32.3	25[ab]	29	30.85
Rivival	35.5[a]	28.0[cd]	25.8[a]	27.8[ab]	38.3	23.7[ab]	31	29.4
PGRC-80021	28.6[ab]	42.6[a]	5.2[c]	27.5[ab]	32.3	14.2[bc]	23	25.25
Melka Awaze	35.7[a]	38.9[ab]	22.1[ab]	31.3[a]	41.7	16.4[bc]	29	30.15
Marko Fana	10.5[c]	38.9[ab]	11.9[bc]	20.4[c]	42.6	8.9[c]	26	23.2
F-test	28.6	34.7	15.63	27.2	38	20.8	29.0	28.1
Mean	**	**	**	**	NS	*	NS	NS
CV	27.8	13.4	32.4	25.2	16.6	34.7	25.6	25.4

Means followed by the same letter are not significantly different at p < 0.05 and 0.01
Note: * Rainfed; ** Irrigated

Vegetative and Pod Characteristics

There was significant difference (P<0.01) among genotypes interms of plant height, pod number per plant, and pod length. Genotypes did not showed significant difference (P>0.05) in days to 50% flowering, pod diameter and pod wall thickness among (Table 5). The tallest plant height was recorded from Melka awaze (80.7 cm) standard check, while Rivival (60.7 cm), Marko Fana (61.2 cm) and PBC-602 (61.7 cm) were short. The highest number of pods per plant was recorded from the genotype PBC-602 (174), while the lowest was recorded from Marko Fana (60). The longest pod was recorded from genotype PBC-602 (116.5 mm), while the shortest were recorded from Marko Fana (87.3 mm), PBC-731

(88 mm), Rivival (88.3 mm) and PGRC-80021 (91 mm) (Table 5). In line with this, Delelegn *et al*. (2014) reported highly significant differences in number of pods per plant, pod length and marketable yield among nine varieties evaluated in Jimma and Seka chekorsa areas of Ethiopia.

Table 5. Vegetative and pod characteristics of hot pepper genotypes at Melkassa, 2017

Genotypes	DF	PH	PNP	PL	PD	PWT
PBC-731	45	71.0^{b}	76.6^{bc}	88.0^{b}	18	2.1
ICPN-9#16	41	66.0^{c}	100.1^{bc}	100.3^{ab}	19.7	1.5
PBC-602	46	61.7^{d}	174.3^{a}	116.5^{a}	18.7	2.0
PGRC-80021	43	70.7^{b}	114.5^{b}	91.0^{b}	15.7	1.8
Rivival	40	60.7^{d}	67.4^{c}	88.3^{b}	20	2.4
Melka Awaze	42	80.7^{a}	87.5^{bc}	99.0^{ab}	17.7	1.8
Marko Fana	41	61.2^{d}	60.1^{c}	87.3^{b}	21	2.2
Mean	42.6	69.7	97.2	95.8	18.6	2
F-test	NS	**	**	**	NS	NS
CV	1.91	1.55	16.89	7.14	22.62	15.01

Means followed by the same letter are not significantly different at p < 0.05 and 0.01

*DF: Days to 50% flowering, PH: Plant height (cm), PNP: Pod number per plant, PL: Pod length (mm), PD: Pod diameter (mm), PWT: Pod wall thickness (mm)

Qualitative vegetative and pod characteristics

PBC-602 had elongate pod shape, green pod color, smooth pod surface, and highly pungent hence fulfills consumers preference for green pod markets. This variety is also tolerant to soil borne diseases compared to the standard check varieties. Rivival, on the other hand, had elongate pod shape, dark green pod color, brown dry pod color, smooth pod surface and medium pungency. This variety has pod characters that fulfills both dry pod and green pod markets requirement (Table 6).

Table 6. Qualitative vegetative and pod characteristics of hot pepper genotypes at Melkassa, 2017

Genotypes	Pod shape	GPC	DPC	Pod surface	Growth habit	Pungency
PBC-731	Elongate	Deep green	Brown	Smooth	Intermediate	Medium
ICPN9#16	Elongate	Light green	Light red	Semi wrinkled	Dense	Low
PBC-602	Elongate	Green	Red	Smooth	Intermediate	High
PGRC-80021	Elongate	Light green	Light red	Semi wrinkled	Intermediate	Low
Rivival	Elongate	Deep green	Brown	Smooth	Intermediate	Medium
Melka Awaze	Elongate	Green	Red	Smooth	Dense	Medium
Marko Fana	Elongate	Green	Brown	Semi wrinkled	Intermediate	High

*GPC: Green pod color, DPC: Dry pod color

Conclusion and Recommendations

Hot pepper (*Capsicum annum* L) is one of the dominant vegetable crops grown in different parts of Ethiopia that plays an important role for nutrition, income generation and foreign currency earnings. The production of the crop, however, is constrained by pre- and post-harvest-pests and limited improved varieties with important traits such as disease resistance. Inorder to mitigate these problems, development of hot pepper varieties that are tolerant to diseases and pests, and have high quality and yield is vital. In the present study seven hot pepper genotypes were evaluated under different environments. The overall combined total green and dry pod yield across locations/season and years showed non-significant difference among genotypes, but ICPN 9#16 (262 q/ha), Rivival (249 q/ha), and PBC 602 (208 q/ha) genotypes gave higher total green pod yield in that order, while PBC-602 (30.5 q/ha), Melka awaze (30.1 q/ha) and PBC-731 (28.4 q/ha) gave higher total dry pod yield. Moreover, PBC-602 had green pod color and highly pungent pod which fulfills the preference of consumers for green pod markets. This variety is also tolerant to soil borne diseases compared to the standard check varieties. Similarly, Rivival had dark green pod color, brown dry pod color and medium pungency which could be used both for dry pod and green pod markets. As a result these two hot pepper genotypes, Rivivial (for dual purpose) and PBC-602 (for green pod) were released for production in mid-to lowland areas of Ethiopia by National Variety Release Committee (NVRC) in 2020. Therefore, we recommend the large scale promotion of thesew varieties to a wider community producers to improve the productivity and production of hot pepper and maximize the benefit of stackholders along its value chain.

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Performance of Tomato Varieties under Different Growing Conditions at Fogera and its Surroundings

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Abstract

Tomato production in an open field condition during the rainy season was difficult mainly because of disease attack. To evaluate the possibility producing tomato under open fields during the rainy season a field study was carried using Melkasalsa and Melkashola varieties under an integrated disease control measure that includes repeated spray of fungicide at Fogera, Northwestern parts of the country. Results of this study revealed the possibility of producing high yield of fresh tomato fruits using these two varieties. Melkasalsa and Melkashola varieties further demonstrated their ability to producing high tomato fruit yield of premium quality under a low cost plastic shelter during the rainy season. However, fruits of Melkasalsa and Melkashola varieties have less preference in the market due to their small fruit size. Fresh tomato types with bigger fruit size did not tolerate disease pressures under rainfed production in open fields, and many of these recently released tomato varieties by MARC were not evaluated at Fogera under different production systems (irrigated, rain fed and protected (low cost plastic shelter). To this effect, 11 varieties viz., Metadel, Miya, Cochoro, Gelilema, Fetan, Bishola, Eshet, ARP, Chali, Melkashola and Melkasalsa were evaluated in randomized complete block design with three replications during the rainy season under open field and under low cost plastic shelter, and in the off-season using irrigation. Varieties Miya, Metadel, ARP and Gelilema produced reasonably high yield of bigger size fruits with superior quality under low cost plastic shelter during the rainy season and hence can be further validated on farmers' fields with their active participation. Contrarily, varieties Chali, Gelelima, Metadel and Fetan produced high yield of good quality fruit that worth demonstration on farmers' fields in open fields in the dry (off) season using irrigation. Ther were no better variety than checks during rain-fed production in open fields.

Introduction

Tomatoes are the most widely cultivated and lucrative vegetables in Fogera, Dera and Libokmkem districts of South Gondar zone of Amhara region. With the expansion of irrigated farming, market-oriented tomato production has been expanding during the last few years, enabling various actor including growers, merchants, consumers, middlemen, transporters, to take part and benefit in the value chain of this important horticultural venture. Off season tomato production using irrigation is a common practice in Fogera, Dera and Libokemkem districts. It is however reiterated and observed that varieties commonly used are local and hybrid varieties with the exception of varieties cochoro and Roma VF. Growers lack information on the availabile many other improved varieties released from

Melkassa Agricultural Research Center (MARC). Seed of these varieties is further unavailable in the surrounding town or market.

On the other hand, tomato production in an open field during the rainy season was difficult mainly because of disease attack. Fentahun *et al*. (2009) underlined that tomatoes are not grown in the rainy season because of disease problems. According to Pandey *et al*. (2006) tomato production during rainy season in open field condition is very difficult and production during this season is very low in Nepal. Kirimi *et.al*. (2011) also reported fluctuations in the supply of tomatoes in the Kenyan market leading to market glut during off-season season and shortage during rainy season. Furthermore, Ayoola (2014) indicated that tomato production in Nigeria is done during the dry season while its production is scarce during the rainy season because of high disease incidence associated with growing tomatoes. Duncan *et al*. (2012) noted that rainy season brings a combination of high temperatures and humidity that favors development and spread of diseases and voracious insects in Southwest Asia.

Using integrated disease control measure including repeated fungicide spray, varieties Melkasalsa and Melkashola were found reasonably suitable for rainfed tomato production. Consequently, through the support from Fogera National Rice Research and Training Center (FNRRTC), farmers in Fogera, Dera and Libokmkem districts are giving due emphasis to rainfed tomato production in an open field for it fetches high return due to shortage of fresh tomato supply in the season. Fungicide application is critical for rain fed tomato production in an open field. Furthermore, the premium quality is not produced and the proportion of nonmarketable tomatoes is high. The use of low-cost plastic shelter is another option for rain fed tomato production by avoiding or minimizing fungicide application. Furthermore, Srinivasan (2011) showed that protective structures enable growers to produce tomatoes successfully during the off season, which enhances the availability of fresh produce at times when they are usually in short supply. Because prices are high during the off season, growers also enjoy higher return per unit area. Trials at Fogera using this low-cost rain shelter technology demonstrated the production of high yield per unit area with superior quality. Farmers have therefore reflected high demand on the use of low-cost plastic shelter for rainfed production.

Evaluation of tomato production under plastic shelter using varieties Malkasalsa and Melkashola indicated that overall performance of varieties under a plastic shelter is much better than in an open field. Varieties, however, did not consistently perform in a similar way in an open field and under rain shelter. A variety performed poor under plastic shelter performed best in an open field, and vice versa. However, these two varieties have less preference in the market for they have small fruit size. It was also observed that most fresh tomato types with bigger fruit size did not tolerate disease pressures under rainfed production condition in open fields. However, many of recently released tomato varieties from MARC were not evaluated at Fogera under different productions systems, viz. irrigated, rain fed and protected (low cost plastic shelter) production practices. Information is thus lacking on the performance of these varieties in the rainy season under low cost plastic shelter and in dry seasons using irrigation. This study was therefore conducted to evaluate the performance of released tomato varieties under different growing conditions (under plastic shelter and in an open field in the rainy season, and in an open field using irrigation in the dry season) with the aim of identifying superior varieties with high productivity and superior quality of tomato fruits.

Material and Methods

This experiment had three separate sub-activities; two of which were conducted in the rainy season under plastic shelter and in an open field while the third sub-activity was carried out in the dry season using irrigation.

Evaluation of varieties under low cost plastic shelter in the rainy season

Field experiments under plastic shelter were carried out at Fogera Research Center during the rainy seasons of 2018 and 2019. The Center is located at the south periphery of Woreta town of Fogera district of South Gondar Administrative zone in Amhara Region, Ethiopia. Woreta lies at 11° 58′ N latitude and 37° 41′ E longitude. It has an altitude of 1819 meter above sea level and receives an average annual rainfall of 1230 mm. Mean minimum and maximum temperature of the area is 12 and 28^0C, respectively. The soil is red clay (vertisol) rich in underground water.

Varieties and design

Seeds of eleven improved varieties of tomato were obtained from Melkassa Agricultural Research Center of the Ethiopian Institute of Agricultural Research. The varieties were Metadel, Miya, Cochoro, Gelilema, Fetan, Bishola, Eshet, ARP, Chali, Melkashola and Melkasalsa. These eleven varieties that includes the two checks, Melkashola and Melkasalsa, were evaluated in randomized complete block design with three replications. Total plot size used for each variety was 11.2 m^2 (2.8m x 4m) accommodating 28 plants in four rows while yield and other data were recorded from the effective plot size of 5.6m^2 (2.8m x 2m) which contained 14 plants in two central rows. Spacing between plants and rows were 0.4m and 1m, in that order. Walkways in between plots and replications were 1m and 1.5m, respectively.

Seedling care

Seedlings of each variety were raised on thoroughly prepared and 5 cm raised beds of 2m x 1m. Seeds were drilled in rows at ten cm inter-row spacing and it was covered lightly with fine soil and mulched with eucalyptus leaves until emergence. Seedlings were thinned at first true leaf stage to allow 2 to 3 cm distance within plants (intra-raw spacing). Seedlings were raised under white plastic cover to avoid rain contact with foliage of seedlings. Plastic cover was made at about 75 cm height from the surface of the seed bed. Watering using watering cans was made just on the soil surface caring to avoid moisture contact with seedling leaves. Weeding was done as necessary. Seedlings generally attained transplantable size in four weeks. Healthy, vigorous and uniform seedlings of pencil size were transplanted in the field. Replanting to replace dead or weak seedlings in field establishment was done a week after transplanting. Seed sowing and seedling transplanting dates in 2018 were on the 23rd of May and 25th of June, 2018, respectively.

Main field preparation and management

Experimental plot was thoroughly plowed and leveled. Ridges were prepared with 25 cm height from the furrow. Transplanting was done at a side of a ridge with 40 cm spacing between plants and 100 cm inter-row spacing.

Inorganic fertilizers in the form of Urea (46:0:0) (100kg/ha) and Nitrate phosphate sulfur (NPS) (19:38:7) (242kg/ha) were applied. NPS was applied at transplanting while urea is applied in two splits, the first at seedling establishment (1-2 weeks after transplanting) and the second one and half months after transplanting. Standard field management practices such as weeding and cultivation were performed uniformly during the growing seasons. Tomato plants were supported (staked) with wooden sticks and ropes immediately before flower initiation. These rainy season trials under plastic shelter were designed to water plots by diverting rain collected from the shelter into furrows of each plot. Plastic shelters at 1.5 meter height from the surface of plots were constructed with the support of wooden poles and sticks. These helped to avoid direct contact of rain with tomato stems and leaves.

Data collection and analysis

Seedling emergence, vigor and field establishment after transplanting were recorded. Field establishment is noted by counting seedlings that successfully resumed growth after transplanting. Vigor is recorded referring to stiffness of seedlings in a plot, one was recorded for plots with the weakest seedling while five refers to plots with very strong seedlings. Disease incidence data, plot cover, 50 per cent flowering and maturity were also collected. Visual judgment is made to record the proportion of the plot surface covered by tomato foliage. Number of days required from transplanting date to the day on which 50% of the plants in a plot flowered was recorded. Fruit yield was harvested at appropriate maturity time (when fruit color turns to yellow and red) and categorized as marketable and un-marketable fruits. Marketable fruits are those with average size and above, and are free from visible damages due to diseases, insects and physiological disorder. Marketable fruits were counted and weighed whereas unmarketable fruits were counted and sorted out based on their respective causes, i.e., diseases, insects, physiological disorder or undersized fruits. Finally, the collected data were subjected to analysis of variance using SAS software version 9.2 and least significance difference (LSD) was used to compare treatment means when statistically significant difference ($P<0.05$) is found.

Evaluation of varieties for open field production in the off-season using irrigation

In this irrigated open field off-season experiment, a total of eleven tomato varieties released from Melkassa were laid out in a randomized complete block design with three replications. The plot size used was 5m wide and 3m long (15m^2) with 1.5m and 1m spacing between replications and plots, respectively. Seedling care and main field management practices were carried as described above for tomato variety evaluation under low cost plastic shelter.

Data collection on plant basis for some important traits such as plant height, fruit length (cm), fruit size (cm) and number of fruits per plant was carried out from ten randomly selected plants while data on days to 50% flowering, days to harvest, major diseases, marketable fruit yield (kg/ha), number of marketable fruits, un-marketable yield (kg/ha), number of un- marketable fruits, and total fruit yield (kg/ha) was collected on plot basis. The collected data were subjected to analysis of variance (ANOVA) using SAS (SAS, 2008) version 9.1 Software, and means were compared using least significant difference (LSD).

Evaluation of varieties for rain-fed production in open fields

Varieties, plot size, seedling care, main field management, data collection technique and method of analysis used here is the same as described above for irrigated trial

Results and Discussion

Evaluation of varieties under low cost plastic shelter in the rainy season

Harvesting was made once in a week and 6 to 8 consecutive harvests were made from a plot. Variety Melkasalsa (10.03 t/ha) followed by ARP (6.351 t/ha) gave high marketable fruit yield for the first two harvests in 2019, whereas Melkashola and Melkasalsa are the highest yielding from the first two harvests of 2018. The highest total marketable fruit yield in 2019 was obtained from varieties Miya (60.512 t/ha) followed by Melkasalsa (59.274 t/ha) and Melkashola (47.735 t/ha). Melkasalsa followed by Melkashola, Miya and ARP are highest yielding varieties when considering total marketable tomato fruit yield in 2018 (Tables 1 and 2).

Percent highest total un-marketable fruit yield in 2019 ranged from 12.55 for variety Melkasalsa to 32.94 for variety Bishola (Table 1), where as in 2018 it varied from 20.92% for variety Melkashola to 36.45% for variety Fetan (Table 2).

Table 1. Marketable yield of subsequent weekly harvest in qt/ha in 2019 rainy season

Variety	Early 2 harvest	4 harvest	5 harvest	6 harvest (total yield)	% of un-marketable fruit
Metadel	53.06^{bc}	298.84^{cd}	381.22^{bc}	385.66^{bc}	19.74
Miya	55.12^{abc}	416.40^{ab}	586.31^{a}	605.12^{a}	13.97
Cochoro	37.99^{bc}	204.73^{def}	266.61^{cd}	269.76^{cde}	20.12
Gelilema	25.00^{bc}	190.42^{def}	327.69^{bcd}	338.49^{bcd}	20.06
Fetan	52.32^{bc}	272.08^{cd}	357.05^{bc}	359.52^{bcd}	16.23
Melkashola	48.01^{bc}	345.39^{bc}	469.88^{ab}	477.35^{ab}	15.86
Bishola	16.26^{c}	122.55^{f}	192.96^{d}	200.17^{de}	32.94
Eshet	24.32^{bc}	217.05^{def}	301.94^{cd}	306.52^{cde}	26.08
ARP	63.51^{ab}	247.35^{cde}	308.84^{cd}	311.25^{cde}	19.11
Melkasalsa	100.30^{a}	479.11^{a}	588.15^{a}	592.74^{a}	12.55
Chali	46.93^{bc}	153.3^{ef}	176.07^{d}	176.65^{e}	27.36
LSD0.05	47.15	117.52	160.51	161.52	10.85
CV %		25.75	26.2	25.93	31.27

Means followed with the same letter within a column are not statistically different at P<0.05

The highest fresh tomato fruit width in 2018 was recorded from varieties Eshet (5.98 cm) and ARP (5.65 cm) while the lowest tomato fruit width was recorded from varieties Melkasalsa (3.35cm) followed by Melkashola (3.38 cm) and Miya (3.99 cm) (Table 2.)

Table 2. Mean cumulative marketable yield of subsequent weekly harvest in quintal per hectare in 2018 rainy season

Variety	two harvests (week 2)	4 harvests (week 4)	6 harvests (week 6)	7 harvests (Total yield)	Fruit width (cm)	Yield plant^{-1} (kg)	% un-marketable yield
Melkasalsa	58.53^{a}	256.45^{a}	377.70^{a}	386.68^{a}	3.35^{f}	1.70^{a}	26.51
Melkashola	59.89^{a}	200.03^{abc}	359.84^{ab}	375.68^{ab}	3.38^{f}	1.60^{ab}	20.92
Miya	36.92^{abc}	157.89^{abcd}	285.06^{abc}	297.82^{abc}	3.99^{ef}	1.38^{abcd}	21.75
ARP	47.67^{ab}	227.23^{ab}	262.03^{abc}	264.58^{abc}	5.65^{ab}	1.19^{abcd}	25.55
Metadel	40.82^{abc}	162.89^{abcd}	235.45^{bc}	247.35^{abc}	5.40^{abc}	1.44^{abc}	29.38
Bishola	26.68^{abc}	96.68^{cd}	223.59^{bc}	242.92^{bc}	5.34^{abc}	1.32^{abcd}	32.81
Eshet	52.53^{ab}	154.38^{abcd}	211.15^{c}	227.54^{c}	5.98^{a}	1.13^{abcd}	35.71
Gelilema	12.32^{c}	68.12^{d}	170.56^{c}	195.79^{c}	4.26^{de}	0.92^{cd}	31.64
Chali	35.02^{abc}	129.23^{bcd}	188.02^{c}	194.77^{c}	4.53^{de}	1.03^{bcd}	23.75
Cochoro	22.69^{bc}	95.71^{cd}	151.39^{c}	161.24^{c}	4.82^{cd}	0.80^{d}	28.00
Fetan	40.61^{abc}	132.15^{bcd}	154.45^{c}	158.43^{c}	5.29^{bc}	0.77^{d}	36.45
LSD (0.05)	34.89	107.24	138.92	142.58	0.68	0.63	

Means followed with different letters within a column are statistically different at P<0.05

Over all combined yield of the two years showed the harvest of high total marketable fruit yield from Melkasalsa (49.59 t/ha) followed by Miya, Melkashola, Metdel, ARP and Gelilema. In addition to Melkashola and Melksalsa, potential fresh market tomato varieties suitable for production under low cost plastic shelter during the rainy season were therefore identified. Varieties Miya, Metadel, ARP and Gelilema are selected for further verification under low cost plastic shelter in the rainy season. These varieties had bigger fruit size than Melkasalsa and Melkashola which is a desirable attribute to fetch good market price.

Table 3. Combined marketable mean yield of 2018 and 2019

Variety	Week 2	Month 1	Month 2
Melkasalsa	56.825	336.425	495.9
Miya	80.095	339.57	484.21
Melkashola	42.465	251.64	387.585
Metadel	50.365	263.035	325.12
ARP	46.57	217.485	303.435
Gelilema	25.84	143.55	290.705
Eshet	58.02	200.865	269.395
Fetan	18.32	142.585	251.155
Bishola	36.505	166.98	232.265
Cochoro	19.475	109.13	180.705
Chali	43.77	142.725	167.54

Evaluation of varieties for open field production in the off-season using irrigation

The highest marketable fruit yield in 2019 dry season was obtained from Variety Chali (41.9 t/ha) while the lowest is from variety Bishola (23.3 t/ha). Percent non marketable yield on the other hand was high from variety Bishola (28.1%) and low for variety Melkasalsa (10.4%). This percentage non marketable fruit is lower than rainfed production both in open fields and under low cost plastic shelter mainly due to less disease pressure in dry season production.

Table 4. Mean marketable yield and related traits of tomato varieties in dry season of 2018

Variety	Mark. Yield (t/ha)	Total Mark. Yield (t/ha)	Fruit Length (mm)	Fruit Width (mm)	Fruit Weight (gm.)	% un-marketable yield
Melkasalsa	30	33.5	60.6	42.13	39.47	10.4
Eshet	33	40.4	55.07	53.27	93.67	18.3
Metadel	40.9	51.3	59.2	55.4	127.23	20.3
Melkashola	38.4	47.7	60.53	37.47	53.5	19.5
Miya	36.2	46	51.8	39.2	58.87	21.3
Gelelima	41.3	49.5	60.6	43.67	70.7	16.6
ARP	38.3	45.3	61.4	54.47	107.37	15.5
Bishola	23.3	32.4	56.6	58.27	123.8	28.1
Chali	41.9	49.7	57.67	45.2	68.57	15.7
Fetan	40.2	45.6	59.2	54.6	108.3	11.8
Chochero	36.3	48.1	61.4	57.47	111.78	24.5
Grand Mean	37.5	44.3	58.55	49.19	87.56	
CV	19.51	16.12	3.46	13.58	12.27	
LSD	11.9	12.2	3.45	11.38	18.28	
P level	*	*	**	**	**	

Evaluation of varieties for rain-fed production in open fields

In this open field tomato production during the rainy season, Melkashola (check) produced the highest marketable tomato yield (21.5 t/ha) in 2018. Percent un-marketable yield is very high for variety Metadel (52.58 %).

All varieties evaluated in an open field in 2019 rainy season produced lower yield than the checks (Melkasalsa and Melkashola) (Table 6). It is therefore confirmed that among released varieties, Melkasalsa and Melkashola are the only suitable varieties for rainfed production in open fields. Dessie (2015) also showed that Melkasalsa and Melkashola were the highest yielding cultivars suitable for open field rain-fed tomato production at Woreta and further reported that un-marketable fruit number due to diseases, insects and physiological disorder ranged from 20.3 to 72.9 percent. Reducing this significant yield loss through the use of multiple disease and insect controlling strategies such as cultural, mechanical, biological and chemical methods could further improve profitability of open field tomato production in the rainy season. The use of disease resistant/ tolerant cultivars is a priority, although other components of integrated pest management practices including fungicide application are critical for rain-fed tomato production in the open field. Greenwald (2013) underlined the importance of multiple strategies to limit development and spread of diseases in an open field rainfed tomato production. These may include growing resistant cultivars, conduct regular disease scouting, monitoring favorable environmental conditions for disease, remove nearby weeds and discard live weed plant material in the Nightshade family, use preventive fungicide applications, immediate removal of diseased plant material at first sign and burn or burry, and discard harvested fruit from infected plants.

Table 5. Mean marketable yield and related traits of tomato varieties under rainfed growing conditions of 2018

Variety	Mark. Yield (t/ha)	Fruit Width (mm)	Fruit Length (mm)	% marketable yield	% of un-marketable yield
Metadel	10.1	51.1	41.7	47.42	52.58
Miya	12	37.7	41.6	70.46	29.54
Chochero	5.2	42.5	42.9	58.19	41.81
Gelelima	9.6	34.7	43.4	52.52	47.48
Fetan	4.9	36.1	43.2	57.94	42.06
Melkashola	21.5	31.7	50.7	69.88	30.12
Melkasalsa	8.2	46.6	45.1	63.94	36.06
ARP	7.4	43.7	44.3	70.14	29.86
Eshet	19.1	28.2	52.9	71.89	28.11
Bishola	7.9	46.4	41.7	59.94	40.06
Chali	8.4	36.6	47.3	51.44	48.56
Mean	10.4	40	45		
CV	29.67	15.41	9.44		
LSD (0.05)	5.25	10.4	7.23		
	**	*	**		

Table 6. Mean marketable yield and related traits of tomato varieties under rain fed growing conditions of 2019

Variety	Marketable yield (t/ha)	Fruit length (mm)	Fruit width (mm)	% marketable yield	% un-marketable yield
Metadel	29.00	55.67	56.67	64.11	35.89
Chochero	23.67	52.17	50.47	71.06	28.94
ARPTomato d2	29.00	56.27	54.73	66.14	33.86
Eshet	27.33	51.33	55.33	65.89	34.11
Fetan	36.00	56.40	57.07	73.48	26.52
Bishola	23.00	59.67	54.00	61.68	38.32
Chali	16.67	54.17	47.25	73.54	26.46
Miya	30.00	51.33	52.07	71.26	28.74
Gelelima	11.00	57.60	44.73	62.22	37.78
Melkasalsa	41.33	60.40	37.27	77.68	22.32
Melkasholla	40.67	58.93	41.33	75.16	24.84
Mersa	19.33	71.20	34.13		
Woyno	15.00	44.00	46.53		
Grand Mean	26.35	65.09	48.50		
CV	39.07	6.43	8.66		
	17.91	6.07	7.09		
LSD(a=0.05)	*	**	**		

Conclusion and Recommendation

Melkasalsa, Miya, Melkashola, Metadel, ARP and Gelilema were the best, in that order, yielding varieties under low cost plastic shelter during the rainy season. Overall marketable fresh tomatoes produced under plastic shelter were found to be high with best quality free from visible damages due to diseases, insects and physiological disorders enabling growers to fetching good market price. Tomato production during the rainy season under plastic shelter enables growers to produce fungicide free fresh tomatoes that are healthy for human consumption. Environmentally friendly production practices by protecting also from other unexpected natural incidences such as hail and strong wind and rainfall are also among other advantages of this technology.

Varieties Miya, Metadel ARP and Gelilema have bigger fruit size than varieties Melkasalsa and Melkashola. It is therefore recommended to further demonstrate these varieties since big sized fresh tomato fruit is preferred in the market and would fetch high price.

Similarly, for open field irrigated production, varieties Chali, Gelelima, Metadel and Fetan are worth demonstrating on farmers' fields. However, for rain fed production in open fields, the performance of all other varieties except the checks (Melkasalsa and Melkashola) was found poor; and hence Melkasalsa and Melkashola are still the only varieties suitable for open field rain-fed production.

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Effect of Plant Population on Carrot (*Daucus carota* var. sativa) Seed Yield and Quality in Arsi Zone, Ethiopia

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Abstract

Development of appropriate recommendation on plant spacing is one of the important agronomic practices that will help improve the productivity and quality of carrot seed. A field experiment was conducted at *Kulumsa Agricultural Research Center under irrigated condition during 2018 and 2019 to assess the response of carrot variety AU-108 (Haramaya 1) to different inter-row spacing. Three inter-rows spacing of 50, 75 and 100 cm were tested using 50 cm intra-row spacing. The experiment was carried out in a randomized complete block design (RCBD) with four replications. Results of this study revealed the significant effects ($p<0.05$) of inter-row spacing on most of measured parameters except days to 50% flowering, number of primary branches per plant, seed yield per primary umbel and seed yield per plant. Accordingly, the highest umbel size (diameter) of 9.309cm, number of seed per umbel (2612.4), seed yield per plant (94.21g), seed yield per hectare (1574.1 kg) and 1000 seed weight (91.83g) were obtained at 75 cm inter-row spacing followed by 50 cm inter-row spacing. Seed yield was observed to decline with increased spacing beyond 75 cm inter-row spacing. Seed yield per plant significantly (r = 0.5206*) correlated with number of branches per plant, umbel diameter (r = 0.59268*), number of umbels per plant (r = 0.576*), number of seed per plant (r = 0.3278*) and thousand seed weight (r = 0.6454*). Thus, 75cm x 50cm, planting density of 26 666 stecklings or plants per hectare (equivalent to 3 plants m^2), is found to be an optimum inter-row spacing to produce high seed yield and quality from carrot variety AU-108 (Haramaya 1). Hence, this spacing combination is recommended for Kulumsa and similar agro-ecologies in the country.*

Introduction

Carrot (*Daucuscarota L. ssp.sativus (Hoffm.) is* originated in Europe and Southwestern Asia (Banga, 1984). China, USA, Uzbekistan, Russia, Japan, France and United Kingdom are major producing countries in the world (FAO, 2018). In Ethiopia, Carrot is produced in a wide range of agro-ecologies from the lowlands to the highlands. Carrot seed production is a recently introduced practice in the country and it is becoming popular among producers for seed source and cash income. The area and production of carrot seed has increased during the last decades. Similarly, seed yield and percent of germination of seeds produced from domestic seeds found to be slightly higher than imported seeds (Lemma, 1998 and Dawit *et al.*, 2004).

Carrot is grown from true seeds and its successful production is dependent upon a sustainable and satisfactory supply of good quality seed (McDonald and Copeland, 1998; Lemma, 1998). Studies have shown the presence of places that have optimum temperatures for carrot seed production in Ethiopia (Dawit *et al.*, 2004). These places are located in cool highland of Oromia, Amhara and SNNPR of Ethiopia (Fantahun *et. al.*, 2003). Due to small scale production and low quality of carrot seed produced in Ethiopia, a large quantity of the seed in the market is imported from other countries.

The small seed production and poor quality can be attributed to lack of optimum seed production technology of vegetable crops, starting from planting time through harvesting and their postharvest treatment (Ziaf *et al.*, 2017). Thus, to improve the production and productivity of carrot domestically, the availability of quality seed is crucial (Dawit *et al.*, 2004). Production of good quality carrot seed is highly affected by various factors amongst which optimum planting density worth mention. Optimum spacing between plants has significant effect on the yield and quality of carrot seed (Kumar *et al.*, 2017) since optimum plant spacing is of prime factor for proliferated biomass production and nutritional availability to plants and the seed (Horbe *et al.*, 2016, Kang *et al.*, 2015). Besides, it helps to avoid shading effect on plants and competition for soil moisture, nutrient elements, light and water (Chhetri *et al.*, 2019). Carrot seed production technology is barely available in the country. Hence, this study was conducted to find out the most suitable inter-row spacing for production of high yield and good quality carrot seed for Arsi highlands of Ethiopia.

Materials and Methods

Description of the study area

The experiment was conducted at Kulumsa Agricultural Research Center (KARC) in 2018 and 2019 under irrigation. KARC is located at 8°00' to 8^{o}02' N and 39°07' to 39°10' E and an altitude of 2210m a.s.l. in Oromia, Ethiopia. The agro- climatic condition of the area is wet with 811mm mean annual rain fall which is a uni- modal rainfall pattern with extended rainy season from March to September. However, the peak rainy season is from July to August. The mean annual maximum and minimum temperatures are 23.1 and 9.9°C, respectively. The coldest month is December whereas; May is the hottest month (Abayneh *et al.*, 2003).

Experimental planting material and field management

The study was conducted using one of the renowned open pollinated carrot variety known by the name Haramaya 1 or AUA-108, which was released by Haramaya University in 2014. The common practiced method of root-to-seed was used for the study (Organic Seed Alliance, 2018). Carrot seeds were sown in June to produce mature roots ("stecklings") on well prepared seed beds in the nursery at a rate of 6 kg/ha. Stecklings were harvested in early September and the best roots of the variety were selected and then transplanted into a seed production experimental field in mid-September to expose plants to low temperature between October and November. The stecklings were irrigated every 2-3 days to avoid water lose and wilting for good seed crop establishment. Depending on the establishment and growth of plants as well as weather conditions subsequent irrigation water applied at an intervals 5 days. Weeding was practiced by hoeing and hand weeding whenever necessary until the crop covered the ground completely. About 175 kg DAP ha^{-1} at transplanting was applied as recommended for fresh root production and Urea (100 $kgha^{-1}$) was top dressed to enhance vegetative growth.

Harvesting of the carrot seeds started when the umbel turned into dark brown color. The matured umbels were harvested from each plot at different time as carrots have distinct order of flowering and maturity depending on umbel position. The king or primary umbel is the first to flower and ripen followed by secondary and tertiary umbels. Umbels were kept under partial sun and seeds were extracted by hand threshing and winnowing. The seeds were then dried, cleaned very carefully, and weighed for different data purpose.

Treatments and experimental Design

The experiment was conducted using three inter- row spacing (100cm×50cm; 75cm×50cm; 50cm×50 cm) and was laid out in a Randomized completely block design(RCBD) with four replications. The gross plot size was $12m^2$ (3m x 4m), each planted with different number of stecklings (24, 32 and 48 per plot) depending on the three inter-row spacing treatments that corresponded to three population densities of 20 000, 26 666 and 40 000 plants per hectare, respectively.

Data collection

Data were collected from the middle rows of the experimental plots and five randomly selected plants. Days to 50% flowering, days to fruit set, plant height (cm), number of primary umbels per plant, number of primary branch per plant, primary umbel diameter (cm), number of seed per primary branch, **s**eed yield of primary umbels (g), seed yield per plant (g), seed yield per hectare (kg), thousand seed weight (g) were data were collected.

Data analysis

The collected data were subjected to Analysis of Variance (ANOVA) using statistical analysis Software (SAS ve2rsion 9.2, 2009). The mean separation was done using (LSD) test at 5% probability level and simple correlation analysis was carried to determine the association among traits by using Pearson correlation methods.

Results and Discussion

Phenology and Growth parameters

Days to 50% flowering and head set

Plant population had no significant (p>0.05) effect on days to flowering and fruit set and hence, days to flowering and head set at closer spacing (high plant density) was not significantly different from that planted at wider spacing (low plant density) (Table 1). However, a decreasing trend was observed in days to flowering and fruit set with decreased planting density. This could be due to the effect of competition among plants for some growth factors, such as nutrients, moisture, light etc. Hence, decreasing planting density appeared to shorten days to flowering and head set. Accordingly, plants at low density (100cm x 50cm) were observed to set seed few days earlier than plants at high planting density (50cm x 50cm). Significant differences between years on some of the traits was also observed visibly due to differences in weather conditions between the years. This finding contradicts with the reports of George (1999) who suggested that higher plant densities could shorten the overall flowering period and increased the evenness in umbel ripening. This may be due to the fact that higher plant densities considerably reduce the development of higher order umbels, letting a concentration of umbels to be produced in the upper part of individual plant stalk.

Plant height (cm)

Plant height of carrot significantly affected (P<0.05) by inter-spacing. Maximum plant height 149.26 cm was recorded from the crop planted at an inter-row spacing of 100 cm x 50 cm followed by 75cm x 50 cm, while the shortest plant height was recorded from 50 cm 50 cm. The year also had highly significant influences on the carrot plant height (Table 1). The highest plant height might be due to the availability of free access of environmental resources (water, nutrient and light) for the plants in the wider plants. Anam *et al.,* (2020) also reported a similar significant of effect spacing on plant height of carrot plants.

Number of primary branch per plant

Number of primary branch per plant was not significantly (P>0.05) affected by inter-row spacing. The highest mean was recorded from the wider spacing (100 cm x 50cm) as compared to the narrower spacing (50 cm x 50 cm). In widely spaced plants the number of branches per plant increased more than closely spaced ones. This might be due to reduced competition for space, nutrients, light and air between the plants among widely spaced plants. Earlier reports by Mengistu and Yamoah (2010) showed that, plants at lower population density produced the highest number of secondary and tertiary umbels (7 and 10, respectively) and their number decreased with increasing plant density. In the present study, the highest number of primary branch/plant (8.981) was recorded at lower population density of 100cm x 75cm (20 000 plants/ha), and it tended to decrease to 8.475 and then to 6.625 as plant population increased to 75cm x 50cm (25 000 plants/ha) and 50cm x 50cm (48 000 plants/ha), respectively. This could be related to the number of branches extending from the main stalk and the primary branches, at the terminus of which umbels of the respective orders may be formed. The non-significant effect of spacing on number of primary branches per plant could be due to the fact that planting densities used in the study might be below the level to create significant differences. Norman (1992) reported that increasing plant density does not affect individual plants if the plant density is below the level at which competition occurs between plants.

Number of Umbel on Primary branch per plant

The mean number of umbel on primary branch was significantly ($P<0.05$) influenced by inter- row spacing. The maximum number of umbels per plant on primary branch was recorded at wider spacing 100 cm x 50 cm (19.45) which was statistically at par with 75 cm x 50 cm spacing. The combined data of both 2018 and 2019 years, minimum number of umbel (12.55) was recorded from spacing of 50cm x 50 cm (Table 1). There was an increasing trend in the number of primary umbels per plant when plant populations decreased in given area. Ahmad and Tanki (1997) observed at a spacing of 60cm x 60 cm which produced more number of umbels, higher umbel weight and better umbel size.

Umbel diameter on primary branch

Inter-row spacing significantly (P<0.05) influenced the diameter of primary umbels. The highest mean of primary umbel diameter (9.309) was recorded for plants that were grown at 75cm × 50 cm row spacing followed by 100 × 50 cm (9.251cm) which were statistically similar with the former. The lowest umbel diameter (7.983cm) was obtained from 50cm x 50cm which was significantly different from others treatments (Table 1). At wider spacing (low population density), plants have minimal competition among them for the available resources that could affect growth, development and ultimately the yield, in this case umbel size. The larger the umbel size (diameter), the higher the chance it contains more number of seeds in it and increase yield. Mazumder *et al*. (2007) stated that plants grown under optimum population density per unit area provides optimum conditions for luxuriant crop growth and better plant canopy area due to maximum light interception, photosynthetic activity, assimilation and accumulation of more photosynthates into plant system and hence more seed yield with best quality traits.

Seed yield and yield components

Number of seed per primary branch

The number of seeds per primary branch was significantly (*P*<0.05) affected by the inter-row spacing. The highest number of seeds per primary branch (2612.4) was recorded for plants that were grown at 75 × 50 cm (2571.6) row spacing followed by 50cm × 50cm (2133.3) spacing (Table 2). This result is partly positively correlated with what was obtained in umbel size already discussed above (Table 1). The wider the spacing the bigger the umbel size and the highest the number of seeds per umbel. Increased plant densities also decrease the number of umbels and quantity of seed produced per plant and generally yield increases with increasing densities (Evans, 2000; Ramnut & Thakan, 2002).

Seed yield per primary Umbel (g)

In carrot, umbels of different orders vary in number, size and seed weight. Seed weight depends upon the umbel order; for the primary umbel, there was a non-significant difference (p<0.05) in seed yield between the row spacing, while the mean pooled yield of the two years showed significant difference. Regardless of the non-significant seed yield differences between the spacing treatments, the highest seed yield per umbel (5.45g) was obtained from 75cm x 50cm spacing followed by 100cm x 50cm (4.9238g) and 50cm x 50cm (4.7075g). Likewise, this result correlates positively with that of umbel size (Table 1) and number of seed per umbel (Table 2). The results indicated that, the maximum seed weight per umbel was obtained in the primary umbels, which is significantly different from secondary and tertiary umbels. The tertiary umbels resulted in lower seed weight, which may be due to their smaller size and less time available to develop (Muhammad and Muhammad, 2002).

Seed yield per plant (g)

Seed yield per plant did not significantly (P<0.05) differed between row spacings. Nevertheless, the highest mean seed yield per plant (94.21 g) was recorded from plants at 75cm x 50cm followed by 82.3g (50cm x 50cm) and 80.94g (100cm x 50cm). Similar results were reported by Mengistu and Yamouh (2010) who reported increased seed weight per umbel with increased plant spacing. This could be due to less effect of competition among plants for growth resources, and also Muhammad and Muhammad (2002) explained the increased seed yield per plant with increasing plant-to-plant distance. However, the planting densities tested in the present study did not create competition to the level needed to affect seed yield per plant. Norman (1992) reported that increasing plant density does not affect individual plants if the plant density is below the level at which competition occurs between plants.

Table 1: Effects of inter-row spacing on phenology and growth parameters of carrot for seed production at Kulumsa, during 2018 to 2019 at irrigation condition

Treatments/ Inter-row spacing	Days to 50% flowering	Days to fruit setting	Plant height, cm	Number of primary branch per plant	Number of umbel on primary branch per plant	Umbel diameter, cm
			Inter-row spacing			
50 cm × 50 cm	65.83a	94.33a	128.77b	6.625	12.55b	7.983b
75cm × 50 cm	66.80a	91.45b	147.55a	8. 475	16.65ab	9.309a
100 cm× 50cm	64.00a	91.58b	149.26a	8. 981	19.45a	9.251a
Mean	65.543	92.453	141.86	6.625	16.217	8.847
LSD	3.00	1.7	13.483	3.1716	4.549	0.8186
CV (%)	11.20	3.60	9.22	37.45	26.59	8.77
Significance	**ns**	*	*	**ns**	*	**
			Year			
2018	66.083	92.9167	117.512b	10.854a	20.267a	9.7625a
2019	65.45	93.00	159.545a	5.2b	12.167b	7.933b
Mean	65.7665	92.9584	138.5285	8.027	16.217	8.84775
LSD	3.0666	2.006	11.009	2.5896	3.7143	0.6684
CV (%)	11.33	1.705	9.226397	37.45513	26.5916	8.770914
Significance	**Ns**	**Ns**	**	**	**	*

Means in the same column followed by the same letters are not significantly different at 5% level of significance according to LSD test ns=non-significant, LSD (5%)= Least significant difference at P=0.05, CV=Coefficient of variation in percent,. *=significance level.

Table 2: Effects of inter-row spacing on yield and yield attributes of carrot for seed production at Kulumsa, during 2018 to 2019 at irrigation condition

Treatment (Inter-row Spacing)	Number of seed per primary branch	Seed yield per primary Umbel (g)	Seed yield per plant(g)	Seed yield kg/ha	1000 seed weight (g)
		Inter-row Spacing			
50 cm × 50 cm	2571.60**a**	4.70	82.3	1511.20**a**	1.74
75cm × 50cm	2612.40**a**	5.45	94.21	1574.10**a**	1.83
100cm× 50 cm	2133.3**b**	4.93	80.94	1082.80**b**	1.745
Mean	2439.10	5.03	85.82	1389.37	1.77
LSD	390.14	1.34	24.06	491.3	0.19
CV (%)	15.16	25.17	26.57	29.44	10.67
Significance	*	**Ns**	**Ns**	*	**ns**
		Year			
2018	2437.30	5.76a	79.56	1653.30**a**	1.80
2019	2440.80	4.30**a**	92.07	1081.50**b**	1.73
Mean	2439.05	5.027	85.82	1387.40	1.76
LSD	318.55	1.09	19.65	339.97	0.16
CV (%)	15.16	25.17	26.57	29.35	10.67
Significance	**Ns**	*	**ns**	*	**ns**

Means in the same column followed by the same letters are not significantly different at 5% level of significance according to Duncan's Multiple Range Test. ns=non-significant, LSD (5%)=Least significant difference at P=0.05, CV=Coefficient of variation in percent,. *=significance level.

Seed yield per hectare (kg/ha)

Inter- row spacing significantly affected the seed yield per hectare ($p<0.05$). The maximum mean seed yield per hectare of 1574.1 kg was recorded from row spacing of 75cm x 50cm followed by 50cm x 50cm spacing that gave a seed yield of 1511.2 kg, and 100cm x 50cm spacing that gave 1082.8kg. The overall mean seed yield was 1389.36 kgha^{-1}. The seed yield obtained from the current study is much higher than what was reported by George (2009). According to George (2009), seed yield of open-pollinated cultivars is about 600 kg ha^{-1} in temperate zone. However, in tropical regions, the European cultivars yield about 300 kg ha^{-1} whereas Asian cultivars produce only about 250 kg ha^{-1}. The greater the plant density, the higher will be the carrot seed yield but poor seed quality (Noland *et al*., 1988). Mazumder *et al.* (2007) stated that plants grown under optimum population density per unit area provides optimum conditions for luxuriant crop growth and better plant canopy area due to maximum light interception, photosynthetic activity, assimilation and accumulation of more photosynthates into plant system and hence produce more seed yield.

Thousands seed weight (g)

Thousand seed weight (TSW) was not affected by inter-row spacing (p>0.05). However, the maximum TSW (1.83g) was recorded from 75cm x 50cm spacing while the minimum (1.736g) was from 50cm x 50cm with mean value of 1.7703g. Similarly, increasing planting density considerably reduced the mean seed weight per umbel of each order (Mengistu and Yamoah, 2010), which could be due to the decreasing number of seeds/umbel and umbel size with increasing planting density.

Correlation analysis

The correlation analysis showed that seed yield per hectare was positively correlated with most of the plant characters. Accordingly, positive and statistically highly significant correlation were noted with number of primary branch per plant (r = 0.521**), thousand seed weight (r = 0.645**) and positively significantly correlated with seed yield per plant (r = 0.161*), plant height (r = 0.100*) and umbel diameter (r = -0.144), number of umbels per primary branch (r= -0.4108) and number of seed per umbel (r = -0.012). Seed yield per plant was positively and statistically significantly correlation with number of primary branch per plant (r = 0.437*), umbel diameter on primary per plant (r = 0.593**) and number of seed per plant (r = 0.328*). The present result was similar with El-Adgham *et al*. (1995) who reported the significant correlation of seed yield/plant with the number of second order umbels and also with the total number of umbels/plant. On the other hand, seed yield per hectare was negatively associated with days to 50% flowering (r = -0.48840*), suggesting that delaying planting of carrot negatively affect the flowering characters and ultimately resulted in reduced seeding potential of umbels (Table 3).

Table 3: Simple correlation coefficients among different parameters of carrot seed production

	DF	DFS	SYPU	SYP	SYha	TSWt	PH	NPUP	NPBP	UDP	NSP
DF	1	0.379*	0.158	-0.167	-0.488*	0.178	-0.477*	0.294*	-0.104	0.240*	-0.238*
DFS		1	-0.011	-0.095	0.066	0.128	-0.615**	0.298*	0.013	0.032	-0.002
SYPU			1	0.184	-0.009	0.167	-0.098	-0.366*	0.006	0.319*	0.226*
SYP				1	0.160	-0.234*	0.262*	0.189	0.437**	0.593**	0.328*
SYha					1	0.645**	0.100	-0.411*	0.521**	-0.144	-0.012
TSWt						1	-0.290	0.027	-0.449	0.325*	0.0189
PH							1	0.126*	0.211*	0.019	0.237*
NPUP								1	0.175	0.169*	0.168*
NPBP									1	0.355*	0.520**
UDP										1	0.406*
NSP											1

Pearson Correlation Coefficients, N = 12 Prob > |r| under H0: Rho=0

DF=Days to 50% flowering, DFS= Days to fruit set, SYPU= seed yield per primary umbel, SYP= seed yield per plant, SYha= seed yield per hectare, TSWt =Thousand seed weight, PH= plant height, NPUP= Number of Primary Umbel per plant, NPBP= Number of primary branch per plant, UDP= Umbel diameter (on primary branch), NSP= Number of seed per primary branch: * = Correlation is significant at the 0.05 level: ** = Correlation is significant at the 0.01 level.

Conclusion and Recommendation

Carrot is grown from true seeds and its successful production depends upon a sustainable and satisfactory supply of good quality seed. The current study was undertaken to investigate the influence of inter-row spacing on seed yield and quality of carrot seed. Results of the study indicated that inter-row spacing had significant influence on seed yield components of carrot. Number of harvested umbels per plant was higher in wider spacing than the closer spacing, which seems to be mainly due to less competition for nutrition and light. This less competition might have resulted in more branching, ultimately production of more umbels per plant. Wider spacing (75cm x 50 cm) resulted in higher umbels per plant, greater mass and size of umbel in carrot crop. This increased production of seed per plant may be due to well establishment of the plant which in turn resulted in production of maximum umbels per plant. As spacing increased the number of umbel per plant decreased and resulted in yield reduction on wider spacing than narrow spacing. Nevertheless, inter-row spacing did not influence the number of primary branch per plant, seed yield per plant, seed yield per primary umbel and thousand seed weight. Generally, the results of this study depicted that higher plant density (narrow spacing) greatly affected plant growth and consequently affected final seed yield of carrot plant. In conclusion planting carrot variety Haramaya 1(AUA-108) at spacing of 75cm (inter-row) by 50cm (intra-row) spacing would be optimum for a higher yield and good quality carrot seed for Kulumsa area and similar agro-ecologies in the country, if used root-to-seed method.

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Effect of Planting Density on Yield and Yield Components of Lettuce (*Lactuca sativa* L.) at Two Agro-Ecologies of Ethiopia

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Abstract

Use of optimum plant spacing (planting density) is one of the important agronomic practices that will help to maximize the productivity of lettuce. A field experiment was conducted to assess the responses of two lettuce varieties to different plant spacing at Debre Zeit and Holetta Agricultural Research Centers representing two different agro-ecologies in Ethiopia in 2019. Nine treatment combinations of three levels of inter-row and three levels of intra-row spacing were studied in a randomized complete block design (RCBD) with three replications in a factorial experiment. The results revealed that marketable and total fresh leaf yield, and fresh leaf weight per plant were significantly affected by the main effect of plant spacing and variety as well as their interaction ($p<0.05$). Increasing planting density increased the total fresh leaf yield per unit area in both varieties, however reduced the fresh leaf weight per plant. The highest fresh leaf yield was obtained at a spacing combination of 40 cm x 20 cm (125 000 plants ha^{-1}) from variety Great Lakes, while variety Rsk-3 gave highest fresh leaf yield at the highest planting density of 30 cm x 20 cm (166 667 plants ha^{-1}). Great Lakes was superior over Rsk-3 in most yield parameters studied though Rsk-3 was better in leaf dry weight percent. Besides, both varieties responded differently in both sites. Great Lakes performed better at Debre Zeit than at Holetta while Rsk-3 did well at Holetta than at Debrezeit. Hence, 40 cm x 20 cm and 30 cm x 20 cm could be used as the optimum plant spacing to grow Great Lakes and Rsk-3, respectively in the respective agro-ecologies.

Introduction

Lettuce (*Lactuca sativa* L.*)* is one of the most popular vegetable crops which occupies the largest production area among salad crops in the world. It is produced commercially in many countries and also widely grown as a vegetable in home gardens (Kristkova *et al*., 2008). Lettuce is an important dietary vegetable, which is primarily consumed fresh in salads. Consumption of lettuce has some health benefits attributed to the presence of vitamin C, phenolic compounds, and fiber content (Vanisree *et al*., 2010). It is also rich in vitamin A and minerals like calcium and iron and also contains protein, and carbohydrate (MRC, 1954). Lettuce can grow in a variety of soil types and climatic conditions, usually likes temperature between 23 °C during the day and 7 °C at night and grows within altitude range of 1800 to 2100 masl. It is best grown in silt loams and sandy soils as these soil types provide better drainage and warm up more readily during the day, which is especially important during cooler periods of the growing season (Kristkova *et al*., 2008).

World production of lettuce has grown significantly for the past decade. In 2018 alone about 27.3 million metric tons of lettuce was harvested from 1.27 million hectare of land (FAO, 2020). In Ethiopia Lettuce is among the widely grown vegetable crops. In the 'Meher' (or rainy season) of 2018 it was grown on 244.92 ha of land and produced 2163.35 quintals by 41 963 households (CSA, 2018). In Ethiopia, however data are not readily available for lettuce off-season production, although it is usually grown using irrigation in the dry season and, hence the quantity of production as well as the area coverage could certainly be higher than what was reported above. The average productivity of lettuce in Ethiopia, however is very low as compared to that of the world's average (CSA, 2018).

Plant spacing for lettuce cultivation is an important factor for attaining maximum vegetative growth and yield. Optimum plant spacing guarantees plants to grow uniformly and properly through efficient utilization of moisture, nutrients and light which resulted in maximum yield of lettuce; and makes the intercultural operations easier (Firoz *et al*., 2009). It helps to increase the number of leaves, branches and healthy foliage. Densely planted crop obstruct proper growth and development of plants while wider spacing ensures the basic nutritional requirements but decrease the total number of plants as well as total yield. Yield may be increased for any crop up to 25% by using optimum spacing mainly in leafy vegetables such as lettuce (Bansal *et al*., 1995).

Currently different lettuce cultivars are under production with different morphological characteristics such as head size, compactness, leaf color, and growth habits requiring different plant spacing. However, information on optimum planting density has been one of the bottle necks which limits lettuce production particularly for the newly released variety. In Ethiopia lettuce is usually grown by small holders where they cultivate few commercial and locally available varieties using their own traditional practices. This influences the crop performance and consequently the productivity and quality of the produce. A recent study conducted on the effect of plant spacing on growth and yield of the only lettuce variety 'Tesfa Mekele' in Northern Ethiopia found that spacing affected biomass yield and related parameters; and recommended a wider spacing of 60 cm x 40 cm (4 plants m^2) for this particular variety (Beyenesh *et al*., 2017). Nevertheless, this recommendation cannot be confidently used for the recent and widely grown varieties with varying architecture and for different growing regions as soil fertility gradient does also determine the number plant densities it holds. Hence, further investigation is critical. The present study was therefore initiated with the objective of assessing the effect of different intra and inter-row spacing on growth and yield of two lettuce varieties in two agro-ecologies in Ethiopia.

Materials and Methods

Description of study area

The present study was conducted at Debre Zeit and Holetta Agricultural Research Centers representing two different agro-ecologies in the Central and West Showa of the Oromia Regional States, respectively in Ethiopia. The agro-ecological characteristics of the two experimental sites are described (Table 1).

Table 1. Agro-ecological data of Debrezeit and Holeta Agricultural Research Centers

Sites	Geographical coordinates	AGZs	Altitude (masl)	Temperature (min/max)	Annual average rainfall	Soil types
Debrezeit	08 ° 44 ' N and 38 ° 58 ' E	Tepid to cool sub-moist highlands	1900	8.9 °C/ 28.3 °C	851 mm	Alfisols/ Mollisols and Vertisols
Holeta	9 º 00 ' N and 38 º 30' E	Tepid to cool moist mountains and plateau	2400	6 ºC/ 22 ºC	1144 mm	Nitosols and Vertisols

Source: MoA (1998); AGZs = Agro-ecological zones

Experimental plant material

The study was conducted on two lettuce varieties (Great Lakes and Rsk-3).The varieties were selected for this study based on their domination in the production system particularly Great Lakes and their differences in morphological traits, i.e, head size, compactness and nature of growth habits. Great Lakes is a very popular head lettuce commercially available in the markets and widely grown by farmers. Its crispy head has the perfect crunch that makes it perfect for garnishing sandwiches (Compositdb, 2006) (Figure 1A). Rsk-3 (Red lettuce) was introduced from Korea and was registered recently in Ethiopia. It is red lettuce and open head growing type with high mineral content and rich in vitamin A, and suitable for continuous piece meal harvests (Zebenay *et al*., 2019) (Figure 1B).

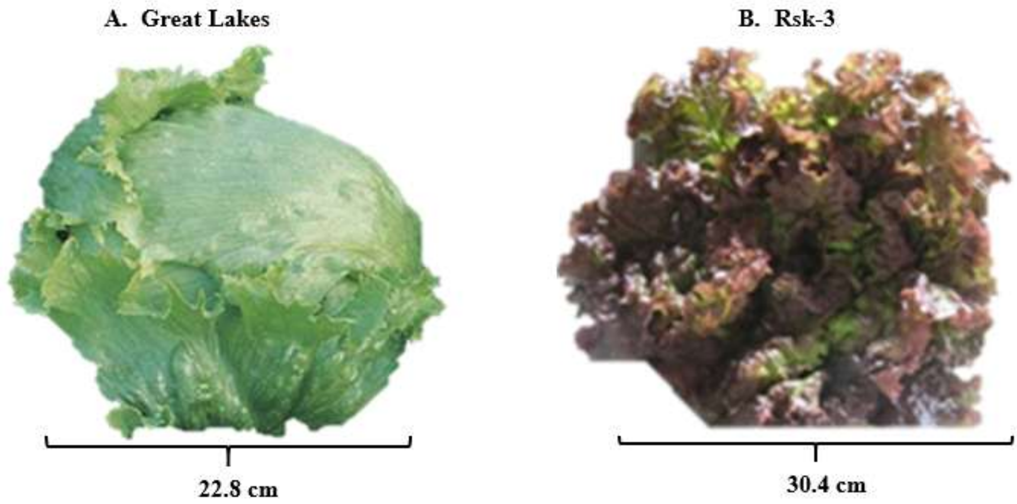

Figure 1. Photos showing the two lettuce varieties (**A. Great Lakes and B. Rsk-3**)

Experimental Procedures

Design and treatment randomization

Nine treatments made by factorial combination of three levels of inter (30, 40 and 50 cm) and three levels of intra-row spacing (20, 30 and 40 cm) were studied on the aforementioned two lettuce varieties. The treatments were laid out in a Randomized Complete Block Design (RCBD) with factorial arrangement in three replications.

Field management

Seedlings were raised on seed beds at a seed rate of 0.2 kg ha^{-1} and transplanted to the experimental plots size of 3.6 m^2 (2 m x 1.8 m) at 3 to 4 weeks after sowing. Seedlings were transplanted based on the spacing treatments to attain different planting densities (50 000, 62 500, 66 667, 83 333, 100 000, 111 111, 12 5000 and 166 000 plants ha^{-1}). Plots were uniformly irrigated every 2to 3 days after transplanting and soil moisture was kept at field capacity to avoid transplanting shock and irrigation continued at weekly interval until harvest. All plots were fertilized with 100 kg of DAP ha^{-1} at transplanting and 180 kg ha^{-1} of Urea in splits; half at transplanting and the rest half three weeks after transplanting. Other agronomic practices including weeding, cultivation, pesticide application were applied uniformly to all the experimental plots as per required.

Data collected

Fresh leaf weight per plant (g plant^{-1}), marketable fresh leaf yield (t ha^{-1}), unmarketable fresh leaf yield (t ha^{-1}), total fresh leaf yield (t ha^{-1}) and leaf dry weight percent (%) were the data were collected for analysis. Fresh leaf weight per plant and dry weight percent were measured from five sample plants taken per plot at full maturity. Leaf dry weight was measured by drying fresh leaf sample from each treatment in an oven set at 65 to 70 ^{o}C for about 48 hours until a constant weight was attained.

Data analysis

Data were subjected to Analysis of Variance (ANOVA) using R statistical software (R Core Team, 2020) and means that are found significantly different were separated using Least Significant Difference (LSD) test at 5% probability level.

Results and Discussion

Results of analysis of variances of fresh leaf yield (marketable and total, t ha^{-1}) and leaf fresh weight (g plant^{-1}) showed the significant influence individual effect of spacing, variety, location and their interaction; while the leaf dry weight percent was influenced by the main effect of variety only (Table 2).

The highest total fresh leaf yield (70.49 t ha^{-1}) was obtained at 40 cm x 20 cm spacing (125 000 plants ha^{-1}) from variety Great Lakes followed by 65.60 t ha^{-1} and 53.36 t ha^{-1} leaf yield from the same variety planted at an inter- and intra-row spacing combination of 50 cm x 20 cm (100 000 plants ha^{-1}) and 40 cm x 30 cm (83333 plants ha^{-1}), respectively. While the least fresh leaf yield of (37.39 t ha^{-1}) was obtained from the wider spacing of 50 cm x 40 cm (50 000 plants ha^{-1}). Whereas, the highest fresh leaf yield (28.11 t ha^{-1}) of Rsk-3 was obtained at 30 cm x 20 cm (166667 plants ha^{-1}) followed by 22.73 t ha^{-1} at 40 cm x 20 cm (125000 plants ha^{-1}) and it continued to decrease with decreasing planting density (Table 3).

Table 2. Analysis of variance for leaf yield and dry weight percent of two lettuce varieties as affected by spacing and location.

Source of variation	Degrees of freedom	MFLY	UFLY	TFLY	FLWPP	LDW (%)
Rep	2	Ns	Ns	ns	ns	ns
Variety(V)	1	***	**	***	***	***
Spacing(S)	8	**	Ns	***	***	ns
Location(L)	1	***	Ns	***	ns	ns
VxS	8	**	Ns	***	ns	ns
VxL	1	***	Ns	***	ns	ns
SxL	8	***	Ns	***	ns	ns
VxSxL	8	***	Ns	***	ns	ns
Residuals	68					
CV (%)		12.18	29.43	11.30	7.8	22.55

"**"and "***"shows statistical significance level of the ANOVA F-test for the different parameters; while "ns" stands for the non-significance at 5% significance. MFLY=Marketable fresh leaf yield, UFLY=Unmarketable fresh leaf yield, TFLY= Total fresh leaf yield, FLWPP=Fresh leaf weight per plant, LDW= Leaf dry weight.

The highest fresh leaf yield obtained from Rsk-3 was 60% less than the highest yield obtained from Great Lakes. Variety Rsk-3 was found to be inferior in total fresh leaf yield and fresh leaf weight plant^{-1} than Great Lakes in all the spacing treatments; however both varieties exhibited significant increase in fresh leaf yields with increasing planting density (Figure 2). Regardless of the overall differences in fresh leaf yield performance between the two lettuce varieties, both responded positively to increasing planting density. Fresh leaf yield increased with increasing planting density although the trend varied for the two varieties (Figure 2) and was positive and significant (R^2=0.60 for Great Lakes and R^2=0.89 for Rsk-3). Increment in the variety Great Lakes started to drop after the planting density reached 125 000 plants ha^{-1} (40 cm x 20 cm) at which the maximum yield was attained. Whereas, variety Rsk-3 showed no sign of dropping after attaining its maximum yield (Figure 3). It was observed that closely spaced plants grow very fast as compared to wider spaced plants which is accounted to competition for photosynthetic active radiation that stimulates growth and increased total yield parameters (Maboko and Du Plooy, 2009).

Table 3. Interaction of plant spacing and variety on fresh leaf yield and leaf dry weight of lettuce (combined over location).

Variety	Spacing (cmxcm)	Pop. density (plants ha^{-1})	MFLY (t ha^{-1})	UFLY (t ha^{-1})	TFLY (t ha^{-1})	FLWPP (g)	LDW (%)
Great Lakes	30x20	166667	42.69d	3.57	46.26d	694.43cd	1.87
	40x20	125000	67.80a	2.69	70.49a	811.13a	2.33
	30x30	111111	47.65c	4.96	52.61c	875.91ab	2.08
	50x20	100000	64.38a	1.22	65.60b	575.46e	1.87
	40x30	83333	52.47b	0.89	53.36c	652.51d	1.77
	30x40	83333	37.41e	3.48	40.89e	640.49de	2.11
	50x30	66667	48.64bc	2.05	50.69cd	895.13a	1.44
	40x40	62500	38.98de	1.33	40.31e	905.93a	1.66
	50x40	50000	36.67e	0.71	37.39e	720.42c	1.54
Mean			48.52	2.32	50.84	752.38	1.85
Rsk-3	30x20	166667	27.15f	0.95	28.11f	210.27g	3.53
	40x20	125000	21.93g	0.80	22.73g	178.29gh	4.52
	30x30	111111	19.83gh	1.56	21.39gh	214.75g	7.81
	50x20	100000	19.55gh	0.71	20.26gh	334.72f	4.47
	40x30	83333	17.92ghi	1.14	19.06ghi	342.66f	4.20
	30x40	83333	14.79i	0.67	15.45i	129.31h	7.33
	50x30	66667	17.78ghi	0.63	18.41ghi	341.02f	6.90
	40x40	62500	14.71i	0.76	15.47i	332.13f	8.70
	50x40	50000	16.89hi	0.63	17.52hi	238.50g	6.11
Mean			18.95	0.87	19.82	257.96	5.95
	CV		12.18	29.43	11.30	7.80	22.55
	LSD (5%)		4.74	2.19	4.59	65.42	8.03
	Significan		**	ns	***	***	ns

Means within a column having the same letters are not significantly different. "*", "**", "***" Significant, highly significant and very highly significant at 5% level respectively. MFLY=Marketable fresh leaf yield, UFLY=Unmarketable fresh leaf yield, TFLY= Total fresh leaf yield, FLWPP=Fresh leaf weight per plant, LDW= Leaf dry weight.

The variety Great Lake gave the highest fresh leaf yield at 125 000 plants ha^{-1} due to the larger number of heads harvested; however at higher density (166 667 plants ha^{-1}), yields started to drop again for the reason that size of individual heads reduced although the number increased. On the other hand, regardless of the increasing planting density, variety Rsk-3 did not show yield dropping. This could be for the reason that, the plant densities used in the study for this particular variety did not reach the level at which it responds to reach its maximum yield (Figure 2).

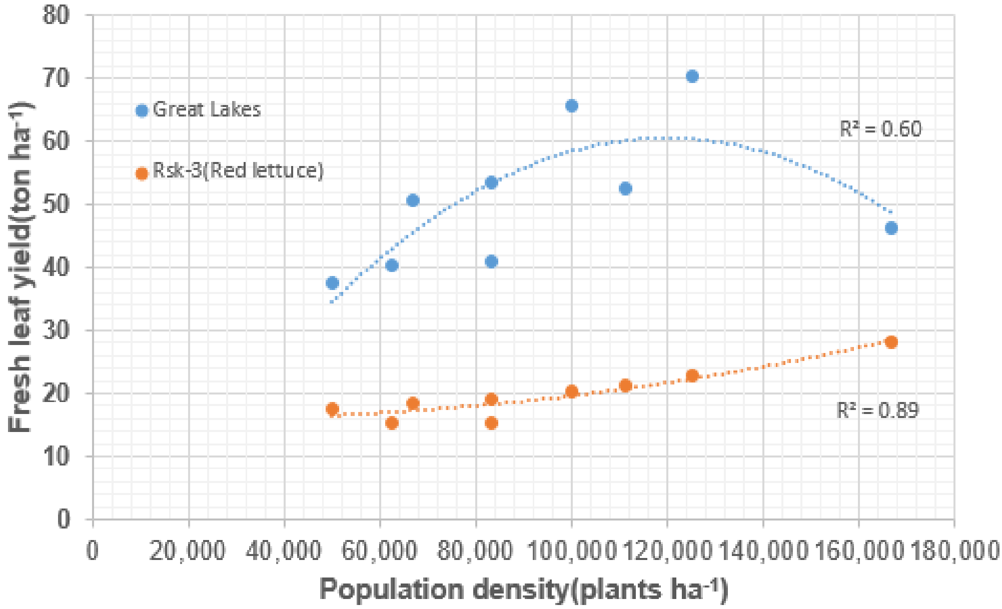

Figure 2. Responses of total fresh leaf yield (t ha^{-1}) of Great Lakes and Rsk-3 to increasing planting density.q

The higher number of plants at closer spacing contributed to higher fresh leaf and dry mass per unit area of lettuce as compared to wider spacing while a tendency of increased fresh leaf and dry mass per unit area was obtained as the plant spacing decreases (Maboko and Du Plooy, 2009). Maboko and Du Plooy (2009) similarly reported the significantly effect of plant population on different growth and yield parameters including fresh and dry leaf mass, with significantly higher values of all variables at the closest spacing of 10 cm x 20 cm (50 plants m^{-2}). The results of the present study indicated that an increase in plant population resulted in a significant increase in yield and yield components of leafy lettuce. This holds true mainly for the results obtained for variety Rsk-3 in the present study; which gave the highest fresh leaf yield at a higher density (17 plants m^{2}) at 30 cm x 20 cm (166 667 plants ha^{-1}).

Maboko and Du Plooy (2009) also reported that differences among cultivars were obtained due to differences in fresh mass, higher leaf area, plant height and leaf number although the latter three parameters were not included in the present study. The highest fresh leaf yield obtained in the present study was from the closest spacing in both varieties, although the spacing used in this study was wider (lower planting density) compared to what was used by Maboko and Du Plooy

(2009). A related study conducted on variety "Tesfa Mekele" in Tigray region of Northern Ethiopia showed similar results in which they reported increasing trend of fresh leaf biomass with increasing planting density (Beyenesh e*t al*., 2017). The highest leaf biomass obtained in the latter study was at 60 cm x 40 cm spacing (4 plants ha^{-1}) although it is wider compared to the present study. A spacing of 30 cm x 30 cm (11 plants ha^{-1}) gave the highest fresh weight of leaves in an experiment conducted on Great Lakes in Ghana (Abdul-Halim *et al,* 2011), which is much more closer to our results as both studies used the same variety. Abdul-Halim *et al.* (2011) found 1.254% of leaf dry weight at 30 cm x 30 cm from Great Lakes although spacing did not affect leaf dry weight in our study, but similar average leaf dry mass (1.85%) was obtained (Table 4). A spacing of 40 cm x 25 cm (10 plants ha^{-1}) gave the maximum yield (7.68 t ha^{-1}) from cultivar Grand Ratids in Bangladish (Alahi *et al*., 2014), which is of course small yield compared to the present study result although the highest yield from variety Great Lakes in the present study was obtained at this plant density.

Great Lakes was superior in fresh leaf weight $plant^{-1}$ over Rsk-3 in all the spacing treatments (Table 3). The average fresh leaf weight $plant^{-1}$ of Great Lakes was 752.45 g with this value ranging from 575.4 g to 905.93 g, while the highest weight was obtained at 40 cm x 40 cm (62 500 plants ha^{-1}) and the lowest was at 50 cm x 20 cm (100 000 plants ha^{-1}). However, the average fresh leaf weight $plant^{-1}$ obtained from Rsk-3 was only 257.96 g at 40 cm x 30 cm (83333 plants ha^{-1}) which is three times lower than that of the Great Lakes (752.45 g). The maximum fresh weight of lettuce per plant was obtained from 40 cm x 30 cm spacing treatment while the minimum was from 40 cm x 20 cm (Hasan *et al*., 2017).

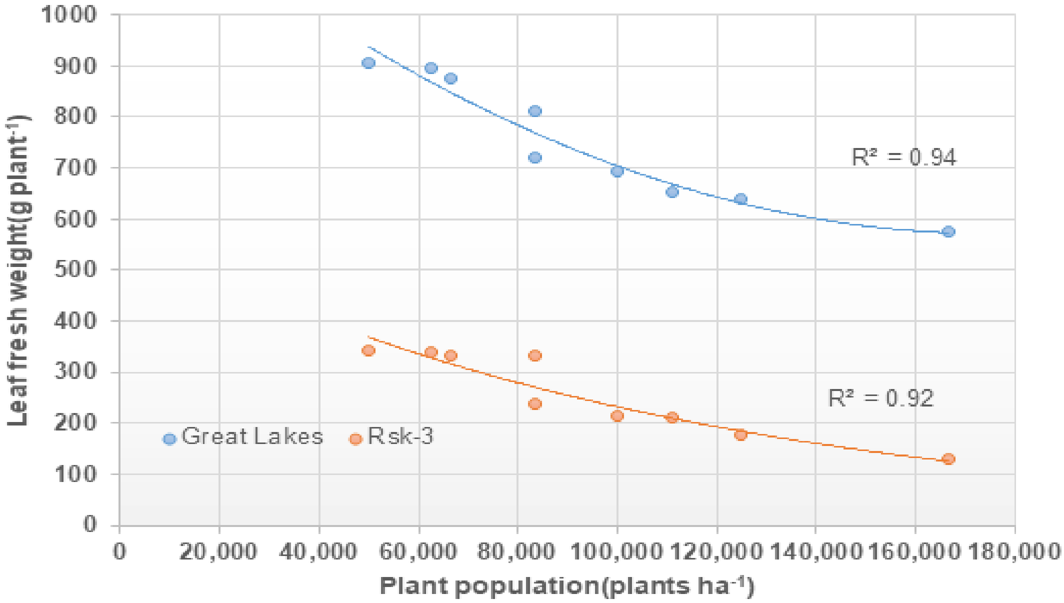

Figure 3. Responses of fresh leaf weight (g plant-1) of Great Lakes and Rsk-3 to increasing planting density

Genetic differences between the varieties (compactness, head size, growth habit, etc.) could be the reason for the difference in fresh yield performance. Great Lakes is headed type lettuce and has compacted/ or folded leaves which contributed to have a higher weight per plant and total fresh yield. Conversely, the loose and open non-heading natured Rsk-3 reduced its fresh weight per plant and the total fresh yield as well. Variations in genetic makeup between lettuce varieties resulted in differences of yield contributing components such as leaf area, plant height, and number of leaves that would cause differences in fresh weight per plant and total fresh yield per unit area (Maboko and Du Plooy, 2009). Unlike the total fresh leaf yield (t ha^{-1}), increasing planting density decreased the fresh leaf weight per plant in both varieties (in other words, increasing plant spacing increased fresh weight $plant^{-1}$) (Figure 3). Our results are in agreement with similar studies which revealed that fresh weight $plant^{-1}$ of lettuce showed statistically significant variation due to different plant spacing. The increases of spacing showed increasing trend in fresh weight of plant since under wider spacing plants receive enough light and nutrients which leads to attain maximum fresh weight of plant (Rincon *et al*., 1998; Tittonell *et al*., 2003; Boroujerdnia and Ansari, 2007). Hence, optimum plant spacing ensured maximum vegetative growth that ensured highest fresh weight $plant^{-1}$ (Hasan *et al*., 2017).

Although spacing did not affect the leaf dry weight of both varieties, varietal differences was observed in which Rsk-3 was better in dry weight percent (5.95%) than Great Lakes (1.85%) unlike the other parameters such as total fresh leaf yield and fresh leaf weight per plant (Table 4).

Significant interaction between variety and spacing treatments was also observed over locations in most of the parameters measured (Table 5). Great Lakes performed better at Debre Zeit than at Holetta and Rsk-3 did well at Holetta than at Debre Zeit at all spacing treatment combinations except at 50 x 20cm (Table 5). The total fresh leaf yield performance of Great Lakes at Debre Zeit (106.58 t ha^{-1}) was three fold higher than at Holetta (34.41 t ha^{-1}) at optimum planting density (125 000 plants ha^{-1}); while Rsk-3 was better at Holetta (30.02 t ha^{-1}) than at Debre Zeit (26.19 t ha^{-1}) at planting density of 166 667 plants ha^{-1} although this difference was not as high as the difference observed in Great Lakes between the locations. Nevertheless, the average yield performance of Great Lakes over the spacing treatments at Debre Zeit was 71.79 t ha^{-1}, which was still superior over its performance at Holetta (29.90 t ha^{-1}). On the other hand, the average yield performance of Rsk-3 was better at Holetta (24.37 t ha^{-1}) than at Debre Zeit (15.27 t ha^{-1}) (Table 5). Lettuce is considered a crop of mild climate and its production in regions of low altitude is impaired due to the high temperatures and the predominance of long days (Cardoso *et al*., 2018).

Based on the results of the present study, it is possible to suggest that the different varieties responded differently to different agro-ecologies, depending on their adaptation. Hence, one can safely conclude that Great Lakes preferred relatively a mid-low altitude and warm temperature of Debre Zeit compared to Rsk-3 which preferred a higher altitude and cooler environment of Holeta.

Table 4. The main effect of spacing on average fresh leaf yield, and leaf dry weight performance of and variety over locations

Treatments	Planting density (plants ha^{-1})	MFLY (t ha^{-1})	UFLY (t ha^{-1})	TFLY (t ha^{-1})	FLWPP (g)	LDW (%)
			Spacing (cm x cm)			
30x20	166667	34.92b	2.26	37.18c	452.35c	2.70
40x20	125000	44.87a	1.74	46.61a	495.02c	3.42
30x30	111111	33.74b	3.26	36.99c	545.33b	4.94
50x20	100000	41.96a	0.97	42.93b	455.09c	3.17
40x30	83333	33.63b	0.78	34.41c	497.58c	2.99
30x40	83333	27.66c	2.31	29.97d	384.90d	4.72
50x30	66667	33.21b	1.34	34.55c	618.07a	4.17
40x40	62500	26.85c	1.05	27.89d	619.03a	5.18
50x40	50000	26.78c	0.67	27.45d	479.46c	3.82
	LSD (5%)	3.25	4.66	3.25	46.26	5.34
	Significance	**	Ns	**	***	ns
			Variety			
Great Lakes		48.52a	2.32a	50.84a	752.45a	1.85b
Rsk-3		18.95b	0.87b	19.82b	257.96b	5.95a
	LSD (5%)	1.53	0.73	1.53	21.81	0.49
	Significance	***	**	***	***	***
	CV	12.18	29.43	11.30	7.80	22.55

Means within a column having the same letters are not significantly different. "*", "**", "***" Significant, highly significant and very highly significant at 5% level respectively. MFLY=Marketable fresh leaf yield, UFLY=Unmarketable fresh leaf yield, TFLY= Total fresh leaf yield, FLWPP=Fresh leaf weight per plant, LDW= Leaf dry weight

Table 5. Interaction effect of variety and spacing on fresh leaf yield at individual location

Variety	Spacing (cmXcm)	Planting density (plants ha^{-1})	MFLY(t ha^{-1})		UMFLY(t ha^{-1})		TTFLY (t ha^{-1})	
			Debrezeit	Holeta	Debrezeit	Holeta	Debrezeit	Holeta
Great Lakes	30x20	166,667	57.30d	28.08abc	4.84	2.29	62.16c	30.37abc
	40x20	125,000	103.61a	31.99a	2.96	2.42	106.58a	34.41a
	30x30	111,111	66.83c	28.48abc	7.75	2.17	74.58b	30.64abc
	50x20	100,000	101.81a	26.94bcde	0.21	2.22	102.03a	29.16abcd
	40x30	83,333	77.34b	27.6abcd	1.16	0.61	78.50b	28.21bcde
	30x40	83,333	49.44de	25.38cde	5.07	1.89	54.51cd	27.27bcde
	50x30	66,667	69.26bc	28.02abc	2.64	1.46	71.90b	29.49abcd
	40x40	62,500	47.43e	30.53ab	0.98	1.67	48.42d	32.20ab
	50x40	50,000	47.04e	26.30bcde	0.37	1.05	47.41d	27.36bcde
Rsk-3	30x20	166,667	25.08f	29.23abc	1.12	0.79	26.19e	30.02abc
	40x20	125,000	18.52fgh	25.35cde	0.42	1.17	18.94efg	26.52cde
	30x30	111,111	13.50ghi	26.16bcde	2.27	0.85	15.77fgh	27.01bcde
	50x20	100,000	21.46fg	17.64f	0.00	1.42	21.46ef	19.06fg
	40x30	83,333	11.97hi	17.60f	0.64	0.69	12.61ghi	18.30g
	30x40	83,333	11.29hi	24.54cde	1.10	1.17	12.40ghi	25.72cde
	50x30	66,667	12.66hi	22.90de	0.00	1.26	12.66ghi	24.16def
	40x40	62,500	7.47i	21.95ef	0.57	0.95	8.05i	22.90efg
	50x40	50,000	9.35i	24.42cde	0.00	1.27	9.35hi	25.69cde
	CV		11.86	11.82	34.41	43.05	10.59	12.01
	LSD (5%)		8.22	5.04	9.04	4.43	7.65	5.41
	Sig.		***	*	ns	ns	***	*

Means within a column having the same letters are not significantly different. "*", "**", "***" Significant, highly significant and very highly significant at 5% level respectively. MFLY=Marketable fresh leaf yield, UFLY=Unmarketable fresh leaf yield, TFLY= Total fresh leaf yield.

Conclusions and Recommendation

The results showed that the best plant spacing of the evaluated is 40 cm x 20 cm (13 plants m^2) and 30 cm x 20 cm (17 m^2) for the headed type lettuce variety Great Lakes and for the loose head lettuce variety Rsk-3, respectively compared to other spacing used in the study. The higher planting density increased the yield parameters except weight per plant and leaf dry mass. In other words, closely spaced plants reduced head weight of both varieties which could be the result of competition among plants. However, this trend was reversed for the leaf yield per unit area and it increased significantly with increased planting density. Regardless of the different plant spacing used, both varieties responded differently to the two environments. It should be noted that the results presented here are only for the data collected in the experimental season with irrigation and cannot be inferred to other production systems/or seasons. Whether the increased plant density will affect head size, leaf number, leaf area, growth season, etc. needs to be examined in future studies.

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Influence of Plant Population on Yield and Yield Components of Head Cabbage (*Brassica oleracae* Var. Capitata L.) in Two Agro-Ecologies of Ethiopia

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Abstract

Cabbage (Brassica oleracia var. capitata) is one of the major vegetable crops grown in Ethiopia. In the 2018 rainy season 31.4 thousand tonnes of head cabbage was produced on 5.17 thousand ha of land. It is produced mainly as a source of vitamin C and income. Despite its importance, the productivity of cabbage in Ethiopia remains very low (6 t/ha) as compared to world (28.8 t/ha) and East Africa (16 t/ha). Lack of improved varieties, insect pest and disease management and agronomic practices are the major reasons for low productivity of head cabbage. Cabbage has been planted at a spacing of 60 cm between rows and 40 cm between plants regardless of variety and agro-ecology. The wide spacing resulted in not only to low yield but also in high proportion of big size heads which were not preferred by consumers as well as retailers. Therefore, the present study was initiated with the objective of improving productivity and market preference of head cabbage. The experiment comprised of two cabbage varieties (Copenhagen Market and Landini F1), five spacings (40 cm x 20 cm, 40 cm x 30 cm, 40 cm x 40 cm, 50 cm x 20 cm, 50 cm x 30 cm, 50 cm x 40 cm and 60 cm x 40 cm (control). It was conducted at Debre Zeit and Kulumsa Agricultural Research Centers during the 2018 and 2019 rainy seasons. Results of the experiment showed that significantly the highest yield (99.69 t ha^{-1}) of Copenhagen Market was obtained when planted at a spacing of 40 cm between rows and 20 cm between plants as compared to the control (59.78 t), which is a 66.7% increase over the control. Landini F1, on the other hand, produced the highest yield (96.9 t ha^{-1}) when planted at 40 cm inter and 30 cm intra-row resulting in an increase of 74.2% as compared to the control that produced only 55.63 t ha^{-1}. A decrease of 27.5% in head weight, 24.4 % in number of non-wrapper leaves, 42.8 % in weight of non-wrapper leaves were observed as the spacing was narrowed down from the control to 40 cm inter and 20 cm intra row. Therefore, the spacing treatments 40 cm inter and 20 cm intra row and 40 cm inter and 30 cm intra row were recommended for Copenhagen Market and Landini F1 cultivars, respectively and Kulumsa was found to be a suitable site for growing both varieties of head cabbage. Moreover, further studies involving different varieties should be undertaken under wider range of agro-ecologies.

Introduction

Head cabbage (*Brassica oleracae* var. capitata L.) is one of the most popular vegetable crops grown worldwide. The total annual world production of cabbages and other brassicas in 2018 was about 69 million metric tonnes (http://www.fao.org/faostat/en) while East African countries produced 14.8 million tonnes of cabbage on about 92.5 thousand ha of land during the same year. Cabbage is also among the widely grown vegetable crops in Ethiopia. In the meher (rainy) season of 2018 it was grown on 5.17 thousand ha of land and produced 31.4 thousand tonnes by 439 thousand households (CSA, 2018). The productivity of cabbage in Ethiopia is very low (6 t/ha) as compared to world average yield of 28.8 t/ha and 16 t/ha of East Africa. Cabbage is known worldwide as sources of vitamin C, minerals and dietary fiber. In Ethiopia, cabbage is usually grown in the mid and high altitude areas of the country both for household consumption and as a source of income. Moreover, a portion of cabbage is exported to neighboring countries like Djibouti and Somalia. In 2018 the country exported 1,575 tonnes of cabbage and lettuce to these countries and earned about 300 thousand USD or about 8.27 million Birr (http://www.erca. gov. et).

Despite the importance of cabbage as source of food, income, foreign currency and employment, its production and productivity has been gripped by several problems. Lack of adapted varieties for the different agro-ecologies of the country, insect and disease management systems, and improved agronomic practices are among the major constraints that have contributed for the low productivity and quality of cabbage. Cabbage head growth, development and maturity vary within and between commercial fields, forcing growers to undertake multiple harvests. Production and management practices such as uniform spacing of plants contribute to reducing such variability in cabbage plant growth, development, and ultimately head size of cabbage. Marketable yields, for a once-over-harvest, should be higher from fields with uniform cabbage head size at time of harvest (Stoffellal and Fleming, 1990). Plant population plays a significant role in the final crop yield and quality under any given condition (Adebooye, 1996; Alofe *et al*., 1996 and Mutungamiri *et al*., 2001). Carlson *et. al*. (2003) reported that evenly spaced stands of plants resulting in optimum plant population, have a greater yield potential than unevenly spaced stand. A blanket recommendation of 60 cm between rows and 40 cm between plants has been used for all varieties and across production areas in Ethiopia. However, the aforementioned spacing led to production of big sized heads often with low production per unit area. The big sized heads, however, were not preferred among retailers and consumers as they were not amenable to existing retailing and varied household utilization system. Therefore, the need for optimum plant population (spacing) that results in high yield and desirable head size had become unequivocal. The objective of the current study thus was to determine the optimum spacing suitable for the two commonly grown varieties across two major agro-ecologies, the high-altitude and mid-altitude areas of the country.

Materials and Methods

The experiment is comprised of two varieties and seven spacing treatments. The varieties were an open pollinated variety with medium head size Copenhagen Market (MoA, 2018) and a hybrid variety with large head size Landini F1 (Hazera Seeds, Israel). Both varieties were grown widely in the mid and highlands of the country. Factorial combinations of the two varieties and the seven spacing treatments (40 cm x 20 cm, 40 cm x 30 cm, 40 cm x 40 cm, 50 cm x 20 cm, 50 cm x 30 cm, 50 cm x 40 cm, 60 cm x 40 cm) were compared studied. The corresponding plant populations per ha were 125 000, 83 333, 62 500, 100 000, 66 666, 50 000 and 41 666, respectively. The experiment was laid out in Completely Randomized Block Design (RCBD) with three replications and was undertaken at Debre Zeit and Kulumsa Agricultural Research Centers. Debre Zeit has an altitude of 1900 m.a.s.l and Alfisol soils while Kulumsa has 2400 m.a.s.l and Luvisol soils.

Seeds of both varieties were sown on raised seed beds and the seedlings were grown for a month until they attained 3-4 leaves. The seedlings were transplanted on 22/08/2018 and 18/07/2019 EC at Debre Zeit, and on 18/09/2018 and 14/08/2019 EC at Kulumsa. The treatments received uniform application of 242 kg of NPS at transplanting and 130 kg Urea in two splits, half at transplanting and the remaining half at 30 days after transplanting. Karate (1 l/ha) and Dimetiote (Roger (1 l/ha) were sprayed against cabbage aphids and flea beetles as deemed necessary.

The experiment was carried on a gross plot size of 4 m^2 per treatment. Five random samples of matured heads were harvested from the central plants to record data such as: diameter, height and weight of heads, and number and weight of non-wrapper leaves. Total yield per plot was recorded as the weight of matured heads in the central rows of each plot, excluding boarder plants, and used to calculate yield per ha. Number and weight of non-wrapper leaves data of head cabbage grown at Kulumsa in the 2019 main season was not considered for analysis. All the other data were analyzed using Satistix 8 statistical package (Analytical Software, 2018) and those which showed significant differences among the treatments were separated using Tukey’s test at 0.05 level of probability.

Results and Discussions

Head yield and yield components

The interaction among all the four factors (location, year, variety and spacing) and the three way interactions except for location, year and variety were not significant for all the parameters recorded. The significant interaction among location, year and variety was only for head height and weight (Table 1). However, the difference was not significant in head diameter, number and weight of non-wrapper leaves. Both Copenhagen Market and Landini F1 produced better heads at Kulumsa as compared to those produced at Debre Zeit. Coppenhagen market and Landini F1 grown at Kulumsa produced 29.5, 24.0, 12.2 and 22.8% better head height and 90.7, 82.3, 64.9 and 89.9% better head weight than those grown at Debre Zeit during the same period (Table 1). The better yield at Kulumsa indicated that the plants at Kulumsa were effective in head formation rather than spending their photosynthates on forming non-wrapper leaves. This is in line with the fact that cool agro-ecologies are more suitable for head formation of cabbage than warmer agro-ecologies. Dixon (2007) indicated that Brassicas need vernalizing temperature of below 10° C to initiate heads. The results further confirmed that Copenhagen Market was more suitable to highland areas like Kulumsa than midlands like Debre Zeit.

Table 1. Interaction effects of location, year and variety (combined over spacing) on yield and yield components of head cabbage

Location	Year	Variety	Head diameter (cm)	Head height (cm)	Head weight (kg)	Yield (t/ha)	Non-wrapper leaves plant^{-1}	
							Number	Weight (kg)
Kulumsa	2018	Copenhagen Market	14.89	18.63a*	2.06a	87.99	12.7	0.70
		Landini F1	14.70	17.75a	1.75ab	74.17	11.41	0.77
	2019	Copenhagen Market	12.99	14.95c	1.55b	87.34	7.66	0.39
		Landini F1	12.75	16.38b	1.50b	79.45	8.42	0.34
Debre Zeit	2018	Copenhagen Market	14.50	14.39cd	1.08c	83.34	15.14	0.67
		Landini F1	13.30.	14.32cd	0.96c	68.16	13.78	0.72
	2019	Copenhagen Market	13.30	13.33d	0.94c	66.88	12.04	0.48
		Landini F1	12.18	13.33d	0.79c	68.83	11.38	0.47
SE			0.39	0.44	0.1	8.08	0.44	0.05
Critical value			ns	1.36	0.32	ns	ns	ns
CV(%)			9.12	9.27	24.90	25.69	12.40	29.03

*Means followed by the same letter are not significantly different at 5% level of probability by Tukey's test at 0.05 level of probability. ns non-significant difference

The interaction between variety and spacing was not significant for all the parameters, except for yield (Table 2). The highest significant yield (99.69 t ha^{-1}) of Copenhagen Market was obtained when plants were planted at a spacing of 40 cm between rows and 20 cm between plants as compared to the control (59.78 t), which increased yield by 66.7% over the control. However, there were no significant differences among the other spacings of Copenhagen Market. Unlike

Copenhagen Market, Landini F1 produced the highest yield (96.9 t ha^{-1}) when planted at a spacing of 40 cm between rows and 30 cm between plants which resulted in a yield increase of 74.2% as compared to the control which produced only 55.63 t ha^{-1}. However, no significant differences were observed in yield among the plants of Landini F1 planted at 40 cm x 30 cm, 40 cm x 20 cm and 50 cm x 20 cm spacings. The interaction of variety, year and location, and variety and spacing was not significant for number and weight of non-wrapper leaves (Tables 1 and 2). The means of variety main factor also indicated that Copenhagen Market produced higher yield (81.39 t/ha) than Landini F1 (72.65 t/ha) irrespective of location, year and spacing treatment. The two varieties, however, did not differ in mean diameter, height, and weight of heads.

Table 2. Interaction of variety and spacing on yield and some yield components of head cabbage (combined over location and year)

Treatment		Head diameter (cm)	Head height (cm)	Head weight (Kg)	Total yield (t/ha)	Non-wrapped leaves plant^{-1}	
Variety	Spacing					Number	Weight (Kg)
Copenhagen	40 cm x 20 cm	12.79	15.13	1.17	99.69a*	10.87	0.45
	40 cm x 30 cm	13.02	14.88	1.18	82.18a-d	11.19	0.50
	40 cm x 40 cm	14.52	15.95	1.50	81.58a-d	11.35	0.55
	50 cm x 20 cm	12.93	14.71	1.22	81.14a-d	11.63	0.56
	50 cm x 30 cm	13.71	15.61	1.37	86.10abc	11.73	0.54
	50 cm x 40 cm	14.15	15.69	1.65	79.23a-d	12.65	0.72
	60 cm x 40 cm	13.99	15.29	1.49	59.78cd	13.46	0.59
Landini F1	40 cm x 20 cm	13.27	14.87	1.01	77.99a-d	10.02	0.45
	40 cm x 30 cm	14.11	15.49	1.29	96.91ab	10.35	0.54
	40 cm x 40 cm	13.95	15.52	1.39	65.77cd	11.26	0.61
	50 cm x 20 cm	13.85	15.67	1.18	79.16a-d	11.17	0.51
	50 cm x 30 cm	13.42	15.04	1.36	69.26bcd	11.52	0.66
	50 cm x 40 cm	14.48	16.18	1.49	63.85cd	11.71	0.62
	60 cm x 40 cm	14.02	15.34	1.28	55.63d	12.32	0.65
SE		0.51	0.58	0.14	8.08	0.58	0.07
Critical value		ns	ns	ns	27.68	ns	ns
CV(%)		9.12	9.29	24.90	25.69	12.40	29.03

*Means followed by the same letter are not significantly different at 5% level of probability by Tukey's test at 0.05 level of probability. ns non-significant difference

Significant differences in yield and yield components were also observed in both locations depending on production year, irrespective of variety and spacing (Table 3). Cabbage produced at Kulumsa in 2018 and 2019 had 7.0% and 22.9% better head yields than those grown at Debre Zeit during the respective years. Moreover, the highest head diameter, head height, head weight, and number of non-wrapper leaves were observed in the cabbage grown at Kulumsa in 2018. The head weight of cabbage grown at Kulumsa was significantly bigger than those grown at Debre Zeit in both years; cabbage grown at Kulumsa had double (1.9 kg) the head weight of those grown at Debre Zeit in 2019 (0.86 kg). Those grown at Debre Zeit during the same year had similar head diameter and number of non-wrapper leaves as those grown at Kulumsa though they had smaller head height and weight. No significant difference in head height and weight of non-wrapper leaves were observed among the treatments. Likewise, Stoffellal and Felming (1990) reported a yield difference of 30% between two consecutive years in cabbage (cv. Bravo). Kleinhenz and Wszelaki (2003) also reported significant differences in marketable yield, head weight, head diameter, and head density between years and seasons.

Table 3. Interaction of location and year on yield and some yield components of cabbage (combined over spacing and variety)

Location	Year	Head diameter (cm)	Head height (cm)	Head weight (kg)	Yield (t/ha)	Non-wrapper leaves $plant^{-1}$	
						Number	Weight (kg)
Kulumsa	2018	14.69a*	18.19	1.90a	81.08a	12.05b	0.74a
	2019	12.87b	15.66	1.53b	83.40a	8.34c	0.36c
Debre Zeit	2018	14.62a	14.35	1.02c	75.75ab	14.36a	0.70a
	2019	12.74b	13.33	0.86c	67.85b	11.71b	0.47b
SE		0.27	0.31	0.07	4.32	0.31	0.04
Critical value		0.71	ns	0.19	11.26	0.81	0.09
CV (%)		9.12	9.27	24.90	25.69	12.40	29.03

*Means followed by the same letter are not significantly different at 5% level of probability by Tukey's test at 0.05 level of probability. ns non-significant difference

The interaction between location and spacing was not significant for diameter and height of head. Significant interactions, however, were observed in head weight and yield (Table 4). At Debre Zeit, the biggest head of 1.65 kg was observed at a spacing of 50 cm x 40 cm between rows and plants which was 41.0% and 39.8% bigger than those grown at 40 cm x 20 cm and 40 cm x 30 cm, respectively, but it had similar head weight as the control. Cabbage head yield obtained at 40 cm x 30 cm spacing was about double as compared to those grown at the control treatment though it did not differ from those planted at spacings of 40 cm x 20 cm and 50 cm x 20 cm, which produced 81.5% and 57.4% better yield than the control. Likewise, cabbage grown at Kulumsa had bigger heads when planted at 50 cm x 40 cm, which is 47.5% bigger than those grown at 40 cm x 20 cm in the same location. But it did not differ from those grown at similar spacing at Debre Zeit. Nonetheless, the head yield obtained at 40 cm x 20 cm spacing was significantly better (34.8%) than the control.

Table 4. Interaction of location and spacing on yield and yield components of cabbage (combined over variety and year)

Location	Treatment	Head diameter (cm)	Head height (cm)	Head weight (kg)	Total Yield (t/ha)	Non-wrapper leaves plant^{-1}	
						Number	Weight (kg)
Debre Zeit	40 cm x 20 cm	12.79	13.80	1.17bc*	85.93abc	11.83	0.46
	40 cm x 30 cm	13.02	14.03	1.18bc	97.33a	12.12	0.51
	40 cm x 40 cm	14.52	14.17	1.50ab	65.66bcd	12.78	0.59
	50 cm x 20 cm	12.93	13.74	1.23abc	74.56a-d	12.75	0.56
	50 cm x 30 cm	13.71	13.42	1.37abc	68.93bcd	13.30	0.65
	50 cm x 40 cm	14.15	14.29	1.65a	62.67cd	13.93	0.74
	60 cm x 40 cm	13.99	13.44	1.49ab	47.35d	14.53	0.59
Kulumsa	40 cm x 20 cm	13.27	16.21	1.01c	91.75ab	9.09	0.45
	40 cm x 30 cm	14.11	16.33	1.30abc	81.77abc	9.42	0.52
	40 cm x 40 cm	13.95	17.31	1.39abc	81.69abc	9.83	0.56
	50 cm x 20 cm	13.85	16.64	1.18bc	85.74abc	10.34	0.51
	50 cm x 30 cm	13.42	17.24	1.36abc	86.43abc	9.95	0.55
	50 cm x 40 cm	14.48	17.57	1.49ab	80.22abc	10.43	0.60
	60 cm x 40 cm	14.02	17.18	1.29abc	68.06bcd	11.25	0.65
SE		0.51	0.58	0.14	8.08	0.58	0.07
Critical value		ns	ns	0.46	27.68	ns	ns
CV(%)		9.12	9.29	24.90	25.69	12.40	29.03

*Means followed by the same letter are not significantly different at 5% level of probability by Tukey's test at 0.05 level of probability. ns non-significant difference

Significant differences were observed among the spacing treatments in yield, head diameter, head weight, and number and weight of non-wrapper leaves but not in head height (Table 5). An increase in yield, head diameter, head weight, and number and weight of non-wrapper leaves were observed with an increase in the space a plant occupies. Growing cabbages, irrespective of variety, in a 40 cm inter 30 cm intra-row spacing produced 55.2% better yield than the control and 25.2% better than the 50 cm inter- and 40 cm intra-row spacings. However, there was no significant difference between the other (40 cm x 20 cm, 40 cm x 30 cm, 40 cm x 40 cm, 50 cm x 20 cm, and 50 cm x 30 cm) spacings. Likewise, an increase of 27.5% in head weight, 24.4 % in number of non-wrapper leaves, 42.8 % in weight of non-wrapper leaves were observed as the spacing was narrowed down from the 60 cm inter- and 40 cm intra-row to 40 cm inter- and 20 cm intra row with only 7.4% reduction in head diameter. However, the cabbage plants grown in different spacings had the same head height. These results concur with that of Stoffellal and Fleming (1990) who reported that cabbage head weight increased quadratically as within row spacing increased. Moreover, uniformity among plants and head weights increased with increase in within row spacing due to improved availability of light, nutrient and water. Barrett *et. al*. (2015) also indicated that larger within row plant spacing reduced interplant competition in high-density cabbage production, thereby maximizing the proportion of marketable heads and marketable yield. Similarly, Haque *et. al.* (2015) recorded the highest number of loose leaves (19), weight (849 g), diameter (19 cm), and thickness (12 cm) of head in widely spaced plants (50 cm x 50 cm) than in narrowly spaced plants (50 cm x 30 cm) which resulted in 14, 617 g, 16 cm, and 11 cm of the respective parameters. They attributed the better growth of plants in the wider spacing to availability of sufficient light and nutrients which led to optimum vegetative growth. The highest head weight per plant (1.65 kg) and marketable yield (66.07 t ha^{-1}) were recorded in the wider spacing than the narrow spacing which resulted in smaller head size (1.32 kg) and yield (52.7 kg).

Table 5. Main effects of spacing (combined over location, year and variety) on yield and yield components of head cabbage

Treatment	Plant population (ha^{-1})	Head diameter (cm)	Head height (cm)	Head weight (Kg)	Yield (t/ha)	Non-wrapper leaves $plant^{-1}$	
						Number	Weight (Kg)
40 cm x 20 cm	125000	13.03b*	15.00	1.09c	88.84a	10.46c	0.45c
40 cm x 30 cm	83333	13.57ab	15.18	1.23bc	89.55a	10.77bc	0.52bc
40 cm x 40 cm	62500	14.23a	15.74	1.45ab	73.68abc	11.30bc	0.58abc
50 cm x 20 cm	100000	13.39ab	14.19	1.21bc	80.15ab	11.55bc	0.53bc
50 cm x 30 cm	66666	13.56ab	15.33	1.36abc	77.68ab	11.63bc	0.60ab
50 cm x 40 cm	50000	14.32a	15.93	1.57a	71.54bc	12.18ab	0.67a
60 cm x 40 cm	41666	14.00ab	15.31	1.39ab	57.7c	12.89a	0.62ab
SE		0.36	0.41	0.1	5.71	0.41	0.05
Critical value		1.08	ns	0.29	17.15	1.24	0.14
CV(%)		9.12	9.27	24.9	25.69	12.40	29.03

*Means followed by the same letter are not significantly different at 5% level of probability by Tukey's test at 0.05 level of probability. ns non-significant difference

Head weight uniformity

The different spacing treatments also showed differences in size and uniformity of heads. Results in Fig. 1 showed that there was a linear increase in the proportion of smaller (0.5 kg-1.0 kg) and medium (1.01-1.5 kg) sized heads at higher population density. More than 87% of cabbage produced in the densest plant population of 125 000 weighed between 0.5 and 1.5 kg while the remaining 12.5% were those which weighed 1.51-2.0 kg with no heads in the largest size category. On the other hand, there was an increase in the proportion of large sized (1.51 – 2.0 kg and over 2 kg) heads with wider plant populations. The highest proportions of 58.3%, 54.2%, 45.8% and 37.5% heads between 1.51 kg and 2.5 kg were recorded with the 62 500, 50 000, 66 666 and 41 666 plants ha^{-1} that corresponded to 40 cm x 30 cm, 50 cm x 30 cm, 50 cm x 20 cm, and 40 cm x 20 cm), respectively. Kolota and Chohura (2015) recorded 75.2% marketable yield ($\geq$ 1.5 kg heads size) when cabbage was grown at 44 000 plants ha^{-1} whereas only 32.2% was marketable at the densest population of 74 000 plants ha^{-1}.

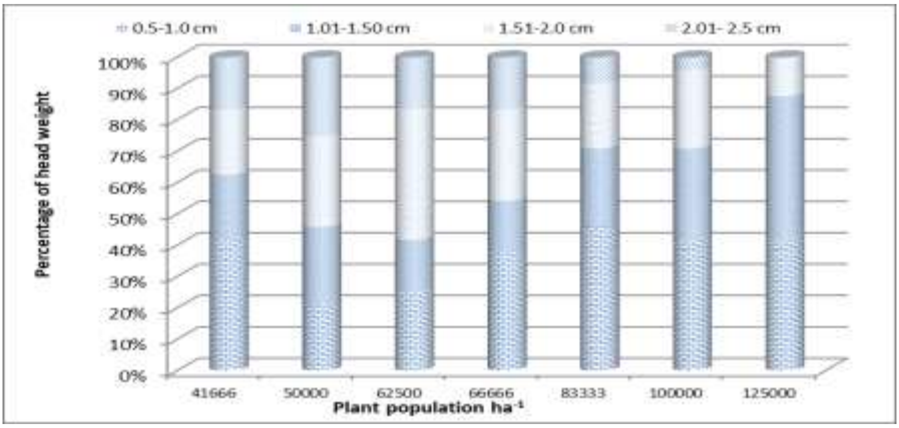

Figure 1. Cumulative percentage of different head size categories recorded in cabbage grown at different plant populations

Correlation among parameters

Correlation analysis among the parameters showed that head diameter (r = 0.26), head height (r = 0.38) and head weight (r = 0.31) had positive and highly significant with yield (Table 6). On the other hand, number and weight of non-wrapper leaves had non-significant correlation with yield.

Significant positive correlations were also observed among diameter, height and weight of heads. Moreover, the parameters were positively and significantly correlated with weight of non-wrapper leaves but non-significantly correlated with the number of non-wrapper leaves.

Table 6. Correlation among yield and yield component parameters of cabbage

Parameter	Head diameter	Head height	Head weight	yield	No. Non-Wrapper Leaves plant^{-1}	Weight non- wrapper leaves plant^{-1}
Head diameter		0.55**	0.52**	0.26**	0.20*	0.53**
Head height	0.55**		0.82**	0.38**	-0.08	0.44**
Head weight	0.52**	0.82**		0.31**	-0.06	0.56**
Yield	0.26**	0.38**	0.31**		-0.17	0.04
No. non-wrapper leaves	0.20*	-0.08	-0.06	-0.17		0.42**
Weight non-wrapper leaves	0.53**	0.44**	0.56**	0.04	0.42**	

n for diameter, height and weight of head and yield = 168 and for no. and weight of non-wrapper leaves = 126

Conclusions and Recommendations

Results of the present study showed that Copenhagen Market produced the best yield (99.69 t ha^{-1}) at 40 cm and 20 cm between rows and plants, respectively whereas Landini F1 produced the highest yield (96.9 t ha^{-1}) at 40 cm inter and 30 cm intra-rows. The control, on the other hand, produced only 59.78 t. Better yields of both varieties were observed at Kulumsa than at Debre Zeit. Therefore, the 40 cm x 20 cm and 40 cm x 30 cm spacings are recommended for Copenhagen and Landini F1, respectively. Kulumsa was found to be the suitable location for growing both cabbage varieties owing to its cool climate suitable for head formation. As the study was conducted at two locations and two varieties, it is thus, recommended that further studies involving other cabbage varieties with different head sizes be undertaken in a wider range of agro-ecologies.

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Participatory Demonstration and Evaluation of Improved Onion Technology in East Shewa Zone of Oromia National Regional State, Ethiopia

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Abstract

Onion is one of the most important vegetable crops cultivated in Ethiopia. However its productivity is low compared to its potential yield on the research plots. So, participatory demonstration and evaluation of an improved onion variety - Nafis with its associated production practices was conducted together with the standard check -Bombay Red in Adama, Lume and Adamitulu-Jidokombolcha (AJ) districts of East Shewa Zone in Oromia National Regional State during 2018/19-2019/20. A total of 37 farmers were purposively selected and hosted the demonstrations on 9.3 hectares. Nafis variety performed higher than the check with 29 320 kg/ha mean bulb yield. This technology gave 10 740 kg/ha more bulb yield than Bombay Red. Nafis was preferred by farmers compared to Bombay Red because of its higher yield, deep red color, medium bulb size, tolerance to disease, pungency, market preference and longer storage life. Therefore, Nafis should be scaled up in a larger area in the East Shewa zone and similar agro-ecologies to enhance onion production and productivity.

Introduction

Onion is one of the most important vegetable crops cultivated in Ethiopia. The crop is produced as a cash crop and it is widely used to increase the taste of the different types of food. Onion is cultivated by smallholder farmers and commercial growers both under irrigation and rain feed conditions the predominant area being irrigation production system (Asfaw and Eshetu, 2015). According to Jibcho *et al*. (2018) onion production has greatly expanded into new areas of the country where it was not known or not highly suitable. Ethiopia is also importing a significant amount of fresh onion bulbs although an increasing trend of gap between the seasonal demand and supply is high.

Currently, area of onion production occupied about 36.4 thousand hectares with a total production of 273,859 tons in Ethiopia (CSA, 2020). The total production and the total cultivated area for onion grew by 36% and 41%, respectively between 2006/07 and 2019/20. The productivity of onion, however, showed an inconsistent trend and smallholder farm yield is low (CSA 2012/13-2019/20) compared to the potential yield (40 t/ha) at research stations (MoANR, 2018). The low productivity could be attributed to use of old variety, limited availability of quality seeds, disease (such as purple blotch) and low adoption of recommended production package (Bedru *et al.,* 2009; Gashawbeza *et al.,* 2009; Muluneh *et al.,* 2019).

The Ethiopian Institute of Agricultural Research (EIAR) has released or recommended a range of high-yielding varieties that can enhance the productivity of Onion in the country. Amon these, Bombay Red and Adama Red are popular varieties. More recently a variety named Nafis that has higher yield than Bombay Red and Adama Red was released. However, variety release in itself is not an end to improve the productivity unless it is promoted and reached their beneficiaries to increase productivity and income. Wider scale utilization of these improved varieties requires intensive promotion work and adoption. The present study was therefore carried out to demonstrate and evaluate the performance of the recently released Onion variety Nafis with its recommended agronomic packages together with the widely used onion variety Bombay Red so that farmers can compare its performance with existing variety and adopt it based on awareness created.

Materials and Methods

Description of the study area

The study was conducted in East Shewa zone Adama, Lume and Adamitulu Jidokombolcha (AJ) districts in Oromia National Regional State. The zone is located east of Addis Ababa. It extends from 7^0 33' 50" N to 9^0 08 ′56" N and from 38^0 24′ 10″ to 40^0 05′ 34″ E in sub-tropical and tropical climatic zones. A large portion of the zone is located along the Central Rift Valley. Based on the annual rainfall and temperature of the area, the major climatic classes of the zone are dry climate and tropical rainy climate (Legesse and Suryabhagavan, 2014).

Farmer selection and field management

Three districts, Adama, Lume and Adamitulu JidoKombolcha (AJ) were selected from the East Shewa Zone based on their area of onion production. In consultation with the district agricultural experts, farmers who have an interest in the technology, access to irrigation, willingness to manage and allocate fields for the demonstration were selected to host the demonstration. Training on onion production and management practices was given to thirty-seven host farmers and ten development agents working in the study site. The training included both theoretical and practical aspects. During visits made in the area, field management gaps were identified by researchers. To fill this gap, field-level training was also given through organizing farmers into small groups on issues raised by farmers.

Following the training, the newly released variety Nafis was planted side by side with the popular check Bombay Red variety. Each demonstration plot was established on 0.25 hectares. The recommended technology package of onion production like seeds and inputs for the demonstration was provided by Melkassa

Agricultural Research Center (MARC). In the demonstration plots, farmers planted the seedlings at the spacing of 40 cm, 20 cm and 5 cm between furrows, rows and plants, respectively. In addition, 200 kg/ha of NPS and 100kg/ha of Urea were applied, where 150 kg of NPS was applied during transplanting while 25 kg of NPS applied after 15 days of transplanting with 50 kg of Urea at first hoeing. During second hoeing (45 days after transplanting) the remaining half of the Urea (50 kg) and 25 kg of NPS were applied. The plots were irrigated depending on the moisture condition of the soil at every 4–7 days interval. Weeding and hoeing were done by hand. Mancozeb, Nativo SC 300, and Redomil Gold pesticides were used to control fungal disease. To control thrips, Profit and Fighter 70% WP were applied. The crop was harvested when 90 percent of the leaves turned yellow and the top leaves start to fall. The harvested bulb of all varieties was left to dry for four days then the leaves were removed to get dry bulbs of onion.

Data collection and analysis

Both qualitative and quantitative data were collected during periodical follow-up of the activity with the joint action of the stakeholders. A data record sheet was developed to collect all necessary data. Field observation and data collection were made following our regular field visits to the demonstration plots. Yield data and farmers' preferences or feedback on the newly demonstrated variety against the popular check variety were also collected. Finally, the collected data were analyzed using descriptive statistics using SPSS. The gaps between the potential yield and demonstration yield as well as extension gap were calculated using the following equations (Samui *et al.*, 2000). That is,

- Technology gap = Potential yield – demonstration yield and
- Extension gap = Demonstration yield – farmers yield

Results and Discussion

Yield performance

The demonstration yield of the Nafis variety performed better than the check-Bombay Red, which is popular among onion-producing farmers. Nafis variety produced an average bulb yield of 29 320 kg/ha as compared to the average yield of the popular Bombay Red check variety (20 740 kg/ha). The highest yielding variety Nafis gave a 41 percent yield increment over the check, Bomay Red variety. Comparing the yield difference across the districts the highest bulb yield (32 210 kg/ha) was recorded in the Lume district. Pooled mean bulb yield of Nafis across respective demonstration districts and across years was also higher yield than the Bombay Red variety. A similar yield increment was also reported by Bedru *et al.* (2009). The yield increase of Nafis variety is due to the combined effect of its high yielding character and relative tolerance to disease (purple blotch) as compared to Bombay Red. The increased yield in demonstration plots showed the feasibility and suitability of Nafis variety under irrigation in the study areas.

Table 1. Yield performance of Nafis as compared to Bombay Red during 2018/19 and 2019/20

Location	Year	No. of demonstrations	Area (ha)	Yield (kg/ha)	
				Nafis	Bombay Red (check)
Adama	2018/19	8	2.0	34600	23240
	2019/20	5	1.3	19640	16500
Mean		13	3.2	27120	19870
Lume	2018/19	8	2.0	31130	10130
	2019/20	5	1.3	33290	22580
Mean		13	3.3	32210	16360
AJ	2018/19	6	1.5	24120	23300
	2019/20	5	1.3	33110	28690
Mean		11	2.8	28620	26000
Pooled Mean		37	9.3	29320	20740

Technology gap and extension gap

Nafis has produced higher yield compared to the popular check Bombay Red. The average yield increment of Nafis over Bombay Red was 48 percent (Table 3). The technology gap indicates the gap between the potential yield and the demonstration yield. Similarly, it indicates the extent to which the technologies are adopted and the yield could increase. This feedback is essential to remove bottlenecks and accelerate the adoption of improved technologies (Neha *et al*., 2018). Hence, the technology gap was calculated for improved onion and found to be 10 680 kg/ha. The technology gap observed may be attributed to dissimilarity in the soil fertility status and weather conditions. A similar result was also reported by Bedru *et al.,* (2009). The highest extension gap was found in Lume and Adama districts (15 850 kg/ha and 7 250 kg/ha, respectively). The extension gap emphasized the need to inform and provide an option for onion-producing farmers through various extension approaches using various methods like training, skill and experience sharing, awareness enhancement via traditional and modern information dissemination channels. This will help facilitate the adoption of improved high yielding varieties with their recommended packages. Producing onions using Nafis variety in the East Shewa zone could also narrow the wide extension gap.

Table 2. Average productivity, technology gap and demonstration gap of onion

Location	Nafis potential Yield (kg/ha)	Demonstration yield (kg/ha)		Yield increase over check (%)	Technology gap (kg/ha)	Extension gap (kg/ha)
		Nafis	Check			
Adama	40 000	27 120	19 870	37	12 880	7 250
Lume	40 000	32 210	16 360	97	7 790	15 850
AJ	40 000	28 620	26 000	10	11 380	2 620
Mean	40 000	29 320	20740	48	10680	8580

Farmers varietal preference

The onion varieties demonstrated were also evaluated by farmers' preference criteria. The criterion used for the evaluation by farmers in all districts were: yield, relative tolerance to disease and insect, bulb size, bulb color (deep red color is the most preferred), pungency, storability, and market preference. Farmers ranked Nafis as the most preferred variety compared to Bombay Red. Accordingly, Nafis ranked first in all the criterion set by farmers except tolerance to insects (Table 4). During group discussion, it was pointed out that seeds shortage of improved variety, disease and insect, high price of chemicals and market price fluctuation was the major constraints hindering onion production and productivity in the areas. The farmers also identified thrips and purple blotch as major pests affecting onion production in these districts. A similar result was also reported by Yetayh *et al.* (2019).

Table 3. Ranking of onion varieties based on farmer's preference criteria

Criterion	Nafis	Bombay Red
Market preference	1	2
Better yield	1	3
Good bulb color	1	2
Average bulb size	1	2
Relative tolerance to insect	3	3
Pungency	1	2
Relative tolerance to disease	1	3
Storability	1	2
Total Score	10	19
Rank	1st	2nd

NB: Preference scale 1–3; high preference = 1; medium preference=2; and low preference = 3

Conclusion and Recommendation

The result of the improved onion technology demonstration and evaluation helped the stakeholders to see the yield potential of Nafis compared with Bombay Red. The study also emphasized opportunities should be given to farmers to use improved varieties of onion with their recommended agronomic practices to narrow the extension gap. The demonstration also created greater awareness and motivated farmers to adopt an improved variety- Nafis. In short the yield obtained from Nafis was higher compared to that obtained from Bombay Red. Moreover, Nafis is preferred over Bombay Red due to tolerance to disease and insect, bulb size, pungency, storage time, market preference. Therefore, Nafis is recommended for large-scale production by replacing Bombay Red to increase the production and productivity in one hand and improve the livelihood of onion farmers in the East Shewa zone and similar agro-ecologies.

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Evaluating of Improved Orange Flesh Sweet Potato (*Ipomoea batatas*[L] Varieties in Mid Land Area of South Omo Zone, Ethiopia

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Abstract

A field experiment was conducted at Jinka Agricultural Research Center site during the 2018 and 2019 cropping seasons. The experimentwas carried out to test the adaptability of improved Orange fleshed sweet potato varieties and select high-yielding variety/ies for the target area. Five improved orange fleshed sweet potato varieties (Kabode, Naspot-13, Naspot-12, Mayai and Kulfo) were tested in randomized complete block design with three replications. The collected data on tuber yield and yield related parameter were subjected to ANOVA (analysis of variance) using SAS 9.3 computer software version. The over years combined analysis of variance result showed a significant ($p<0.05$) difference for vine length, tuber diameter and the number of tubers plant^{-1}; very highly significant ($p<0.001$) difference for tuber length and dry matter and highly significant ($p < 0.01$) difference for marketable tuber yield and total tuber yield. However, there was non-significant ($p>0.05$) difference in the number of marketable tubers per plant among the varieties. The interaction of varieties and year also found to be highly significant ($p<0.01$) in dry matter. The higher mean value of marketable tuber yield (43.21 ton h-1) and total tuber yield (46.9 ton h-1) was recorded from the variety Kabode and had a good mean performance for yield-related parameters and dry matter content. Therefore, variety Kabode was identified as the highest yielding and adaptable orange fleshed sweet potato variety at the midland area of South Omo Zone and similar agro-ecologies in different parts of Ethiopia.

Introduction

Sweet potato (*Ipomoea batatas* L.) is a dicotyledons plant belonging to the family *Convolvulaceae* which is a tuberous root crop mainly cultivated in tropical and subtropical areas (Kurabachew, 2015; Oggema *et al*., 2007). It is known as one of the most important food security crops by its reliable yield and growing in a wide range of environmental conditions using low inputs (Ewell, 2002). Following potato and cassava, it is the world's third most important crop, and one of the root and tuber crops widely cultivated in East Africa as basic food for rural communities (Laban *et al*., 2015).

In Ethiopia, it is cultivated and utilized in the south, southwestern and eastern parts by the small-scale farming system (Gurmu F., 2019). Nationally, the total area covered by a sweet potato is 53,449 ha with a productivity of 34.58 tons/h in the 2017/18 cropping season (CSA, 2018). Most sweet potato varieties currently grown by farmers in the country are white-fleshed. While, the orange-fleshed sweet potato varieties, which are recognized to be a strong source of vitamin A, are a new to the country (Kurabachew, 2015). It is believed that OFSP varieties were introduced in Ethiopia in the year 2005 (Muzhingi *et al*., 2011).

Orange fleshed sweet potato is an excellent food security crop since it is easy to cultivate, vigetativly propagated and relatively drought tolerant once established (Low *et al*., 2007). Furthermore, for poor families in developing nations, it gives considerable amounts of energy (293 to 460 kJ/100 g) as well as vitamin A (Low *et al*., 2007; Fanzo *et al*., 2013) because of OFSP contain a significant level of beta carotene, which is used by the body to generate vitamin A. (Wariboko and Ogidi, 2014).

Vitamin A deficiency (VAD) is known as a public health issue in developing countries including Ethiopia. Vitamin A deficiency leads to blindness, retarded growth and death (Gurmu, 2019). Across the country, children and mothers have a prevalence rate of 0.8 and 1.8 percent for night-blindness, respectively due to shortage of vitamin A (Tiruneh and Urga 2017 2019). The consumption of just small amounts of foods prepared from the OFSVs could eliminate or greatly reduce Vitamin A deficiencies in both young children and pregnant and lactating women (Harvest Plus, 2002). As a result, production of orange-fleshed sweet potato (OFSP) is one food-based approach that has great potential to decrease Vitamin A deficiency (VAD). But, farmers largely cultivate white-fleshed sweet potato varieties which have no beta carotene, poorly suited and have low root yields. Therefore, identifying environmentally adapted OFSP varieties in the area is essential to address food security issues and combating Vitamin A deficiency. The objective of this experiment was to find out adaptable of improved orange fleshed sweet potato varieties and select high-yielding variety/ies for the study area.

Material and Methods

Description of the experimental site

The experiment was conducted atJinka Agricultural Research Center research site during 2018 and 2019 cropping seasons. Geographically, the administrative center of South Omo Zone Jinka is located in the southern region and is found about 729 kilometers from the capital Addis Ababa. Astronomically, Jinka lays roughly between coordination of 360 33" 370 67"E and 50 46" 6057" with an altitude of 1450 m.a.s.l. The rainfall distribution of the area is bimodal with the main rainy season extending from January to May and the second cropping season, from July to October. The average annual rainfall of the area in the last ten years was 1307.3 mm with two seasons while an average of temperatures ranging from 21.0 ºC to 28.0 ºC. The soil of the experimental site is sandy loam in texture with a soil pH of 6.41 (Tekele and Walelign, 2014).

Treatments and experimental design

Five improved orange fleshed sweet potato varieties obtained from Hawassa Agricultural Research Center were included in the experiment. The trial was laid in a Randomized Complete Block Design (RCBD) with three replications.The net plot size was 2.4m*4.8m with intra and inter row spacing of 30 cm and 60 cm, respectively. Healthy cuttings from each variety were planted on the prepared ridge. All other agronomic practices were done as per the standard operation recommended for sweet potato production.

Data collected

To evaluate the performance and adaptability of Orange Fleshed Sweet Potato (OFSP) varieties all the data on tuber yield and yield related parameters such as tubers length, tubers girth, number of tubers per plant, number of marketable tubers per plant, marketable tuber yield, total tuber yield and dry matter were recorded. The middle harvestable rows were used as a representative sample to avoid the border effect. Total tuber yield per hectare was calculated as:-

$$yield\ ton\ h^{-1} = \left(\frac{yield\ per\ plot\ (kg) * 10000\ m^2}{11.52m^2\ (net\ potot\ size}\right)/1000$$

For tuber dry matter content, a peeled fresh tuber is chopped into small pieces and weighted. Then, it was put into an oven-dry at 125°C for 24 hours. After that, it was weighed again to determine the dry weight and calculated as: $DM = \left(\frac{dry\ root\ weight\ (g)}{freash\ root\ weight\ (g)}\right) * 100$

Data analysis

The collected data were subjected to analysis of variance (ANOVA) using the SAS computer software version 9.0. Mean separation was carried out using Least Significance Difference (LSD) test at a 5% probability level. Over-years data were combined after testing of normality and homogeneity of the collected data.

Result and Discussion

The combined analysis of variance over the two years results revealed that there were significant ($p<0.05$) differences among the varieties in all tuber yield and yield related parameters except the number of marketable tuber per plant (Table 1). This result is in agreement with Mekonnen, *et al*. (2015) who reported that the OFSP varietal effect had a significant influence on the yield and yield-related parameters. The years' effect significantly ($p<0.01$) affected tuber length, tuber diameters, number of marketable tuber plant^{-1}, and total tuber yield (Table 1). However, the variety x years interaction effect was non-significant ($p>0.05$) for all parameters except dry matter content (Table 1).

Vine length: The mean of vine length differed significantly ($p<0.05$) among the varieties (Table 1). The vine length ranged from 213cm for Mayie to 131.73cm for Kulfo (Table 2). This indicates that variety Maie can be used as a good vine source especially where production is aimed at producing sweet potato vines for feed. This result conforms with the report of Mekonnen (2015a) and Kathabwalika *et al*.(2013) who reported significant differences among the orange fleshed sweet potato genotypes in vine length.

Tuber length and diameters: From the analysis of variance, tuber length and diameters were highly significantly($p<0.001$) and significantly ($p<0.05$), respectively were affected by varieties (Table 1). The variance in tuber diameter and width seen across the OFSP varieties may be due to genotypic differences. The tuber length varied from 22.9 cm for Kabode to 15.61cm for kulfo and tuber diameter ranged from 9.66cm for Naspot-13 to 6.82cm for Mayai (Table 2). This result conforms with the findings of Gebremeskel *et al*.(2018) who reported significantly longer tubers (26.33 cm) and tuber diameters (5.3 cm) from the variety Kabode.

The number of tuber plant^{-1} and unmarketable tuber plant^{-1}: Varieties differed significantly ($p<0.05$) in the numbers of tuber per plant (Table 1)**.** The maximum number of tuber per plant (6.6) was recorded from the variety Naspot-12, while the minimum number of tuber per plant (4.03) and unmarketable tuber per plant (2.5) was recorded on Kulfo (Table 2). A similar result was also reported by (Shumbusha *et al.*, 2014) in the orange fleshed sweet potato genotype.

Marketable: Highly significant ($p<0.01$.) difference was observed in marketable tuber yield among the varieties (Table 1). Mekonnen *et al.*(2015a) reported similarly significant differences in marketable tuber yield among OFSP varieties. The highest marketable (43.21 ton h^{-1}) tuber yield was recorded from varieties Kabode. In contrast, the lowest marketable (20 ton h^{-1}) tuber yields was recorded from the variety Kulfo (Table 2). This shows that variety Kabode can transform most of its photosynthetic products into carbohydrates stored in tuberous tuber below ground as compared to the other varieties. Tuber yield could be related to genetic variations among genotypes in partitioning photosynthesis (Assefa *et al*., 2020).

Table 1: Mean Square Values for Yield and Yield Components of Orange fleshed sweet potato as Varieties at Jinka Agricultural Research Center Research Site in 2018 and 2019 Cropping Season

S.varation	DF	VL	TL	TD	NTP	NMTP	MTY	TTY	DMC
Replication	2	2589.7	6.99	1.76	5.29	1.73	118.3	131.3	1.40
Treatment	4	6238*	69.04^{***}	3.66^{*}	5.13^{*}	2.96^{ns}	463.3^{**}	576.8^{**}	290.4^{***}
year	1	31066.6	154.64^{***}	5.85^{*}	14.14^{**}	8.11^{*}	231.29^{ns}	19.84^{ns}	5.08^{ns}
Yer*tret	4	681.8ns	8.35^{ns}	2.43^{ns}	3.1^{ns}	1.07^{ns}	97.07^{ns}	100.18^{ns}	34.05^{**}
Error	18	1373.6	5.73	1.17	1.37	1.04	84.38	107.39	6.9

Where: VL= Vine Length, TL= Tuber Length, TG= Tuber Girth, NTP= Number of Tuber Plant^{-1}, NMTP= Number of Marketable Tuber Plant^{-1}, MTY= Marketable Tuber Yield, TTY= Total Tuber Yield, DMC= Dry Matter Content

Table 2: Combined Means Values of Yield and Yield Component of Orange fleshed sweet potato Varieties Tested at Jinka Agricultural Research Center Research Site in 2018 and 2019 Cropping Season

Varieties	**Cm**				**Ton h^{-1}**			**%**
	VL	TL	TD	NRPP	NMTPP	MTY	TTY	DMC
Kabode	190.07^{a}	22.9^{a}	8.78^{a}	5.73^{a}	4.06	43.21^{a}	46.9^{a}	33.43^{a}
Naspot-13	197.93^{a}	21.53^{a}	9.66^{a}	5.56^{a}	3.36	36.83^{ab}	42.8^{a}	28.08^{b}
Naspot-12	199^{a}	17.15^{b}	7.97^{ab}	6.6^{a}	4.15	38.11^{ab}	44.5^{a}	33.7^{a}
Mayai	215.83^{a}	22.81^{a}	6.82^{b}	5.56^{a}	3.08	31.9^{b}	39.9^{a}	33.58^{a}
Kulfo	131.73^{b}	15.61^{b}	7.9^{ab}	4.03^{b}	2.46	20^{c}	22.4^{b}	17.58^{c}
Mean	186.91	20	8.02	5.5	3.42	34.02	39.33	29.27
LSD (0.05)	44.95	2.9	1.31	1.42	Ns	11.14	12.57	3.18
CV%	19.8	11.97	13.49	21.29	29.87	27	26.34	8.97

*Where: - VL= *Vine Length, ***TL= Tuber Length *TD= Tuber Diameter, *NTP= Number of Tuber Plant^{-1}, NMTP= Number of Marketable Tuber Plant^{-1}, **MTY= Marketable Tuber Yield, **TTY= Total Tuber Yield, ***MDC= dry matter content, LSD= Least Significance Difference, CV= Coefficient of Variation.*

Total tuber yield: highly significant differences ($p<0.01$) among the varieties was also observed for total tuber yield (Table 1). Similarly result of Kathabwalika*et al.* (2013) observed a significant difference in total tuber yield among the orange fleshed sweet potato genotypes. The highest (46.9 ton h^{-1}) total tuber yield was recorded from the variety Kabode followed by the varieties Naspot-12 (44.5 ton h^{-1}), Naspot-13 (42.8 ton h^{-1}) and Mayai (39.9 ton h^{-1}) which were none significantly different from each other; whereas the lowest (22.4 ton h^{-1}) total tuber yield was observed from Kulfo (Table 2). The difference in total tuber yield might be associated with the potential of varieties to adapt to the testing agro-ecology. These results are in agreement with the findings of Mwanga *et al.* (2016) and Dibi *et al.* (2017). But, the current tuber yield result contradicts the finding of Gebremeskel *et al.* (2018) and Birhanu *et al*. (2014) who reported higher total tuber yield from Kulfo and the mean tuber yield of Kabode remained below average in their trial.

Dry matter content: Very highly significant ($p<0.01$) difference occurred in dry matter content (DMC) among the OFSP varieties evaluated (Table 1). The over years mean for DMC varied from 33.58% to 17.58% (Table 2). According to the combined mean, the highest DMC (33.7%) was recorded from Naspot-12 followed by Mayie (33.58%) and Kabode (33.43%) which were not significantly different among each other. However, the lower DMC (17.58%) was recorded from the variety Kulfo (Table 2). The varieties which had higher DMC is sweetest and acceptable than varieties which had lower DMC (Gurmu *et al*., 2017). These values of DMC of OFSP varieties are in agreement with the report of Gurmu and Mekonen (2019) who reported tuber dry matter content of 31.9 % for Eju/Ukr-to 22.9 % for Kulfo OFSP genotypes. Similarly, Mekonnen, *et al*. (2015) reported lower DMC from Kulfo as compared to other varieties. The average dry matter content in sweet potato vary widely depending on varietal difference, environment and climatic condition (Vijayan and Mohan, 2017). Shumbusha *et al*. (2014) also suggest that varietal gene actions are important in controlling DMC.

Conclusion and Recommendation

The result of the over two years combined analysis of variance showed that most important tuber yield and yield related parameters such as: tuber length, tuber diameters, number of tuber per plant, marketable tuber yield, total tuber yield and dry matter content had significant ($p<0.05$) differences among the tested Orange Fleshed Sweet Potato varieties. The highest mean marketable tuber yield (43.21 ton h^{-1}) and total tuber yield (46.9 ton h^{-1}) was recorded from the variety Kabode and had a good mean performance for yield-related parameters and dry matter content than Naspot 13, Naspot-13, Mayai and Kulfo varieties. Therefore, variety Kabode was identified and recommended for demonstration owing to its high yield and adaptation in the midland area of South Omo Zone and similar agro-ecologies.

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Evaluation of Cassava (*Manihot esculenta* Crantz) Genotypes for Root Yield and Related Traits in Southwest Ethiopia

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Abstracts

The root yield of cassava is highly affected by genotype, environment and genotype by environment interactions (GEI). The size of GEI hinders identification of superior genotypes in terms of performance, stability and adaptability. A key step in applied plant breeding is identification of superior genotypes that are well adapted to target environments. The objectives of this study were thus to estimate the magnitude of GEI and to select stable cassava genotypes with superior fresh root yield, root diameter and plant height, and to identify the most discriminating and representative test environments in Ethiopia for future breeding programs. The study was conducted for two cropping seasons (2016-2019) at Jimma, Metu and Teppi, southwest Ethiopia. Eight cassava genotypes and one standard local check were evaluated using a randomized complete block design with three replications. Data from fresh root yield, root diameter and plant height were collected and subjected into analyses of variance. A combined analysis of variance detected the presence of significant variation among locations, and year and their interactions for fresh root yield, root diameter and plant height. Genotypes performance stability analysis across these environments (locations and years) revealed that G1 (IITA 1000388) and G8 (IITA 1050127) had the highest mean fresh root yield across environments, whereas G2 (IITA 011196) and G4 (IITA 1010098) were superior for root diameter and plant height. Environments 2 and 5 were epitome for high fresh root yield, root diameter and plant height, respectively and highly close to the ideal environment. Overall, G1 (IITA 1000388) and G8 (IITA 1050127) were identified to be the best genotypes based on their relative response to a respective environment. Environment 2 was the most suitable environment for discriminating between genotypes and representative of test environment.

Introduction

Cassava is a crop that belongs to the genus *Manihot* and family *Euphorbiaceae.* It is among the most important root crops in tropical and sub-tropical areas of the world and provides food for one billion people (Bokanga, 1999; Nuwamanya *et al.,* 2010). It is also an important food crop in developing countries that stands fourth source of calories, after rice, sugar cane and maize worldwide (Akinwale *et al.,* 2011). Its edible storage roots supply energy for more than 800 million people worldwide (Ceballos *et al.,* 2006). The aerial and roots part of the crop is also used to produce tapiocas, special flours, appetizers, and animal feed during the dry season.Cassava is grown well in drought-prone, marginal wastelands under poor management where other crops would fail (Tewodros and Zelalem, 2015). Hence, it has significant contribution in the diets of the people living in these parts of the country. In Africa the crop is the most important staple food grown that plays a major role to alleviate food crisis (Hahn and Keyer, 1985). In Ethiopia cassava is cultivated in the South, Southwest and Western parts of the country to overcome hunger.

Though casave has the ability to grow in marginal areas and variable environments (Mkumbira *et al.*, 2003), different genotypic responses occur due to the interaction of genotype x environment (G x E). GEI is defined as the differential or inconsistent performance of genotypes across environments, and it reduces the association between phenotypic and genotypic values (Romagosa and Fox, 1993). The effects of these two factors, however, are not always additive because of the interaction between them. A significant GEI results from changes in the magnitude of differences between genotypes in different environments or from changes in the relative ranking of the genotypes (Jandong *et al*., 2019). The presence of significant G x E interaction presents problems of comparing varieties and recommending genotypes for wider adaptation (Moussa *et al*. 2011). Hence, G x E interaction effects should be analyzed using appropriate techniques in order to understand their existence, pattern and magnitude (Annicchiarico, 2002). To this effect evaluation of genotypes in multiple environments and years is crucial. Understanding the nature of G x E interactions and quantifying their magnitude is also essential for crop improvement and to identify the most discriminating and representative test environments in southwest Ethiopia. However, information on the magnitude of G x E on yield and yield components of improved cassava genotypes in Ethiopia is lacking. Identification of yield contributing traits and knowledge of GEI along with root yield stability have tremendous importance for developing new varieties with improved adaptation and yield in the target environments.

Various procedures are vaiable to evaluate the G X E and stability of genotypes under different set of environments. Evaluation of the G x E interactions using the F-test is a relatively straightforward approach. However, this analysis does not give detailed information of genotypes respose to environmental variations. Hence, employing alternative procedures such as additive main effect and multiplicative interaction (AMMI), and genotype plus genotype × environment (GGE) bi-plot methods that will help to predict the responses of genotypes in diverse environments are crucial. AMMI is a statistical model that combines analysis of variance with principal component analysis to adjust the main effects and G×E interaction effects (Aina *et al*., 2007). Equally, the GGE bi-plot analysis is used to determine the relationship between genotypes and display environments graphically (Yan *et al*, 2000). These models provide valuable insights for assessing the extent of G×E interactions in multi-environmental trials. This study was therefore, designed to estimate the magnitude of G x E interactions, to identify stable and high yielding cassava genotypes for root yield and related traits, and to identify the most discriminating and representative test environments in southwest Ethiopia.

Materials and Methods

Description of study areas

The multi-locational evaluation trail was conducted in three locations namely; Jimma, Metu and Tepi Agricultural Research Centers which are considered as the representative cassava growing areas of southwest Ethiopia. The experiments were conducted for two cropping seasons (2016-2019) in all three locations. This made a total of six environments considering one location and one cropping season as one environment. Jimma Agricultural Research Center (JARC) is located at 1753 m.a.s.l., 7^{o} 40.00' N latitude and 36^{o} 47’.00’ E longitude. The area receives mean annual rainfall of 1432 mm with mean maximum and minimum temperatures of 29.2 ^{0}C and 8.90 ^{0}C, respectively. The soil of experimental plot is sandy loam. Metu sub-center of JARC is situated at 625 km to the southwest of Addis Ababa. The site is located at 8°18′ .00' N latitude, 35°35′ .00’ E longitude and at an altitude of 1550 meters above sea level. The area receives mean annual rain fall ranging from 1200 to 1520 mm. The average temperature of the area is 20^{0}C. The soil of Metu sub-center is sandy loam. Tepi Agricultural Research Center is located at a distance of about 220 km to the west of Jimma. The site is located at 7^{o} 40.00' N latitude, 36^{o} 47’.00’ E longitude and an altitude of 1200 meters above sea level.

Plant materials, experimental design and trial management

A total of nine cassava genotypes (eight from IITA and one from Jimma as standard check) were used for this study. The list of genotypes and areas of collection was presented in Table 1. In each environment the experiment was laid out in a randomized complete block design with three replications. Each cassava genotype was assigned to one plot in each replication. The gross plot size for each treatment was 6m x 4m, using inter-row and intra-rows spacing of 1m, respectively. Cuttings of the same size and age were used as planting material. Planting was done at mid pril during the main growing season after the rain commenced when the soil was adequately moist. One month after planting, seedlings were earthed up and frequently weeded. All other agronomic practices were applied as per the recommendation.

Table 1. List of nine cassava genotypes and their areas of collection

ID	Genotypes	Areas of collection
G1	IITA 1000388	IITA
G2	IITA 011196	IITA
G3	IITA 1980505	IITA
G4	IITA 1010098	IITA
G5	IITA 1020326	IITA
G6	IITA 1010131	IITA
G7	IITA 192B006	IITA
G8	IITA 1050127	IITA
G9	Kello	Jimma

Data collection

Data were collected from eight plants of each plot and the average values were used for data analysis at maturity. The characters that are used for data analysis included plant height (m), fresh root yield, root girth, root diameter (cm) and root fresh weight (t/ha).

Data analysis

Initially simple analysis of variance (ANOVA) was carried on data collected at locations during both years. Subsequently, homogeniety test of error variance was carried before running a combined analysis of variance. Following the confirmation of absence of error variance heterogeniet, a combined analysis of variance (ANOVA) was performed to determine the effects of environment (E), genotype (G) and year (Y) and their two and thrtee ways interaction. A combined analysis of fresh root yield, root girth and plant height data across the environments were carried using GenStat 14th edition (Payne *et al*. 2011) and SAS version 9.0 (SAS, 2000) statistical packages. The following statistical model was used for combined analysis of variance across environments:

$$Yijkl = \mu + Gi + Ej + GEij + Rk(j) + Bl(k) + \varepsilon ijkl$$

Where: Yijkl is observed value of genotype *i* in block *l* and replication *k* of environment *j*, μ is grand mean, Gi is effect of genotype *i*, Ej is environment or location effect, GEij is the interaction effect of genotype *i* with environment *j*, Rk(j) is the effect of replication *k* in environment *j*, Bl(k) is the effect of block *l* in replication *k*, ϵijkl is error (residual) effect of genotype *i* in block *l* and replication *k* of environment *j*.

G x E and stability analysis

The G x E interaction and stability analyses were conducted using a GGE bi-plot procedure (Yan, 2001; Yan *et al*. 2007) in GenStat 14th edition. The model for a GGE bi-plot based on singular value decomposition (SVD) of *t* principal components is:

$$Y_{ij} - \mu - \beta_j = \lambda_1 \xi_{i1} \eta_{j1} + \lambda_2 \xi_{i2} \eta_{j2} + \varepsilon_{ij}$$

Where: Y_{ij}= is the performance of genotype *i* in environment *j*, μ= grand mean, β_j = main effects of environment j, $\mu + \beta_j$ = the mean yield across all genotypes in environment j, λ_1 and λ_2= are the singular values (SV) for the first and second principle components (PCA 1 and PCA 2) respectively.ξ_{i1} and ξ_{i2} = are eigenvectors of genotype i for PCA 1 and PCA 2, respectively, η_{j1} and η_{j2} = eigenvectors for environment j for PCA 1 and PCA 2, respectively. ε_{ij}= residual associated with genotype i in environment j.

Results and Discussion

Analysis of variance

Results of a combined ANOVA was carried to determine the effects of environment (E), genotype (G) and year (Y) and their two and thrtee ways interaction as presented in Table 2. Variance due to environment (E) were very highly significant ($p \leq 0.001$) for all the traits studied. Similarly, variance due to genotype (G) was highly significant ($p \leq 0.001$) for fresh root yield and diameter. Likewise, year (Y) was highly significant ($p<0.001$) for fresh root yield, plant height and root diameter at $p \leq 0.01$. The Y x E interactions on the other hand were non-significant for root diameter except for fresh root yield and plant height at $p< 0.01$ level of probability. Equally, G X E interaction and three way interaction effects (G x Y x E) showed highly significant ($p<0.01$) for almost all traits and significant ($p \leq 0.05$) for fresh root yield (Table 2). Hence, undertaking stability analysis of genotypes for these traits is vital.

Table 2. Combined analysis of variance and significant tests for cassava yield and related traits of nine genotypes tested in two years and three locations.

Source of variation	DF	Mean squares		Plant height (cm)
		Fresh root yield (t/ha)	Root diameter (cm)	
Environment (E)	2	5127.61***	3.766**	4.511***
Genotype (G)	8	597.44***	1.658**	0.122
Year (Y)	1	6440.36***	4.272**	1.634***
Y*E	2	5551.99***	0.964	2.170***
Rep (Y*E)	10	175.94*	1.195*	0.31***
G*E	16	176.42*	1.535**	0.207**
G*Y	8	154.06*	1.195**	1.102**
G*Y*E	16	164.00*	1.097**	1.076**
Error	161	89.19	0.57	0.09

*, **, ***significant at 0.05, 0.01 and 0.001 % of probability level.

Performance of genotypes across individual locations

Root Yield

The mean fresh root yield value of genotypes averaged over environments (Table 3) indicated that genotypes IITA 1000388 and IITA 1010131 had the highest and lowest tuber fresh yield of 51.76 and 35.62 t/ha, respectively. The environments mean fresh root yield ranged from 31.53 t/ha (ENV-3) to 70.09 t/ha (ENV-2) and average tuber yield over environments and genotypes is 42.73 t/ha. ENV-2 and ENV-5 identified as the most favorable for tuber yield (70.09 and 43.63 t/ha, respectively) and are suitable environments. ENV-3 and ENV-4 were unfavorable since they resulted in the lowest mean tuber yield (31.53 and 33.75 t/ha, respectively). 0918765823r

Table 3: Mean values of cassava root yield (tons/ha) evaluated in the 6 environments.

Genotype	Environments						Overall mean
	ENV-1	ENV-2	ENV-3	ENV-4	ENV-5	ENV-6	
IITA 1000388	38.44	86.60	39.04	40.13	53.18	53.18	**51.76**
IITA 011196	32.13	65.90	28.43	31.33	42.09	41.55	40.24
IITA 1980505	35.10	62.55	27.31	32.85	48.31	47.15	42.21
IITA 1010098	38.05	71.39	34.51	37.21	47.14	46.64	45.82
IITA 1020326	32.94	58.24	28.55	30.95	35.54	35.08	36.88
IITA 1010131	28.77	57.50	22.54	26.92	39.45	38.56	35.62
IITA 192B006	30.13	68.71	31.32	30.70	33.25	33.53	37.94
IITA 1050127	33.36	90.09	35.39	36.37	53.71	53.72	**50.44**
Kello	37.95	69.81	36.65	37.28	40.00	39.97	43.61
Mean	34.10	**70.09**	31.53	33.75	**43.63**	43.26	42.73

Root diameter

The highest root diameter was observed in environment-2 followed by environment-1 and environment-6 (Table 4). On average, genotypes IITA 011196 and IITA 1010131 produced the highest and the lowest root diameter of cassava, respectively.

Table 4: Mean of cassava root diameter (cm) evaluated in the 6 environments

Genotypes	**Environments**						**Overall mean**
	ENV- 1	**ENV- 2**	**ENV- 3**	**ENV- 4**	**ENV- 5**	**ENV- 6**	
IITA 1000388	5.958	6.536	4.973	5.342	5.758	5.806	5.729
IITA 011196	5.790	6.369	5.192	5.577	5.753	5.795	**5.746**
IITA 1980505	5.591	6.065	5.384	5.630	4.842	4.866	5.396
IITA 1010098	5.170	5.746	4.935	5.329	5.263	5.297	5.296
IITA 1020326	5.189	5.828	5.019	5.510	5.845	5.885	5.546
IITA 1010131	4.406	5.049	4.319	4.819	5.126	5.165	4.814
IITA 192B006	5.705	6.095	5.177	5.285	4.111	4.131	**5.804**
IITA 1050127	4.590	5.211	5.307	5.807	5.468	5.490	5.312
Kello	5.717	6.305	3.995	4.350	5.288	5.351	5.168
Mean	**5.346**	**5.912**	4.922	5.294	5.273	5.310	5.343

Plant height

The tallest cassava genotypes were IITA 1010098 and IITA 1980505 and had plant height value of 2.351 and 2.299 m, respectively (Table 5). Environment-5 and environment-6 are the best environments for better plant growth as shown in plant height with mean value of 2.79 and 2.24 m, respectively (Table-5). The environments contributed significantly to the differential performance of genotypes across environments resulting in either cross over or non-cross over G x E.

Table 5: Mean of cassava plant height evaluated in the 6 environments

Genotype	Environments						
	ENV- 1	ENV- 2	ENV- 3	ENV- 4	ENV- 5	ENV- 6	Overall mean
IITA 1000388	1.986	1.951	1.968	2.047	2.955	2.162	2.178
IITA 011196	2.522	2.378	1.930	1.886	2.730	2.267	2.286
IITA 1980505	2.263	2.111	2.007	1.910	3.328	2.177	**2.299**
IITA 1010098	2.202	2.216	2.149	2.317	2.802	2.417	**2.351**
IITA 1020326	2.175	2.175	2.020	2.174	2.617	2.318	2.247
IITA 1010131	2.149	2.098	1.892	1.970	2.636	2.179	2.154
IITA 192B006	1.634	1.759	2.031	2.338	2.688	2.216	2.111
IITA 1050127	2.056	2.017	2.128	2.187	2.271	2.274	2.156
Kello	1.907	1.891	2.018	2.113	3.082	2.173	2.197
Mean	2.099	2.066	2.016	2.105	**2.790**	**2.243**	2.220

G x E and stability analysis using GGE bi-plot

Fresh root yield

GGE-bi-plot analysis of fresh root yield using PC1 and PC2 is presented in Figure 1. This figure shows which genotype performs best where or which is best for which environment. Based on over mean fresh root yield performance of the genotypes across the six environments, IITA 1000388 is leading by its impressive performance in ENV-1 among tested environments (Figure 1). On the other hand, IITA 1050127 and IITA 1010098 were the most stable genotypes due to their proximity to the horizontal axis. As graphically revealed on the bi-plot, the most stable environment for mean performance in terms of fresh root yield is ENV-1 and is closely followed by ENV-4. For fresh root yield, principal component-1 (PC-1) explained 79.22% of the total variation, whereas PC-2 explained 10.76%, with both axes accounting for 89.98% of the total variation (Figure 1).

Root diameter

The percentage of GGE explained by PC-1 and PC-2 for root diameter was 38.33% and 29.14%, respectively (Figure 2). The bi-plot explained 67.47% of the total variation. Consequently, genotypes G1 (IITA 1000388), G2 (IITA 011196), G4 (IITA 1010098) and G5 (IITA 1020326), which had large positive PC-1 scores, had the highest mean root diameter. On the other hand, genotypes G6 (IITA 1010131) and G8 (IITA 1050127), which had large negative PC-1 scores, had low root diameter (Figure 2). Genotypes that had PC-2 scores near zero such as G3 (IITA 1980505), G4 (IITA 1010098) and G5 (IITA 1020326) were relatively stable. Among these genotypes, only G2 (IITA 011196) and G6 (IITA 1010131) had wider root diameter. Three environments, ENV-4, ENV-5 and ENV-6 had larger PC-1 scores and efficiently discriminated among the genotypes for root diameter. Genotype G4 (IITA 1010098), G5 (IITA 1020326), G1 (IITA 1000388) and G2 (IITA 011196) were the best performer at ENV-4, ENV-5 and ENV-6. ENV-1 and ENV-2 were not a good environment for any of the genotype for root diameter. Genotypes G4 (IITA 1010098) and G5 (IITA 1020326) had shorter absolute length of projection and therefore they can be considered stable with above average root diameter.

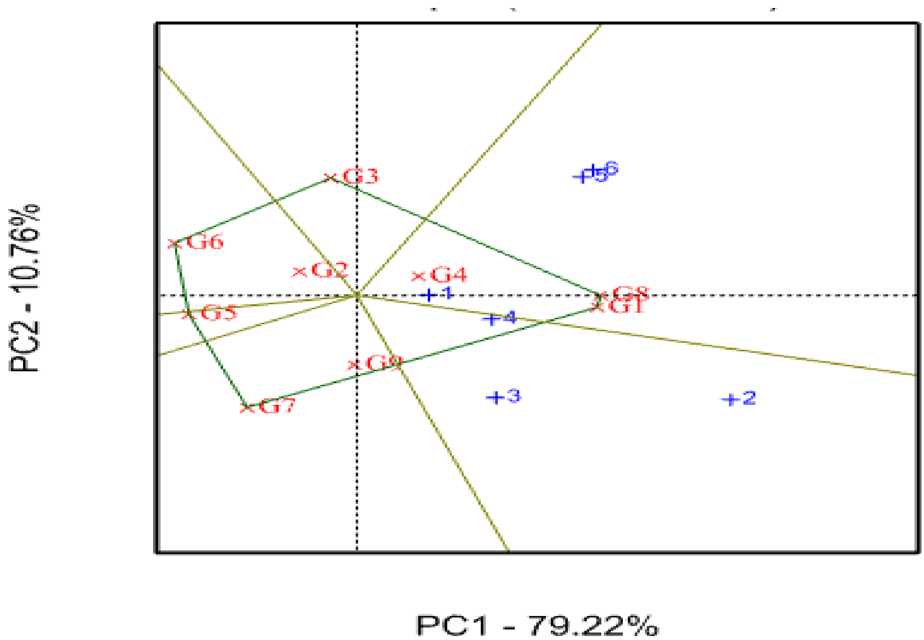

Figure 1: GGE-biplot showing environments and respective cassava genotypes for fresh root yield

Plant height

The GGE-biplot analysis of plant height is presented in Figure 3. Genotype G3 (IITA1980505) had relatively higher PC-1 values with high average plant height. On the other hand, the genotypes G9 (Kello), G1 (IITA 1000388) and G8 (IITA 1050127) had shorter plant heights that were below average. The genotypes G1 (IITA 1000388), G9 (Kello), G8 (IITA 1050127), and G4 (IITA 1010098) had PC-2 scores near zero. Among these genotypes, G3 (IITA 1980505) had relatively tallest height from tested cassava genotypes.

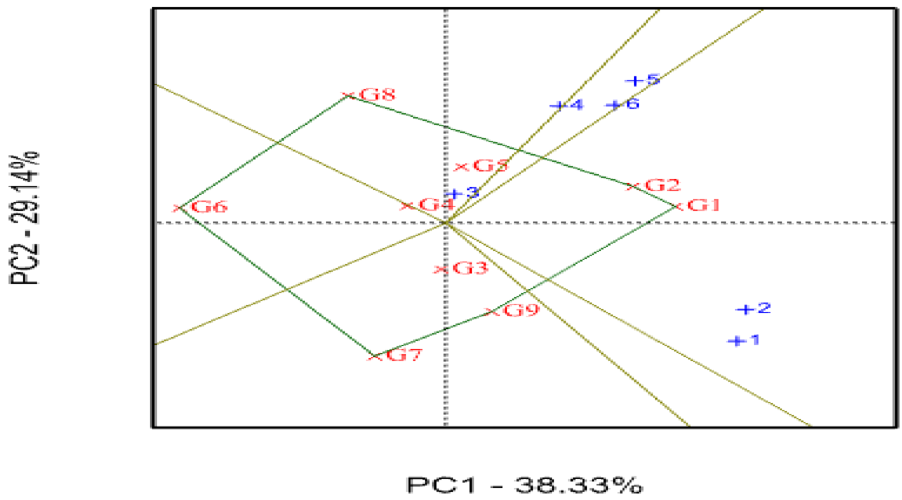

Figure 2: GGE-biplot showing environments and respective cassava genotypes for root diameter

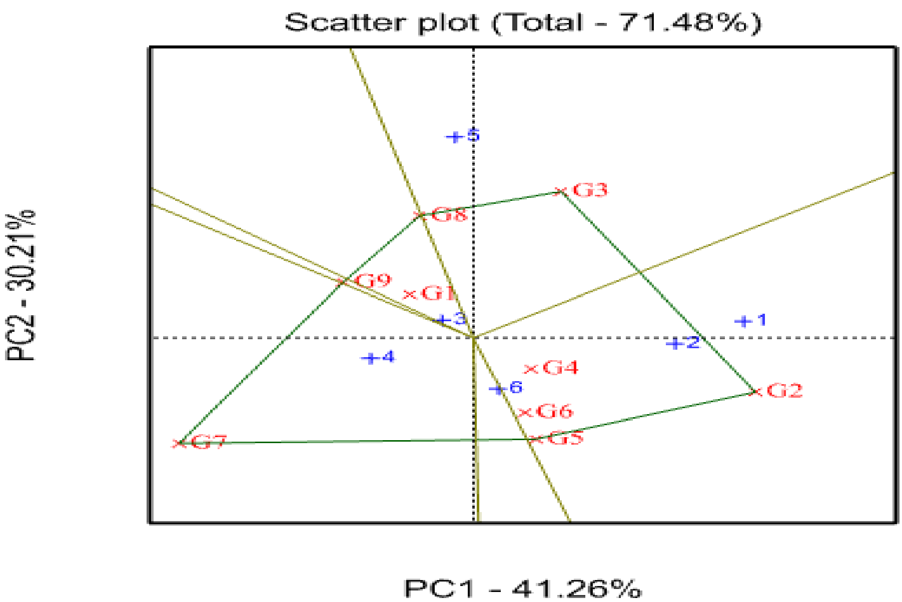

Figure 3: GGE-biplot showing environments and respective cassava genotypes for plant height

ENV-2, ENV-1 and ENV-5 had relatively large PC-1 scores and hence they discriminated better among genotypes for plant height. ENV-6 had PC-2 scores near zero but was the worst performing environment for plant height (Figure 3). The genotypes located at the apex of each sector, genotypes G9 (Kello) and G1 (IITA 1000388), were considered best performers at ENV-3 while G4 (IITA 1010098), G6 (IITA 1010131) and G5 (IITA 1020326) were best performers at ENV-6. Genotypes G1 (IITA 1000388), G4 (IITA 1010098) and G9 (Kello) had shorter absolute projections and therefore they were stable across the test environments. Nevertheless, G4 (IITA 1010098) had lower plant height than G3 (IITA 1980505). Most of the genotypes had above average mean plant height since they were displayed at the right of the AEC*y*-axis. G7 (IITA 192B006) was the worst performing genotype for plant height.

Discussion

The combined analysis of variance (ANOVA) for tuber yield and yield components showed very highly significant variations among environments (L) and genotypes (G) but without similar variations in genotype x environment (G x E) interaction in all traits considered in this study. The significant variations observed in tested traits among the genotypes across environments indicates the existence of variability among the source of genotypes. The present study revealed the presence of G x E interactions for all the three traits studied: fresh root yield, root diameter and plant height with different magnitudes such as 2.63% for fresh root yield, 19.55% for root diameter and 9.57% for plant height. The result further revealed that both the genotypes and environments had significant influence on the yield and yield components performance of cassava in southwest Ethiopia. Furthermore, the significant genotype by environment interaction indicates that the genotypes performed differently across the different environments revealing the complication of selecting a single genotype for all environments, thus need stability analysis for the three traits (Kundy *et al.*, 2014). Similar to the reports of Aina *et al*., (2009) there were significant variations among locations for yield and yield components of cassava. Further, Benesi *et al*., (2004) and Tesfaye *et a*l., (2017) reported genotype x environment (G x E) interaction had significant influence on the starch contents of cassava genotypes collected from Malawi.

Genotypes that pass through the right of the bi-plot origin line are with above average values, while those to the left are with below average values for the trait of interest (Yan 2001; Yan and Kang, 2003). Consequently, genotypes G1 (IITA 1000388), G2 (IITA 011196), G4 (IITA 1010098) and G5 (IITA 1020326) had highest mean root diameter

Genotypes with PC-2 scores near zero are the most stable (Yan *et al.* 2000, Yan, 2001). Genotypes 3 (IITA 1980505), G4 (IITA 1010098) and G5 (IITA 1020326) had relatively low PC2 scores and therefore can be considered relatively stable for root diameter. Among the tested genotypes, G1 (IITA 1000388) and G2 (IITA 011196) were the most stable genotypes with high root diameter. However, when the height of genotypes is considered, G7 had the shortest genotypes among other. Similarly, G4 (IITA 1010098) is the tallest genotype with average stability but low root diameter. Genotypes G1 (IITA 1000388), G4 (IITA 1010098), and G2 (IITA 011196) had shorter absolute projections and they were stable and high yielding for plant height across the test environments. However, G6 (IITA

1010131) had low value of plant height. Breeders face big challenges when breeding to improve the fresh root yield of cassava due to the presence of negative correlations with plant height hence simultaneous improvement of the two traits is a challenge in cassava breeding program (Tewodros and Getachew, 2013). However, in the present study, G1 (IITA 1000388) was stable with above average fresh root yield (51.76 t/ha) and plant height (2.178 m) and can be recommended for further testing to release for wider production.

Environments with large PC-1 scores are superior in discriminating between the genotypes and those with PC-2 scores near zero are more representative of an average environment (Yan *et al*. 2000; Yan, 2001). Four of the test environments, namely ENV-1, ENV-4, ENV-5 and ENV-6 are efficiently discriminated between the test genotypes for fresh root yield and can be considered good environments for testing of cassava genotypes for fresh root yield. Some of the genotypes showed specific adaption to some environments. Accordingly, G1 (IITA 1000388), G8 (IITA 1050127) and G9 (Kello) were the best performers at ENV-4, while G4 (IITA 1010098) was the best performer at ENV-1. Therefore, these genotypes can be recommended for adaptation to specific environments. However, among these genotypes, only G2 (IITA 011196) had root diameter and was stable across environments. ENV-4, ENV-5 and ENV-6 are best environments for root diameter. On contrary, ENV-1 and ENV-2 were not good environments for evaluating genotypes for root diameter. In this study, some of the genotypes, such as G2 (IITA 011196), G4 (IITA 1010098), G5 (IITA 1020326) and G6 (IITA 1010131) had relatively higher PC-1 values and had high average plant height value. Among these genotypes, G6 (IITA 1010131) had high plant height value. However, this genotype had below average root diameter. Generally, two genotypes designated as G1 (IITA 1000388) and G8 (IITA 1050127) were identified as having above average root diameter values of 5.729 and 5.312 cm, plant height of 2.178 and 2.156 m and, stable and high fresh root yields of 51.76 and 50.44 t ha-1, respectively and selected for final evaluation and recommendations.

Conclusions and Recommendation

In the present study, highly significant effects of genotypes, locations, years and their interactions observed for all traits considered. The G×E analysis enabled identification of cassava genotypes with narrow adaptation, which can significantly improve productivity in specific environments. Two stable and high yielding genotypes G1 (IITA 1000388) and G8 (IITA 1050127) were also identified and promoted for variety verification based on their relative response to a respective environment. The results obtained from this study will help cassava breeders and producers for widespread adaptation and cultivation in unaddressed areas of the Ethiopia having similar environment. Thus, the study makes a significant contribution to food security and income generation to the society in the country.

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Evaluation of Cassava Genotypes for High Root Yield and Stability in Diverse Environmental Conditions of Ethiopia

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Abstract

In Ethiopia, cassava is grown mainly in Southern Nation, Nationalities and Peoples Region. However, it expanding to the northern, eastern and western parts of the country. In this study, eleven cassava genotypes promoted from previous preliminary work were evaluated at different agro-ecological areas of the country by including one standard and local check. The eleven cassava genotypes, i.e., 1038, 869, Umbure, M94/0117, 1554, 1630, 1708, M94/0125, 196/624, Kello and Local variety, were planted for two growing seasons of 2015/2017 and 2017/2019 at four research centers and sites namely Hawassa, Dilla, Areka and Jimma. The experiments were laid out in a randomized complete block design and replicated three times. Data on storage root length, storage root girth, storage root weight, above ground biomass weight/plant, harvest index and storage root number were recorded. The collected data were subjected into analysis of variance to determine variability among the genotypes and identify stable genotypes across different locations. The results of this analysis showed the presence of significant difference among cassava genotypes in root yield. Based on genotypic stability index, the cassava genotypes 1708 and M94/125 were selected as the best varieties due to their high stability and yield performance in various environmental conditions. The correlation coefficient analysis indicated association among different agronomic trait. Accordingly, total root yield of cassava was highly significantly and positively correlated with storage root length (r=0.86) while highly significantly and negatively correlated with above ground biomass weight (r= -0.74), plant height (r=-0.77) and storage root girth (r= -0.042).

Introduction

Root and tuber crops are considered as the third important crops after cereals and grain legumes. Root and tuber crops include cassava (*Manihot esculenta* Crantz), sweet potato (*Ipomoea batatas*), taro (*Colocasia esculenta*), yams (*Dioscorea* sp.), Elephant foot yam (*Amorphophallus paeoniifolius*), arrowroot (*Maranta arundinacea*) and other many indigenous root and tuber crops (Nteranya, 2015). These crops are among the most efficient producers of dry matter and edible energy and play an important role in food security and nutrition and adapts well to the changing climate. Root and tuber crops in general and cassava in particular are well known for their unique traits of resilience to climate change. Under the present situation of changing climate where cereals crops production is seriously challenged, tuber crops have the potential to serve as an alternative food crop. It is one of the most drought tolerant crops, capable of growing on marginal soils, and productive crop in low moisture areas. Besides, it is tolerant to pests, diseases and drought and adaptable to various agro-ecological zones as well as poor soils making it an ideal crop of the developing and less developed nations (Padmaja and Jyothi, 2018).Consequently, cassava is referred to as one of the "Future Crops". Cassava produces the highest dry mater among all starchy crops (3 t/ha) followed by yams (2.4 t/ha) and sweet potato (2.1 t/ha) (James, 2018).

Cassava is a major staple food in the developing world, providing a basic diet for over half a billion people. According to FAO, the world production of cassava is 228 million tons (Mt) in 2018 with productivity of 11.3 tones/ha. The top five producers of cassava are Nigeria, Democratic Republic of Congo, Thailand, Indonesia and Brazil (FAOSTAT, 2017). In addition to its significance as food crop, it is an important industrial crop for production of starch, sago and bio-ethanol in countries like Thailand, India, Indonesia and Vietnam.

In Ethiopia, it is mainly cultivated by resource poor farmers on small plots of land. It is an important food security crop and income source to household. It is increasingly becoming a source of industrial raw material for production of starch, ethanol, waxy starch, bio-plastics, glucose, bakery and glue. It is grown in almost all parts of the country. But, south, south western and western parts of the country are known to be a major producing areas (Tesfaye *et al.*, 2013 and 2017). During 2013 cropping season an estimated area of 4942 hectares was planted with cassava and a total of 53036.2 tons of cassava was produced in Southern region of Ethiopia (SNNPR, BOA, 2014). The average productivity of cassava in the country is about 25 ton per hectare (SNNPR, BoA, 2014).

Different varieties are grown by farmers. The varieties found in farmers' field are low yielding, late maturing, and bitter type with some genotypes containing high hydrogen cyanide (Anshebo *et al.*, 2004). To address these challenges different research activities on variety improvement are undertaken with the main objective of developing widely adaptable, high yielding, and disease and insect pest tolerant varieties with desirable quality during previous years. As a result four cassava varieties with low hydrogen cyanide content for food and one variety with high starch content for industrial purpose were released at national level. Cassava varieties which are released for food purposes were released and are being distributed to different major producing areas of southern parts of the country. The areas of distribution included Gamogofa, Wolita and Gedeo zones, and Sidama region from southern part whereas Sekota and Mytsebri from Northern part of the country. Crop improvement research is a continuous process to increase productivity of a given crop and identify variety with wide environmental adaptation. Accordingly, evaluation of eleven cassava genotypes including one standard and one local check were undertaken at different agro-climatic conditions with the main objective of identifying and selecting promising genotypes having high root yield and higher performance stability value. Thus, this paper reports the result of cassava genotype evaluation under different agro-ecological conditions of the country.

Materials and Methods

Description of the study areas

The altitude, longitude, and latitude describing the experimental sites are presented in the following Table 1.

Table 1. Altitude, longitude and latitude of experimental site of Hawassa, Dilla, Jima and Areka

Location	Altitude (masl)	Longitude	Latitude
Hawassa	1708	38° 28' 34"E	7° 3' 43" N
Dilla	1476	38 ⁰ 21'	6 ⁰ 22'
Jima	1753	36⁰E	7⁰46'
Areka	1774	37° 42' 0.00" E	7° 04' 0.01" N

Plant materials and land preparation

The experiments were conducted for two consecutive years during 2015/2017 and 2017/2019 growing seasons at the research fields of Hawassa, Dilla, Areka and Jimma. The eleven cassava genotypes were laid out in a randomized complete block design with three replications during each growing condition. The list of cassava genotypes used in the study were 1038, 869, Umbure, M94/0117, 1554, 1630(1), 1708, M94/0125, 196/624, Kello and Local farmers variety.

The land in each site was adequately ploughed and harrowed, and ridges were prepared manually for planting the trials. Mature cassava cuttings measuring 25 to 30 cm were planted using a spacing of 1m × 1m on the top of ridge at an angle of 45^0 to the ground surface. There was no fertilizer applied to the trials and weeds were manually weeded as necessary. Agronomic data such as growth parameters including plant height, stem diameter, height at first branching, storage root yield and harvest index were recorded. Harvesting was done at 18 months after planting. Storage root yield per plot was recorded and extrapolated to tons per hectare.

Data collection and analysis

The collected data were subjected to analysis of variance using Gen-Stat software version (Payne, 2012) to determine the significance of the main effects and interactions. Combined analysis of all growth parameters as well as root yield and yield components from the different growing environments was done after error homogeneity test.

Regarding to stability analysis, additive main effect and multiplicative interaction (AMMI) model in Gen Stat (Payne, R, 2012) was used to determine stability of the genotypes across environments. AMMI stability value (ASV) was calculated for each genotype according to the relative contributions of the principal component axis scores (IPCA1 and IPCA2) to the interaction sum of squares. The AMMI Stability value (ASV) was calculated as described by Purchase *et al*. (Falconer and Mackay, 1996). The larger the IPCA score is, either negative or positive, the more adapted a genotype is to a certain environment. Smaller ASV scores indicate a more stable genotype across environments (Farshadfar *et al*, 2011). Yield stability index was also calculated using the sum of the rank based on yield and ranking based on the AMMI stability value.

Where: YSI = RASV + RY, (Joseph, 2017)

RASV is the rank of the genotypes based on the AMMI stability value; RY is the rank of the genotypes based on yield across environments (RY). YSI incorporates both mean yield and stability in a single criterion. Low values of both parameters show desirable genotypes with high mean yield and stability (Tumuhimbise *et al*, 2014 and Bose *et al*, 2014).

Results and Discussion

Results of analysis revealed the highly significant ($P< 0.001$) effect of genotypes and environment on most of the traits studied (Table 2). Genotype by environment interaction effect was significant ($P<0.05$) for marketable root number per plant, while very significant ($P< 0.01$) for total marketable yield (ton/ha), plant height and total yield (ton/ha).

Table 2. ANOVA results of eleven cassava genotypes tested at four locations during 2015/2017 and 2017/2019 growing seasons

Variable	**Df**	**SS**	**MS**	**MSe**	**F value**
MRYKG	10	4973.35943	497.33594	1.819	6.24**
MRYT	10	8933.17779	893.31778	2.676	5.38**
MRNPP	10	9790.5848	979.0585	3.292	4.40**
TYKG	10	5709.08694	570.90869	1.94	6.31**
TTT	10	10116.45511	1011.64551	2.805	5.45**
STaH	10	176.001894	17.600189	0.756	3.06**

*Note: **= highly significant at α value less than 0.01*

The AMMI analysis of variance indicated highly significant (*P* < 0.001) effects of genotype, environment, and interaction for almost all traits (Table, 3). Genotypic factors accounted for larger proportion of the treatment sum of squares for marketable root number per plant and for total root yield. The mean performance of all genotypes across the four environments showed significant (*P* < 0.01) genetic variability for almost all yield and yield related traits (Table 3).

Table 3. AMMI analysis of variance for eleven cassava genotypes for yield and yield related traits

		Mean sum of squares					
Source	d.f	SC	MRNPP	MRYKG	MRYT	TYKG	TRY
Treatments	43	135.4***	16016.45***	1360***	1818***	1519	1822***
Genotypes (G)	10	17.6***	16016.45***	497***	893***	571	1012***
Environments E)	3	1831.0***	136.44***	16016***	20369***	17906	19822***
Block	8	2.9	125	100*	158*	234	365**
GXE	30	5.1	280*	182***	271**	196	292**
IPCA1	12	9.1*	382*	285***	430**	277	420**
IPCA2	10	4.0*	298*	169***	265**	205	320*
Error	212	7.2	263	65	159	73	171

Source	df	Sum of Squares					
		SC	MRNPP	MRYKG	MRYT	TYKG	TRY
Treatments	43	5823	128202	58479	5823	65306	117546
Genotypes (G)	10	176	9790	4973	176	5709	10116
Environments (E)	3	5493	110005	48049	5493	53717	59467
Block	8	23	1004	804	23	1868	2924
GXE	30	154	8407	5456	154	5880	8751
IPCA1	12	109	4587	3420	109	3328	5040
IPCA2	10	40	2976	1694	40	2045	3199
Error	212	1534	55670	13706	1534	15403	

*Note: *, **, * * * = significant at P < 0.05, P < 0.01, and P < 0.001, respectively, ns = not significant (P > 0.05), df = degree of freedom, sc= stand count; MRNPP = marketable root number per plant; MRYT= marketable root yield tone/hr, TRY= total root yield*

Average root yield of all genotypes across the four environments was 45.61t/ha. The genotype 1708 had the highest overall root yield of 55.87 /ha followed by a genotype 1554 (35.64 t/ha). Three cassava genotypes namely 1708, M94/0117, M94/0125 and 1038 had significantly higher root yields compared to the other genotypes (Table 4).

Table 4: Mean performance of eleven cassava genotypes evaluated during two years cropping season in four environments

Genotype	Hawassa	Dilla	Areka	Jimma	ARY
1554	33.0	27.92	48.17	33.49	35.64
Umbure	35.00	51.05	42.42	41.75	42.55
869	46.00	43.34	58.40	47.93	48.92
196/624	39.00	43.65	46.06	37.35	41.51
1038	50.00	49.69	68.53	41.85	52.52
1630(1)	43.00	42.71	40.92	44.53	42.79
1708	53.00	50.43	63.27	56.79	55.87
M94/0125	52.00	61.25	56.32	40.81	52.59
M94/0117	50.00	59.69	55.38	45.53	52.65
Kello	35.00	29.80	41.94	43.18	37.48
Local	37.00	42.50	30.09	47.40	39.25
ARY	**43.00**	**45.64**	**50.13**	**43.69**	**45.61**

Note: *- ARY= Average root yield*

Stability analysis helps to identify genotypes whose performance remains stable over several years and environments (Mutegi, 2009). To this effect different stability analysis methods are often used by breeders to identify genotypes that have stable performance and respond positively to improvements in diverse environmental conditions (Farshadfar, 2011). AMMI stability value (ASV) indicates the stability of genotypes. The multiplicative interaction (AMMI) stability value (ASV) ranked the genotypes based on the least score. Genotypes with low ASV value are considered more stable whereas those with high values are considered less stable (Hagos and Abay, 2013).

Based on the ASV, genotype 196/624 was identified as the most stable genotype for root yield since it had the lowest ASV ranking where as genotype 1038 was ranked the least stable because it had the highest ASV score. However, the stability parameter alone without yield performance will not be a criterion for selecting genotypes for genotypes identified to be stable could be low yielder (Joseph, 2017) while looking yield alone as selection criteria may result in selection of high yielding genotypes but unstable ones. Sometimes, the most stable genotypes may not have high yield. Therefore, high root yield is considered together with stability parameter in the estimation of yield stability index (YSI). The YSI is similar to genotype stability index

(GSI) as indicated by Fardshadfar (2011) which combines both yield and stability across environments into one index and enables to select best performing varieties with better stability feature. The YSI is a result of sums of the rank of mean yield across environments with the rank of the ASV of genotypes (Baraki, 2014).

Genotypes with lower YSI are desirable since they combine high mean yield performance with stability parameter (Baraki, 2014). Based on the YSI value, genotypes 1708, M94/0125, 869, 624 and M94/0117 were identified to combine both better yield performance and stability. Though genotypes 624 and 869 had good stability, they have less yield compared to these selected genotypes. Similarly, M94/0117 had high yield but low stability compared to the rest two selected cassava genotypes namely 1708 and M94/125 (Table 5)

Table 5. Ranking of eleven cassava genotypes based on storage root yield, AMMI stability value (ASV), and yield stability index (YSI)

Genotype	Mean FSR	Rank (A)	IPCA-1	IPCA-2	ASV	ASV rank (B)	YSI (A+B)	YSI rank
1038	52.52	4	-3.10336	1.03952	27.67816	11	15	7
869	48.92	5	-1.10051	1.14506	1.531183	2	7	2
Umbure	42.55	7	0.10067	-2.05193	2.05193	5	12	6
M94/0117	52.65	2	-1.72801	-0.72419	9.865226	9	11	5
1554	35.64	11	1.43398	1.81255	2.022597	4	15	8
1630(1)	42.79	6	1.37900	-0.48917	10.96997	10	16	9
1708	55.87	1	0.32385	1.55808	1.558143	3	4	1
M94/0125	52.59	3	-1.51093	-1.93649	2.143843	6	9	3
196/624	41.51	8	0.10730	-0.18924	0.192358	1	9	4
Kello	37.48	10	1.60733	1.68057	2.232948	7	17	10
Local	39.25	9	2.49068	-1.84476	4.90066	8	17	11

Note: - FSR= fresh storage root yield

Hence, differences in environmental adaptations of cassava genotypes have significant importance in identifying and selecting location specific genotypes for different environments. Additive main effect and multiplicative interaction analysis identified highest yielding genotypes in each of the four environments (Table 6). Five genotypes 1708, M94/125, M94/0117, 1038 and 869 were selected for the environment Hawassa while M94/125, M94/117, 1708 and 1630 were selected as the top genotypes for Dilla environment. The top four genotypes in Areka were 1708, M94/117, 196/124, and 1038. The top genotypes in Jima were 1708, 1630, M94/0117 and M94/125. The variations of cassava genotypes in response to different environmental conditions have been reported by different authors. Significant genotypic variations were observed for growth parameters such as plant height, stem diameter, and height at first branching indicating opportunity for selection (Aina *etals*, 2009). This indicates that cassava yield is positively affected by favorable environments. Similar observations were made by Joseph *et al*, (2017) who observed higher yields under optimum environmental conditions. Genotype X environment interaction was observed over the different environments as indicated by diverse environmental adaptation of some cassava genotypes. This resulted in variations in the mean ranks of the genotypes in the different environments.

Table 6: Ranked cassava genotypes based on root yield using AMMI stability value in four different environments

		Rank			
Environment	Effect	1	2	3	4
Hawassa	-0.967	1708	M94/125	M94/0117 &1038	869
Dilla	-0.804	M94/125	M94/117	1708	1630 (1)
Areka	4.386	1708	M94/117	196/124	1038
Jima	-2.614	1708	1630 (1)	M94/0117	M94/125

The correlation coefficient analysis indicated positive and significant association among most recorded traits. Cassava total root yield was highly significant to storage root length. A highly significant and negative correlation was found between total root yield and above ground biomass weight (r= -0.74), plant height (r=-0.77), primary branch (r=-0.87), and storage root girth (r= -0.042). However, it was not significantly correlated with storage root number, storage root weight per plant, above ground biomass weight (ton/ha), storage root weight (ton/ha), and storage root girth. Above ground biomass with ‘r’ value of ‘0.81’ is highly significant and positively correlated with storage root length. On the contrary, it was negatively and highly significantly correlated to primary branch with (r= 83). It was negatively but significantly correlated with primary branch and storage root number with (r = -0.71 and -0.3 respectively) and not significantly correlated with storage root weight per plant. Primary branch was highly significantly and positively correlated to storage root length (r=0.94). There were no any statistical correlation between above ground biomass per plant and plant height, storage root number and storage root weight per plant. Similarly, there was no any statistical correlation between primary branch and storage root girth, storage root number and storage root weight per plant (Table 7).

Table 7. Pearson correlation coefficients of storage root yield and yield component of cassava clones

	TTT	TYKG	Agbpp	Agbwtha	Ph	Pribran	Srg	Srl	Srn	Srwpp	Srwtha
TTT	1	0.99**	-0.74**	-0.74**	-0.77**	-0.87**	-0.04	0.86**	-0.58	-0.08	-0.08
TYKG		1	0.72**	0.72**	0.83**	0.87**	0.10	-0.84**	0.66*	0.02	0.02
Agbpp			1	-1	-0.48	-0.83**	-0.06	0.81**	-0.30	-0.33	-0.33
Agbwtha				1	-0.48	-0.83**	-0.06	0.81**	-0.30	-0.33	-0.33
Ph					1	-0.71**	-0.27	0.56*	-0.78**	0.21	0.21
Pribran						1	-0.26	0.94**	-0.48	-0.05	-0.05
Srg							1	0.22	-0.26	0.06	0.06
Srl								1	0.36	0.20	0.20
Srn									1	0.27	0.27
Srwpp										1	-1
Srwtha											1

Note: PH= plant height in Cm ;SRL= storage root length in cm; SRg= storage root girth in mm; srwtha =storage root weight tons per hectare ;srwpp= storage root weight kg per plant ;agbpp = above ground biomass weight per plant in kg ; agbwtha =above ground biomass weight in ton per hectare; HI= harvest index; pribran =primary branch; srn=storage root number; sc stand count per plot

Conclusion and Recommendation

The yield performance of crop is affected by both environment and genotypic variation. In this experiment, the cassava genotypes 1708 and M94/125 are selected as the best varieties which integrate high yield with stability to different environmental conditions. Based on this, the genotypes 1708 and M94/125 are promoted to the variety verification stage to be released for wider scale of production and utility following their official release.

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Evaluation of Improved Cassava (*Manihot esculanta Cratz)* Varieties in Mid Land Area of South Omo Zone, Ethiopia

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Abstract

An experiment was conducted at Jinka Agricultural Research Center site during the 2018 and 2019 cropping seasons to test the adaptability of improved cassava varieties and to select high-yielding variety/ies for the target area. Four improved cassava varieties (Hawassa-04, Kello, Qulle and Chicu) and one local check were evaluated in randomized complete block design with three replications. Root yield and yield-related data were collected and subjected to analysis of variance (ANOVA) using SAS 9.3 software. Results of ANOVA revealed the significant ($p<0.05$) effect of varieties and year on root yield and yield-related characters such as root length, root diameter, number of root per plant, number of marketable and unmarketable root per plant, marketable root yield, total root yield and dry matter content. However, there was no significant interaction between year and variety. The highest mean value of total root yield (56.91ton h^{-1}) was recorded from Hawassa-04 followed by Kello (42.8-ton h^{-1}). These varieties also had good mean performance in yield-related parameters than local and Qulle varieties. In general, the varieties Hawassa-4 and Kello had 50.95% and 13.5%, respectively better yield than local check. Therefore, the variety Hawassa-04 followed by Kello were recommended to be promoted to wider scale use at the midland area of South Omo Zone and similar agro-ecologies.

Introduction

Cassava (*Manihot esculenta* Crantz) is a dicotyledon perennial shrub plant that belongs to the family Euphorbiaceae. It is native to Brazil and was familiarized to Africa by the Portuguese in the sixteen century (FAO and IFAD, 2001; Andoh, P.K., 2010). Now it is extensively cultivated for consumption in the tropics and subtropics (Burns *et al*., 2010). It is known as an important food security root crop for many African countries smallholders farmers because of its wide adaptation to a variety of soil, climate, drought tolerance and generally, able to grow in difficult environments (FAO and IFAD, 2001; Misganaw and Bayou, 2020). In addition, its storage root is rich in carbohydrates, calcium, vitamin B, C, and essential minerals (Alo *et al*., 2017).

The crop was believed to be introduced to Ethiopia in the middle of the nineteenth century (Tassew, 2007) and it is currently widely grown in the southern part of Ethiopia and plays an important role for consumption, animal feed and income generation to many rural and urban households (Tesfaye *et al*., 2013). The average total coverage and production of cassava per annum in Southern region of Ethiopia is 4942 hectares with the yield of 53036.2 tones (SNNPR, BOA, 2014).

South Omo zone is also considered as one of potential areas of cassava production in southern Ethiopia. Nevertheless, its production and productivity in the southern region in general is constrained by various factors of which lack of high yielding and adaptable varieties to the area and hence cultivation of low yielding, less nutritive, disease susceptible and late maturing varieties by farmers worth mention (Anshebo *et al*., 2004; Gezahegn *et al*., 2018). To alleviate these problems, different research activities have to been carried nationally and improved cassava varieties were released by Hawassa Agriculture Research Center. However, there are limited studies on the performance of these varieties in different agro-ecologies. Therefore, this study was designed to test the adaptability of improved cassava varieties and to select the high-yielding variety/ies for South Omo zone areas.

Material and Methods

Description of the experimental site

The experiment was conducted at Jinka Agricultural Research Center research site during 2018 and 2019 two consecutive cropping seasons. Jinka is located in the southern part of Ethiopia in SNNP Regional State. The administrative center of South Omo Zone Jinka is located 729 km southwest of Addis Ababa at a geographical coordinate of 36^0 33' to 37^0 67'E longitude and 5^0 46' to $6^0$57'N latitude and an altitude of 1450 m.a.s.l. The rainfall distribution of the area is bimodal with the main rainy season extending from July to October and the second cropping season from January to May. The average annual rainfall of the area during the last ten years was 1307.3 mm with two seasons, while average temperatures range from 21.0 ºC to 28.0 ºC. The soil of the experimental site is sandy loam in texture with a soil pH of 6.41 (Tekele and walelign, 2014).

Treatments and experimental design

Four improved cassava varieties (Hawassa-04, Kello, Qulle and Chichu) and one local check were evaluated in this study. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. The total size of each plot was 16 m^2 which contains 4 meters width and 4 meters long. The spacing was 1 m between plant and ridge which contained four rows per plot giving 10,000 plants per hectare. Healthy stem cuttings from 12 months old cassava measuring 30 cm were planted at 45^0 orientations on well-prepared land. The crop is grown under rain-fed conditions. Weeding was performed five times during the whole crop growth period. The crop was harvested 15 months after planting.

Data collected

Quantitative data on agronomic parameters such as root length, root diameters, number of roots per plant, number of marketable roots per plant, number of unmarketable root per plant, marketable root yield, unmarketable root yield, total root yield and dry matter content were recorded at the harvest. Four representative plants were taken from the harvestable row of each plot from the respective treatments by avoiding plants on the boarder rows. Total root yield per hectare was calculated as:-

$$\text{Yield, ton h}^{-1} = \left(\frac{\text{yield per plot (kg)}*10000\ \text{m}^2}{16\text{m}^2\ \text{(net plot size}}\right)/1000$$

To determine root dry matter content, undamaged root sample from each varieties were randomly selected just after harvesting. The selected roots form each varieties were peeled and sliced in to small pieces and then, a sample of 100g (W1) fresh were placed in an oven and dried for 24 hours at 105^{o}C (Teye, *et al*., 2011). The oven-dried samples were weighed (W2) and DM (%) was then calculated as: $DM\ \% = \left(\frac{w2\ (g)}{\text{w1(g)}}\right) * 100$ (Misganaw and Bayou, 2020).

Data analysis

The collected data were subjected to analysis of variance (ANOVA) using the SAS computer software version 9.00. When found significant mean separation among varieties was carried out using Least Significance Difference (LSD) test at a 5% probability level. Over years data were combined after testing the normality and homogeneity of error of collected data.

Results and Discussion

The combined analysis of variance results for the two years' data is summarized in Table 1. Significant differences for all parameters except dry matter content were observed among the varieties. The mean square for year's effect was highly significant for the number of roots per plant, the number of unmarketable roots per plant, and dry matter content. For variety x year interaction, the mean square was not significant for all parameters.

Varieties had a significant ($p<0.05$) effect on root length and a very highly significant ($p<0.001$) effect on root diameter. The longest root was recorded from varieties Hawasa-04 (54.5cm) followed by Kello (50.8cm) and the shortest was recorded from Chichu (41.4 cm) (Table 2). The highest root diameter (8.85cm) was recorded from the variety Howassa-04 while the lowest root diameter (5.7 cm) was recorded from the local variety (Table 2). Storage root size and storage root diameter contributed better than other root yield related traits to cassava yield improvement in this study as previously reported by Tadesse *et al*. (2018).This study was in agreement with the findings of Gebisa and Gezu (2017) and Misganaw and Bayou (2020) who stated that root length and diameter are significantly ($p<0.01$) affected by variety.

Significant differences ($p<0.05$) were also observed among the varieties in the number of roots per plant and number of marketable roots per plant. The highest number of roots per plant (9.83) and marketable root per plant (8.12) were recorded from Hawassa-4 followed by Kello. The lowest number of roots per plant (7.45) and number of marketable roots per plant (5.16) were recorded from Chichu and Qulle, respectively (Table 2). The variation in the number of roots per plant and marketable root per plant area mainly depends on the varietal difference. The number of roots per plant is one of the primary root yield components and contributed for higher production potential of that of Hawassa-04 and Kello than the other tested varieties (Muli, 2019).

Table 1. Combined ANOVA result of mean squares for root yield and yield components of Cassava varieties tested in 2018 and 2019.

SV	DF	RL	RD	NRPP	NMRPP	NUMRP	MY	TY	DM
Replication	2	6.25	0.04	1.41	0.40	0.30	57.86	66.32	0.54
Year	1	29.60^{ns}	0.05^{ns}	19.60^{*}	0.46^{ns}	14^{***}	165.2^{ns}	101.2^{ns}	210.67^{***}
Treatment	4	141.03^{*}	9.94^{***}	7.78^{*}	7.33^{**}	2.18^{*}	501.5^{*}	444.6^{*}	8.66^{ns}
Yer*trt	4	20.77^{ns}	0.13^{ns}	3.07^{ns}	3.51^{ns}	1.28^{ns}	37.82^{ns}	32.31^{ns}	20.67^{**}
Error	18	46.57	0.67	2.16	1.52	0.55	119.71	130.37	3.71

RL= Root length, RD=Root Diameter, NRPP= Number of Root $Plant^{-1}$, NMRPP= Number of Marketable Root $Plant^{-1}$, NUMRPP= Number of Unmarketable Root $Plant^{-1}$, MRY= Marketable Root Yield, UMY= Unmarketable Root Yield, TY= Total Root Yield, DMC=Dry Matter Content, SV= Source of variation, DF= Degree of freedom

The number of unmarketable roots per plant does also significantly affected at ($p<0.05$) and ($p<0.01$) accordingly. The lowest number of unmarketable root per plant (1.33) was recorded from the variety Chichu and the highest number of unmarketable root per plant (2.66) was observed on Kello and Qulle, respectively (Table 2). Based on the mean result, the number of unmarketable roots per plant has directly proportional to unmarketable root yield.

The evaluated varieties had significant ($p< 0.05$) difference in marketable and total root yield. The difference in root yield might be associated with the potential of varieties to adapt to the testing agro-ecology. The higher marketable root yield (54.35 ton h^{-1}) and total root yield (56.91 ton h^{-1}) were recorded from Hawassa-04; whereas the lower marketable root yield (30.48-ton h^{-h}) and total root yield (35.01-ton h^{-h}) were recorded from Qulle with no significant difference over the variety local and Chichu (Table 2). In general, the total root yield of the varieties Hawassa-4 was yielded better than the local check by 50.95%. This result is in agreement with the findings ofTesfaye *et al*., (2018) who reported that Hawassa-4 was high yielder than Qulle. But, these yields were higher than the yield obtained from the study of Misganaw and Bayou (2020) who evaluated the performance of the same varieties in Fafen District, Ethiopia

Table 2. Combined means values of yield and yield component traits of Cassava varieties tested at Jinka Agricultural Research Center Research site, 2018 and 2019 cropping seasons.

Varieties	RL (cm)	RD (cm)	NRPP	NMRP	NURP	MRY (ton ha^{-1})	TRY (ton ha^{-1})	DMC (%)
Hawass-4	54.5^{a}	8.85^{a}	9.83^{a}	8.12^{a}	1.7^{bc}	54.35^{a}	56.91^{a}	43.25
Chichu	41.4^{b}	6.86^{b}	7.45^{b}	6.12^{bc}	1.33^{c}	37.26^{b}	39.51^{b}	44.04
Local	47.23^{ab}	5.7^{c}	8.12^{ab}	6.5^{bc}	1.62^{c}	34.18^{b}	37.70^{b}	43.56
Qulle	49.43^{ab}	5.86^{bc}	7.75^{b}	5.16^{c}	2.58^{ab}	30.48^{b}	35.01^{b}	42.83
Kello	50.8^{a}	6.17^{bc}	9.79^{a}	7.12^{ab}	2.66^{a}	38.98^{b}	43.29^{ab}	45.91
Mean	48.67	6.69	8.59	6.60	1.98	39.95	42.39	43.91
LSD (0.05)	8.27	0.99	1.78	1.49	0.9	13.27	13.85	Ns
CV%	14.02	12.29	17.14	18.67	37.6	28.02	26.82	4.39

**RL= Root length, ***RD=Root Diameter, *NRPP= Number of Root Plant^{-1}, **NMRPP= Number of Marketable Root Plant^{-1}, NUMRPP= Number of Unmarketable Root Plant^{-1}, *MRY= Marketable Root Yield, UMY= Unmarketable Root Yield, *TY= Total Root Yield, DMC=Dry Matter Content, CV=Coefficient of Variance, LSD= List Significance Difference*

Conclusion and Recommendation

The current study result showed the significant performance difference of varieties in all root yield and yield related characters except dry matter content while the interaction between year and variety was non-significant. The higher mean value of root length (54.5 cm), root diameter (8.85cm), number of roots per plant (9.85), number of marketable roots per plant (8.12), marketable yield (54.35 ton h^{-1}) and total root yield (56.91 ton h^{-1}) was recorded from the varieties Hawassa-04 followed by Kello. The varieties Hawassa-4 and Kello gave 50.95% and 13.5%, respectively better yield over local check. Therefore, the variety Hawassa-04 followed by Kello were identified as the highest yielding and adaptable Cassava variety at the midland area of South OmoZone and similar agro-ecologies. In addition, it is advisable to undertake a demonstration of these Hawassa-04 and/or Kello varieties to improve cassava production in the study area.

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Genotype X Environment Interaction and Stability Analysis of Storage Root Yield and Related Traits of Sweet Potato (*Ipomoea batatas* L.) in Southwest Ethiopia

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Abstracts

The economical yield of sweet potato is highly affected by genotype-environment (G × E) interactions. The objectives of this study were to assess the nature and magnitude of G x E interactions of sweet potato genotypes and to identify mega-environments for future breeding strategies. The study was conducted across six environments in southwest Ethiopia. Nine sweet potato varieties and one local check were evaluated using a randomized complete block design with three replications at Agaro, Gera and Haru for two consecutive years from 2019-2020. Marketable root yield, root length and root diameter data were collected and analyzed using the additive main effect and multiplicative interaction and genotype main effect plus genotype by environment interaction bi-plot analyses. A combined analysis of variance detected significant variation in marketable root yield, root length and root diameter among genotypes and locations. However, genotypes and locations interaction effect showed significant variation for only marketable root yield. Local variety, Hawasa-09 and Busto had broad adaptability for marketable root yield while Senensa and Awasa-83, Wondo Genet and local varieties were superior in root length and diameter, respectively. Environments 1 (Agaro) and 5 (Haru) were epitome and highly close to the ideal environment for high marketable root yield and root diameter. Overall, environment 1 (Agaro) was the most suitable environment for discriminating among genotypes and for being a representative test environment. Three mega-environments (MGE) were identified for sweet potato breeding; where environments 2, 5 and 6 combined into MGE-1, environments 3 and 4 were categorized into a separate MGE-2 and MGE-3, respectively.

Introduction

In Ethiopia, root crops production was started 3000 years ago in the way that domestication of indigenous root crops like Ethiopian dinich (*Plectrantus edulis*), anchote (*Coccinia abyssinica*), enset and introduced root crops like cassava (*Manihot esculenta*) and sweet potatoes (*Impomoea batatas*) are many thousand years ago (Gurmu, 2019). Among these crops, sweet potato is a major crop, especially in developing countries and has high yield potential and its plasticity to environmental regimes makes it as one of the best crop for food and nutrition security in Ethiopia. It is the third and fifth most important crop in terms of its value of production and calorie contribution to human diets, respectively. *Batatas* is a member of family c*onvolvulaceae*, in which there are over 400 *Ipomoea* species distributed throughout the tropics; and although some of these species have fleshy roots, they are usually unpalatable but *batatas* is the only one of economic importance. In Ethiopia, about 1.3 million people grow sweet potato to ensure food and nutrition security. Sweet potato is grown from low to mid-land of the country on an area of 54,016 ha with productivity of 35.9 tha^{-1} (CSA, 2017). The distribution and production of this crop is centered in Southern region following the feeding habit of the community. Sweet potato has a lot of advantages. Environmentally, it protect soil erosion through its creeping and land covering habit, economically it is a source of income and a staple food with plenty of carbohydrate, carotene and vitamin sources for food and nutrition security (Manrique and Hermann, 2000). Though it was not cultivated on wider hectares of land, its production is practiced at backyard level where small holder farmers grow local landraces in marginal soil, using few to no organic manure in southwestern part of Ethiopia. Even though it copes harsh environments, sweet potato is highly responsive to environmental variations (Manrique and Hermann, 2000).

Different varieties of the same crop species and the same genus respond differently to different environments due to the effect of different soil fertility gradients, unexpected rainfall and presences and absence of biotic and abiotic stress (Lakew *et al*., 2017). This requires evaluation of different crop genotypes at different environment to identify superior, adaptable and stable genotypes in diverse agro-ecologies. Currently, about 31 varieties of sweet potatoes were developed and registered by the public research institutions in Ethiopia. These varieties were developed based on their yield performance, maturity types, altitude and pro-vitamin A contents. But, shortage of high yielding and adaptable varieties to the traditionally uncommon environment is evident. So, providing farmers with adaptable and high yielding varieties appropriate to the environment is indispensable. Therefore, this study was designed, to identify widely adaptable sweet potato variety/ies and to determine the effect of genotype, environment and genotype x environment interaction and storage root yield stability across environments.

Materials and Method

The study was conducted in Southwestern part of Ethiopia at three different locations viz., Agaro, Gera and Haru for two consecutive years from 2019-2020 G.C and for one season (2020) at Metu. The description of agro-ecological and climatological conditions of the study sites is summarized in Table 1 below.

Table 1. The summary of agro-ecological and climatic description of the study areas

Study Site	Site code		Altitudinal range (masl)	Latitudinal range	Longitudinal range	Average Rainfall (mm)	Average Temperature (^{0}C)
	2019	**2020**					
Agaro	A	Ag	1560	7°51' .00' N	36°51' 35' E	1520	23.35
Gera	G	Ge	1970	7° 31.60' N	36° 15'.00' E	1877.8	18.6
Metu	-	M	1650	8°18' .00' N	35°35' .00' E	1520	21
Haru	H	Ha	1750	8°58'	38°48'	1727	21.5

Experimental materials and design

A total of nine white fleshed sweet potato varieties and genotypes along with one local check were evaluated for their yield performances and yield stability under rain fed condition at different testing sites of Jimma Agricultural Research Center for two consecutive years, 2018/19 and 2019/20 cropping seasons. The nine varieties with respective local variety are listed in Table 2 below. The experiment was laid out in randomized completely block design (RCBD) with three replications.

Table 2. Lists of the ten tested varieties evaluated in the study at the three locations, 2018/19 and 2019/20 cropping seasons.

Varieties	Source
Temesgen	Hawassa Research Center
Beletech	Hawassa Research Center
Busto	Unknown/local collection
Hawassa-09	Hawassa Research Center
Local	Unknown local collection
Arbaminch	Unknown/local collection
Belella	Hawassa Research Center
W/Genet	Unknown/local collection
Awassa-83	Hawassa Research Center
Sensa	Unknown/local collection

Source: Gurmu, (2019)

Experimental procedures and spacing

Land was ploughed during dry season to reduce weed and insect pest infestation before planting at all locations. The plowed land was then harrowed and ridges were prepared before planting the cutting materials on the ridge. The cuttings were planted on the ridge at the recommended inter and intra-row spacing of 60cm and 30cm, respectively. A gross plot size of 4.5m^2 which contained five rows per plot accommodating 25 plants was used.

Data collection and analysis

After six month of planting, yield and related characters such as fresh root yield, root length and root diameters were collected and subjected to ANOVA using SAS vers.9. Additionally, root yield data and related traits were subjected to multivariate analysis, AMMI, to know the main effect of genotype and environment as well as their interaction effects on the yield and related traits. GGE bi-plot analysis was also used for grouping environments into mega-environment and identification of ideal environments. The AMMI model used:

$$Y_{ij} = \mu + g_i + e_j + \sum_{k=1}^{n} \lambda_k a_{ik} \gamma_{jk} + \varepsilon_{ij}$$

Where yij=yield of i^{th} genotype at J^{th} environment, g_i= ith genotype mean deviation, ej=the jth environment deviation, λ_k=square root of eigen value of the PCA axis k,a_{ik} and γ_{jk}=are principal component scores for PCA axis k of the i^{th} genotype and ε_{ij} is the residual.

The AMMI Stability Value (ASV) was also used to estimate the distance from the coordinate point to the origin in two dimensional scatter graph of IPCA score against IPCA2. ASV detected the variation of tested genotypes in yield stability and it was calculated as per Purchase (2000).

$$ASV = \sqrt{[\left(\frac{\text{IPCA1 sum of squares}}{\text{IPCA2 sum of squares}}\right) \times (\text{IPCA 1 score})^2] + (\text{IPCA 2 score})^2}$$

Where IPCA and are interaction principal component axis

The GGE bi-plot model method is based on the model developed by (Yan et al., 2000).

$$Y_{ij} - \bar{y}_j = \lambda_1 \xi_{i1} \eta_{j1} + \lambda_2 \xi_{i2} \eta_{j2} + \varepsilon_{ij}$$

Where yij=yield of i^{th} genotype at J^{th} environment, $\bar{y}_j$=overall mean of the genotype in j^{th} environment, $\lambda_1 \xi_{i1} \eta_{j1}$ and $\lambda_2 \xi_{i2} \eta_{j2}$ are the first and the second principal component, λ_1 and λ_2 are also the auto values of the first and the second IPCA while ξ_{i1} and ξ_{i2} are score of the first and the second principal components respectively whilst ε_{ij} is the error associated with the model.

Result and Discussion

Analysis of variance

The result of the combined analysis of variance indicating the effects of genotypes, environment, year, and their interaction is displayed in Table 4. This result has shown that variance due to all main effects is highly significant over fresh marketable root yield. Also, varieties were highly significantly different in storage root girth but not root length. Fresh marketable root and root length was significantly affected by year at 0.001 and 0.01%, respectively while root girth was not (Table 4). However, the variation due to interaction effect of these main effect viz., Y*G, Y*E, E*G and G*E*Y) were non-significantly different for all attributes except G*Y for fresh root yield (Table 2).

Table 3. Results of the combined analysis of variance of ten WFSP varieties yield and related traits across four locations

Sources of variation	DF	Mean squares		
		Fresh root yield (t/ha)	Storage Root Length (cm)	Storage root girth(m)
Environment (E)	3	15665.98***	506.76***	3363.89***
Genotype (G)	9	337.88*	21.19*	502.69***
Year (Y)	1	35573.48***	109.76**	326.29ns
Y*E	2	7732.04***	452.92***	6958.14***
G*E	27	426.29ns	15.48ns	148.18ns
G*Y	9	755.86*	2.65ns	85.84ns
G*Y*E	27	352.68ns	12.26ns	72.10ns
Error	138	345.90	11.42	139.94
CV		37.99	15.81	17.75
LSD		11.35	2.06	7.22

and two consecutive years, 2018/19 and 2019/20 cropping seasons.
*, **, ***, Significant at 0.05, 0.01 and 0.001 % of probability level.

The AMMI analysis of variance of fresh storage root yield, storage root length and storage root girth revealed the presence of significant variation among tested genotypes. Environment, genotypes and GEI explained 75.14%, 2.73% and 22.13% to the total variation of the storage root yield. Additionally, the first principal component (IPAC1) was highly significant and extracted 48.88% of total variation. But, IPCA2 were non-significant for storage root yield and root length whereas both IPCA1 and IPCA2 of root girth showed non-significant differences. Additionally, environment, genotypes and their interaction effect contributed 74.16%, 6.08% and 19.73% for total variation of root length, respectively.

The first IPCA1 contributed 50.15% of the total variation. Similarly, environment, genotypes and their interaction contributed 69.65%, 13.01% and 17.33% of variations for root girth, in that order (Table 4). Generally, variation due to environment was much more than individual and interaction effect of genotypes and environment. This means that environmental based selection needs more effort.

Table 4. AMMI analysis of variance for sweet potato yield and related traits of ten varieties tested across six environments in Southwest Ethiopia.

Source of variation	DF	Storage root yield (TRY)					Root length (RL)				Root diameter (RDi)		
		SS	MS	Variation explained (%)	G x E Explained (%)	SS	MS	Variation explained (%)	G x E Explained (%)	SS	MS	Variation explained (%)	G x E Explained (%)
Treatments	69	111444	1615			3356	48.63			34763	503.80		
Genotypes	9	3041	338**	2.73		204	22.64**	6.08		4524	502.70**	13.01	
Environment	6	83743	13957**	75.14		2489	414.91**	74.16		24215	4035.80**	69.65	
Block	14	3506	250	0.22		286	20.43	8.52		1903	135.90	5.47	
Interactions	54	24660	457**	22.13		662	12.27**	19.73		6024	111.50ns	17.33	
IPCA-1	14	12055	861**		48.88	332	23.69**		50.15	1881	134.40ns		31.22
IPCA-2	12	7233	603ns		29.33	147	12.22ns		22.20	1785	148.70ns		29.63
Residuals	28	5373	192		21.79	184	6.58		27.79	2358	84.20		39.14
Error	126	44306	352	39.76		1362	10.81	40.58		17821	141.40	51.26	

Df. degrees of freedom, ns: non-significant ($P > 0.05$); *, ** significant at $p \leq 0.01$.

Performance of genotypes across individual locations

Mean storage root yield and related attributes which depicted performance ability of the tested ten sweet potato varieties were summarized below (Table 5). The result showed that the maximum storage yield was recorded from the improved varieties Belella followed by Awassa-83 and Busto with 57.08 t/ha, 52.23 t/ha and 51.61 t/ha, respectively (Table 5). But, other varieties provided yields below the overall mean. Concerning environmental suitability, the maximum mean yield was recorded in E-1 (Agaro), E-5 (Haru) and E-7 (Metu) with average yield of 64.37, 63.93 and 63.56 t/ha and were identified as ideal environment (Table 5).

Table 5. Mean storage rot yield (t/ha) of 10 sweet potatoes varieties over two cropping season at four testing locations.

Genotype	E-1	E-2	E-3	E-4	E-5	E-6	E-7	Mean
Temesgen	62.58	42.80	73.43	8.45	66.58	13.39	72.29	48.50
Belete	60.63	49.08	83.42	11.97	48.75	18.35	60.50	**47.53**
Busto	67.19	61.56	54.49	19.20	70.89	18.56	69.36	**51.61**
Hawassa-09	63.67	58.94	49.57	16.08	67.30	15.09	65.34	47.99
Local	66.04	61.82	51.43	18.69	69.45	17.57	67.37	**50.34**
Arbaminch	62.70	68.55	27.24	19.42	68.39	13.58	59.52	45.63
Belella	73.32	59.22	53.13	20.06	90.44	18.80	84.60	**57.08**
W/Genet	59.55	64.54	62.99	18.67	42.30	20.02	48.86	45.27
Hawassa-83	67.92	**67.74**	52.71	22.78	67.49	21.19	65.79	52.23
Sensa	60.11	82.54	26.04	26.16	47.67	19.09	41.92	43.36
Mean	64.37	61.68	53.44	18.15	63.93	17.56	63.56	48.95

E- Stands for environment

Similarly for storage root length, though there were no as such significant variations observed, Beletech (23.48 cm) and Temesgen (22.25 cm) varieties were superior than others while variety Senensa (19.84 cm) gave root length below the mean value (Table 6). Also, the mean of environment 6 was largest than other environments (26.79 cm) while the mean of environment 4 was the least of all for root length (Table 6).

Table 6. Mean root length (cm) of 10 sweet potatoes varieties over two cropping season at four testing locations

Genotype	E-1	E-2	E-3	E-4	E-5	E-6	E-7	Mean
Temesgen	20.00	16.96	22.06	14.29	26.59	31.90	23.95	22.25
Beletech	24.09	24.31	24.44	17.49	23.74	26.61	23.67	23.48
Busto	19.44	19.46	21.00	12.76	23.33	25.49	22.28	**20.54**
Hawasa-09	21.28	19.64	21.47	15.33	20.97	26.11	20.27	20.72
Local	22.59	21.40	22.62	16.51	21.58	26.33	21.18	**21.74**
Arbaminch	21.14	24.33	22.84	13.37	24.54	22.91	24.65	21.97
Belella	19.78	18.53	21.66	13.49	25.18	28.56	23.39	21.51
W/Genet	19.79	17.22	21.01	14.03	23.31	28.74	21.48	**20.79**
Hawasa-83	21.46	19.48	21.64	15.63	21.20	26.76	20.38	20.94
Senensa	19.02	19.02	20.38	12.36	22.23	24.52	21.33	19.84
Mean	20.86	20.03	21.91	14.53	23.27	**26.79**	22.26	21.38

The variety Temesgen also gave largest root girth of 72.97 mm than all tested varieties followed by Belella, local, Hawasa-09 and Busto with value of 70.67, 70.64, 69.96 and 69.41mm, respectively. Totally, four varieties provided root girth below genotypes mean viz., Beletech (59.56mm), Senensa (60.64mm), A/Minch (60.80mm) and Wondo Genet (64.01 mm) (Table 6).

Related to environmental mean, the maximum root girth of 87.03 mm and 73.01 mm were obtained in environment 6 and 1, respectively. Environment 2 (58.10 mm) and 4 (50.15 mm) were less favorable to root girth with less than mean value (Table 6).

Table 7. Mean root girth (mm) of 10 sweet potatoes varieties over two cropping season at four testing locations

Genotype	E-1	E-2	E-3	E-4	E-5	E-6	E-7	Mean
Temesgen	62.06	56.47	70.02	55.70	65.46	92.99	69.40	67.44
Beletech	65.12	50.64	58.61	44.02	57.74	80.99	59.82	59.56
Busto	77.12	62.70	68.32	47.97	67.81	84.34	77.62	69.41
Hawasa-09	82.27	60.89	66.38	56.11	68.08	93.31	62.68	69.96
Local	72.82	61.94	71.04	53.83	68.86	90.65	75.34	70.64
Arbaminch	82.34	54.95	54.70	39.49	59.22	75.98	58.94	60.80
Belella	75.96	63.99	70.51	48.67	69.09	84.95	81.51	70.67
W/Genet	68.31	55.65	63.71	46.64	62.26	83.41	68.12	64.01
Hawasa-83	75.66	63.53	72.95	58.36	71.11	95.42	73.77	72.97
Senensa	68.47	50.27	58.67	50.69	58.90	88.25	51.21	60.92
Mean	73.01	58.10	**65.49**	50.15	**64.85**	87.03	67.84	66.64

AMMI stability values (ASV)

Variation in yield of sweet potato was observed from environment to environment which showed the presence of crossover G x E interaction (Yan and hunt, 2001) as cited by Lakew *et al*., 2017) and in ASV method, a genotype with least ASV score is the most stable and genotype with least yield stability index are considered as high yielder (Verma *et al*., 2016; Duma *et al*., 2019).

Table 8. AMMI stability values (ASV) and IPCA scores for TRY, RDW and TDi of 10 tested genotypes at six environments in SW Ethiopia

Genotype	SRY				SRL				SRG			
	Mean	IPCAg1	IPCAg 2	ASV	Mean	IPCAg1	IPCAg2	ASV	Mean	IPCAg1	IPCAg2	ASV
Temesgen	48.50	-3.81	0.78	35.01	22.25	-2.56	-0.24	27.31	67.44	2.35	1.72	3.64
Beletech	47.53	-3.87	-2.79	10.72	23.48	1.18	0.30	4.65	59.56	0.38	-0.045	3.21
Busto	51.61	-0.19	0.92	1.63	20.54	-0.04	-0.65	0.65	69.41	-1.84	0.98	3.59
Hawasa-09	48.00	0.03	0.92	1.63	20.73	0.38	0.95	0.96	69.96	0.63	-2.21	2.21
Local	50.34	0.13	0.87	1.54	21.74	0.76	0.97	1.14	70.64	0.11	1.15	1.15
Arbaminch	45.63	3.06	1.56	10.99	21.97	1.43	-1.65	2.06	60.80	-2.53	-2.57	3.57
Belella	57.08	-0.53	3.93	6.96	21.51	-0.98	-0.58	1.75	70.67	-1.92	1.74	2.74
Wondo Genet	45.27	-0.32	-3.80	6.73	20.80	-1.04	0.34	3.20	64.01	-0.21	0.76	0.76
Hawasa-83	52.23	0.65	0.04	18.72	20.94	0.22	1.06	1.06	72.97	0.87	0.43	1.81
Senensa	43.36	4.86	-2.42	17.82	19.84	0.15	-0.49	0.49	60.92	2.18	-1.96	3.12

IPCAg = integrated principal component analysis, SRY=storage root yield tones per hectare, RL = Root length (cm), RDi = root diameter (cm)

According to the result, AMMI stability value of storage root yield indicated significant levels of stability variation among the evaluated 10 sweet potato varieties. Accordingly, local check, Busto and Hawasa-09 variety with ASV of 1.54, 1.63 and 1.63, respectively were found stable varieties while other varieties were found non-stable with larger AMMI stability value in storage root yield (Table 5). For storage root length the most stable varieties with the smallest ASV were Senensa (0.49), Busto (0.65) and Hawasa-09 (0.96). On the other hand, W/Genet, local check and Awasa-83 were stable varieties with ASV of 0.76, 1.15 and 1.81, respectively.

Additive main effects and multiplicative interaction (AMMI) analysis of variance

As indicated below in Figure 1, three varieties Busto, Hawassa-09 and Awasa-83 were found to be widely adaptable varieties as found closer to the center of the bi-plot. Additionally, genotypes found at the right hand side of the bi-plot had positive correlation with the environment of the same side. The yield of varieties considered better than average yield if the angle of vertex of genotypes with IPCA 1 is less than acute angle, near average if right angle and below average if the angle of vertex between varieties and IPCA 1 is greater than 90^o (Duma *et al*.,2019). The varieties like Senensa and Awasa-83 showed yields above average. On the other hand, varieties Senensa, Beletech, WondoGenet, Temesgen and Belella, are located furthest from the center of the origin and showed specific adaptability to Agaro, Gera and Haru, respectively. These environments located furthest from the center such as Ge, Agaro and Ha had highly discriminating ability. These environments having shortest vertex had poor discriminating ability and considered to form one mega environment. Ag has poor discriminating ability while Har, Gera and Metu have medium discriminating ability (Figure 1).

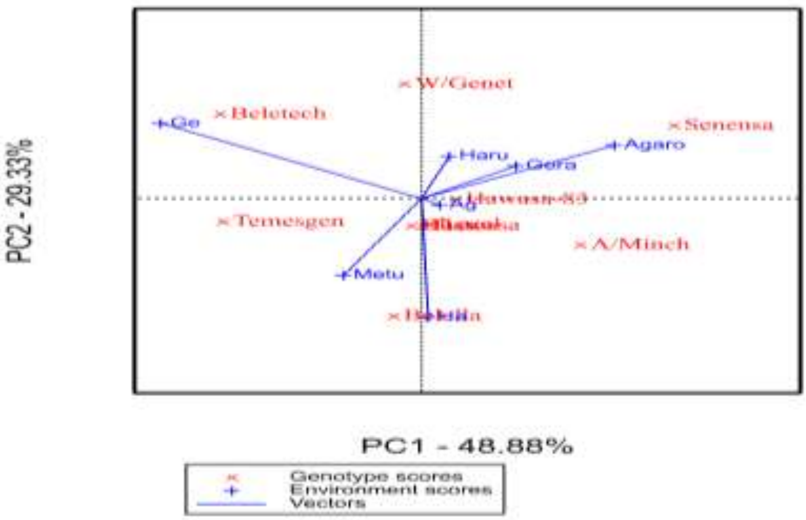

Figure 1. AMMI bi-plot for IPCA 1 against IPCA 2 scores for 10 sweet potatoes varieties and seven environments on marketable storage root yield

In AMMI bi-plot analysis result of storage root yield, IPCA 1 and IPCA2 explained 70.10% of variation where IPCA-1 and IPCA-2 explained 48.88% and 29.33% each of the total variation, respectively. Varieties Hawasa 09, Hawasa-83 and Busto were widely adaptable due to their closeness to the center. Additionally, genotypes found at the right hand side of the bi-plot had positive correlation with the environment of the same side and the varieties like Senensa, Arba Minch, and Awassa-83 showed yields above average. The yield of varieties considered better than average yield if the angle of vertex of genotypes with IPCA 1 is less than acute angle, near average if right angle and below average if the angle of vertex between varieties and IPCA 1 is greater than 90^{o} (Duma *et al*., 2019).

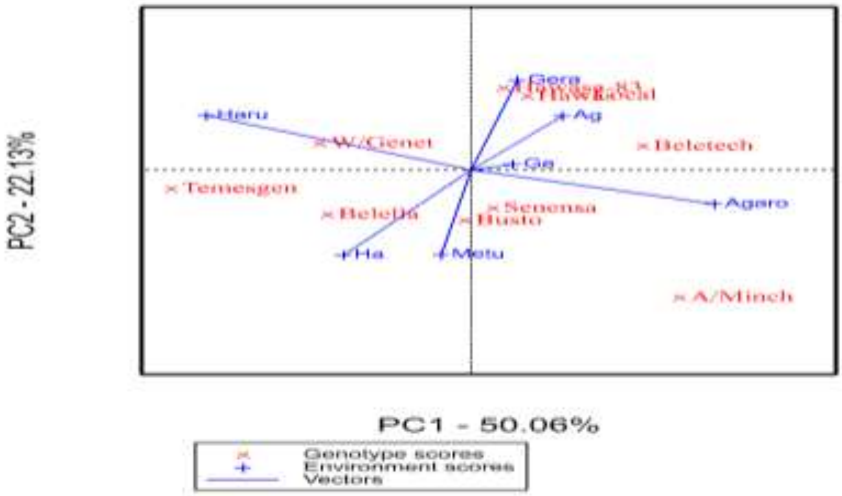

Figure 2. AMMI bi-plot for IPCA 1 against IPCA 2 scores for 10 sweet potatoes varieties and seven environments on root length

The first and the second PCA contributed 72.28% of the total variability in which IPCA-1 shared 50.06% and IPCA-2 shared 22.13% of total variation (Figure 2). The AMMI result for root length revealed that variety Senensa and Busto were widely adaptable varieties due to their closeness to the center of bi-plot whilst Temesgen and A/Minch showed specific environmental adaptability because of their furthest from the origin of the bi-plot. According to the AMMI bi-plot of root length Hawasa-83, Hawasa-09, local and Beletech provided above average root length. In addition, each variety had well adaptability to its closest environment in which Hawasa-83, Hawasa-09, local and Beletech provided well adapted at Gera Senensa and Busto to Metu, Belella to Ha and W/Genet to Haru. Agaro and Haru had longest vertex having highest discriminating ability while Gera has shortest vertex with poor discriminating ability (Figure 2).

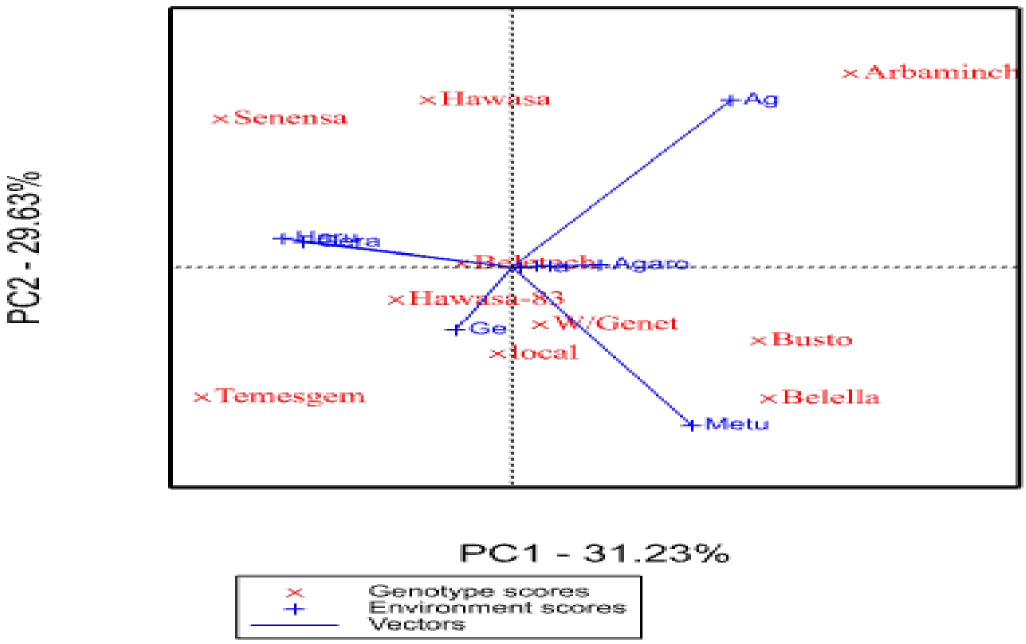

Figure 3. AMMI bi-plot for IPCA 1 against IPCA 2 scores for 10 sweet potatoes varieties and seven environments on root diameter

Concerning root diameter, the first IPCA-1 and IPCA-2 of AMMI bi-plot each contributed 31.23% and 29.36% of the total variation, respectively. In this parameter, Beletech was found closest to the bi-plot origin indicating its wide adaptability and positive correlation with the environment located on the left hand side specifically Gera and Haru. Only variety Abaminch was showed above average root girth which located at right hand side well adapted at Ag environment.

As apparently put in Table 1 and methodology, similar location at different cropping seasons were considered as different environments. For this reason, different cropping seasons act differently on tested varieties. That is because of rain fall, temperature and other environmental factors that vary with season. So, the above result indicated that similar location with different seasons showed high and poor discriminating ability on different crop traits. That is why crop respond differently to these environment differently. This achievement was in parity with the Guch and Zobel (1997) who stated that components of variance error of genotypes such as rain fall, temperature, and disease incidence can result in unique to each year-location combination contributing variation in genotypes response differently to these conditions.

Mega-environmental (ME) analysis using GGE bi-plots

Mega environment represent the division/merging of groups of environment into meaningful mega-environment based on agro-ecological similarity and the response of crop traits to certain environments (Yan and Tinker, 2005). On the GGE bi-plot polygon, the set of lines drawn from the center and intercept with different sides of the polygon. This indicated that, different genotypes won at different locations creating more than one mega environments. This idea supported with the citation of (Yan *et al*., 2007) that when all environment markers fall into a single sector, a single cultivar had the highest yield in all environments and if environment markers fall in to different sectors this indicates different cultivars won in different environments. The GGE bi-plot polygons for marketable fresh root yield, RL and RG are presented below as Figure 4, Figure 5 and Figure 6, respectively. The polygon GGE bi-plot of marketable fresh root yield (Figure 4) indicated three ME in which Agaro, Metu and Haru formed the first mega environment; Agaro Gera and Haru formed the 2nd ME whereas Ge alone formed the third GE. The variety found at the vertex of the polygon considered as winner or well performing variety in the ME. A group of environments or single environment creates ME sector and these environments act similarly on the variety/ies located in the ME as well as the genotype/ies respond equally to the environments. In the 1st ME, Ag, Metu and Ha had similar effect on fresh root yield of their respective Belella which located on that ME vertex performed well in the environment. This idea was supported with the statement of Duma *et al*., (2019) who stated that the environments in the mega environment considered as homogenous environments acting similarly on the genotype/s located on the vertex of the ME sector. In the second ME variety A/Minch and Senensa were the winner being located on the vertex of the sector (Figure 4).

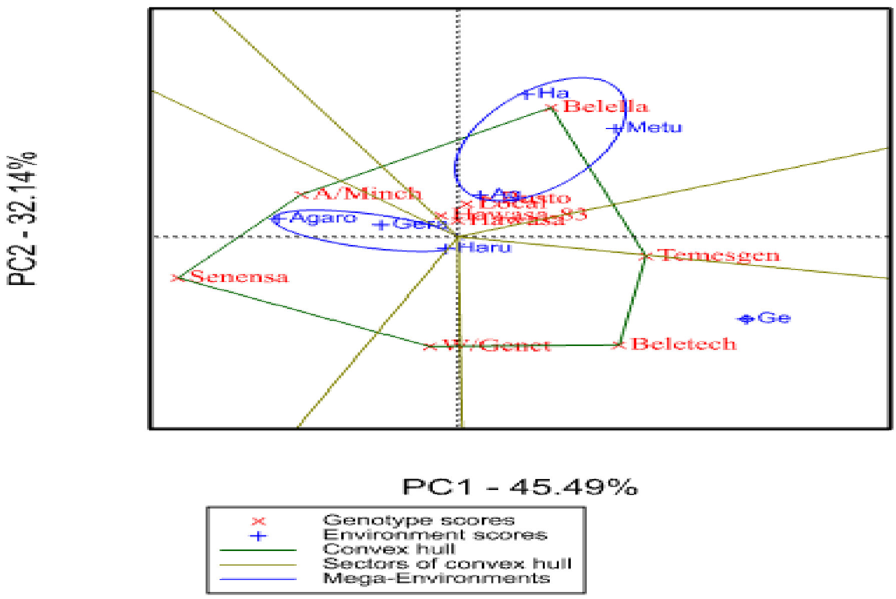

Figure 4. The ‘mega environment polygon view for Marketable fresh root yield of the GGE bi-plot analysis representing 10 sweet potatoes varieties

The principal component interaction -1 and -2 of GGE bi-plot of root girth extracted 50.97% and 17.83% of total variation. Three mega environments were formed in this GGE bi-plot polygon. The first mega environment (ME-1) was formed from Ag, Agaro and Metu environment and variety Busto and Belella won in this environment. Ha, Ge and Ha Mega formed mega environment-2. In this mega-environment local, Hawasa-83 and Hawasa-09 varieties performed better. The Gera environment alone formed the third mega environment. In this mega environment variety Temesgen was a winner variety (Figure 5).

For root length, the first two principal component IPC-1 and IPC-2 were accounted for 67.48% of total variance where IPC-1 explained 40.32% and IPC-2 accounted for 27.16% of variation. In this analysis total of two ME were formed. Two environments Ha and Haru formed the first ME. In this ME, variety Temesgen was the well performer variety. The second mega environment was formed from Gera, Ge, Agaro, Ag and Metu environments. Similarly, variety won in this ME were A/Minch, local check and Beletech varieties. The fourth ME was formed from Ha alone and in this environment variety Temesgen performed best. Environment within the same ME have similar effect on the genotype performance and the genotypes within the same MGE were assumed to have similar response to the environments located in the MGE sector. So, since the environments within the same MGE act similarly, testing at one environment of all can save time and cost expenditure incurred at multi-locations.

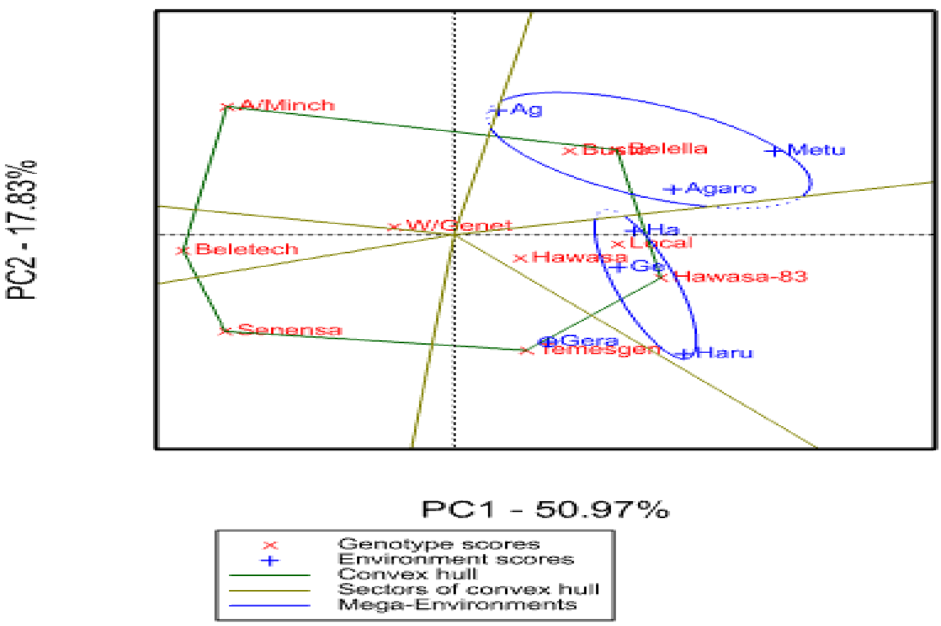

Figure 5. The ‘which won where’ polygon view for root girth of the GGE bi-plot analysis representing 10 sweet potatoes varieties

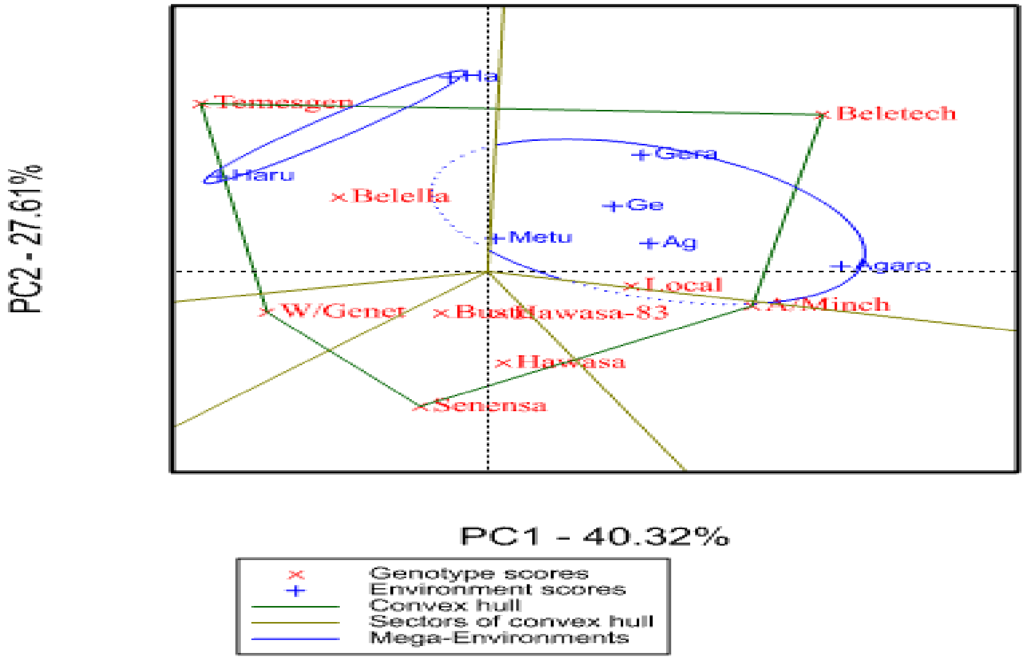

Figure 6. The 'which won where' polygon view for root length of the GGE bi-plot analysis representing 10 sweet potatoes varieties

GGE bi-plot focused on genotypes ranking and stability

The figurative representations of well performing and stable varieties among tested varieties are presented on Figure 7, 8 and 9 below. Based on the result, for marketable fresh root yield, PC1 explained 45.490% and PC2 explained 32.14% of the variation. The variety closest to ideal genotype has both high performance and most stable genotype of all tested (Yan *et al*., 2007) as cited in Duma *et al*., 2019).

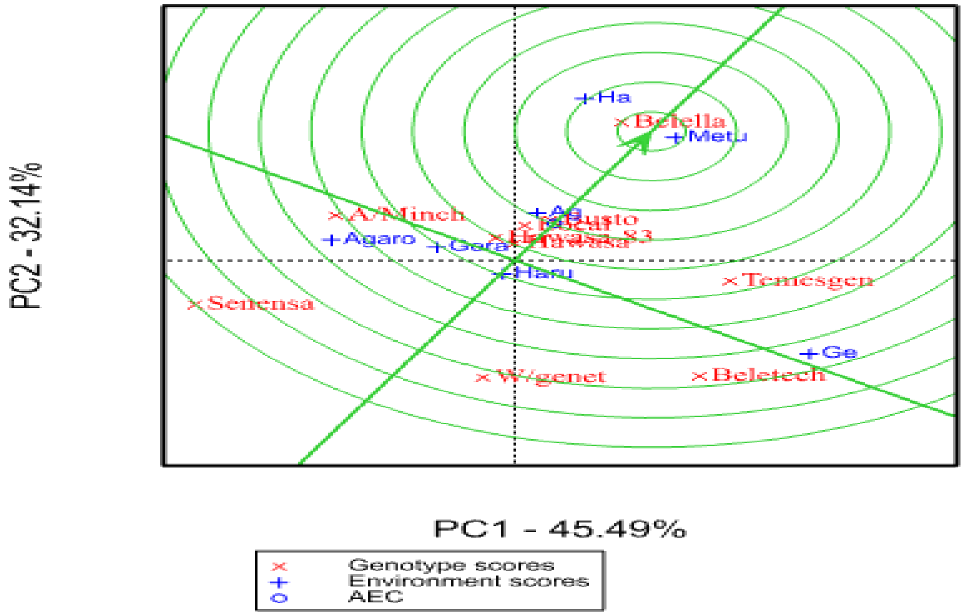

Figure 7. The average environmental coordination (AEC) view showing performance and stability of tested 10 varieties on fresh root yield of white fleshed sweet potatoes.

Varieties Belella was found the ideal, stable and high yielder varieties concerning marketable fresh root yield. Similarly, regarding root girth and root length, local check Hawasa-83 variety were found to be the best performer, stable and ideal genotype. For root girth, PC1 and PC2 contributed to 68.77% of total variation with 50.94% and 17.83% each respectively. Additionally, for root length, PC1 extracted 40.32% and 27.61% with 67.93% of total variation. In this bi-plot, Beletech was the best ideal and stable variety.

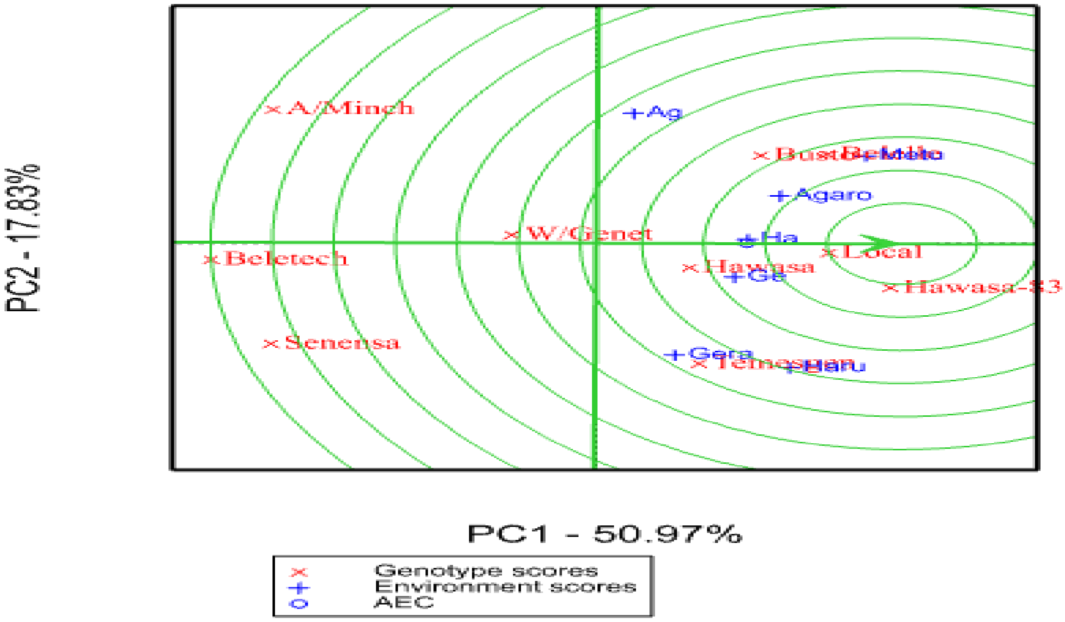

Figure 8. The average environmental coordination (AEC) view showing performance and stability of tested 10 varieties on root girth of white fleshed sweet potatoes

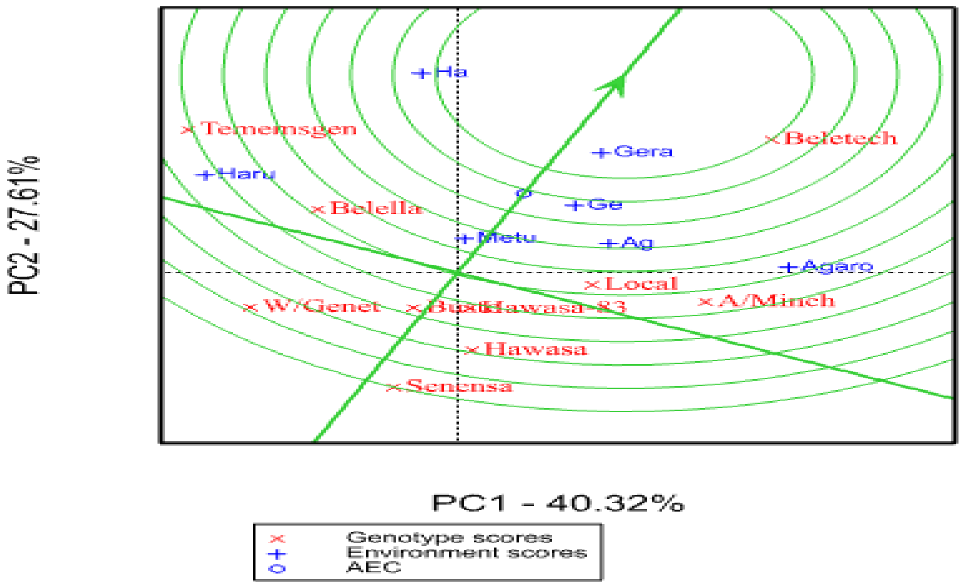

Figure 9. The average environmental coordination (AEC) view showing performance and stability of tested 10 varieties for root length of white fleshed sweet potatoes

Generally, variety Busto showed the best performances and stable variety and considered as ideal variety in all traits.

Environment discriminating ability and representativeness using GGE bi-plot:

The analysis was done which focused on comparison of ideal environment within mega- environment using GGE bi-plot. The ideal environment has high discriminating ability and representativeness. The result indicated that Metu was found the suitable and ideal environment for fresh root yield and storage root girth of sweet potatoes. Next to Metu, Ha was also the ideal environment for fresh root yield of sweet potatoes.

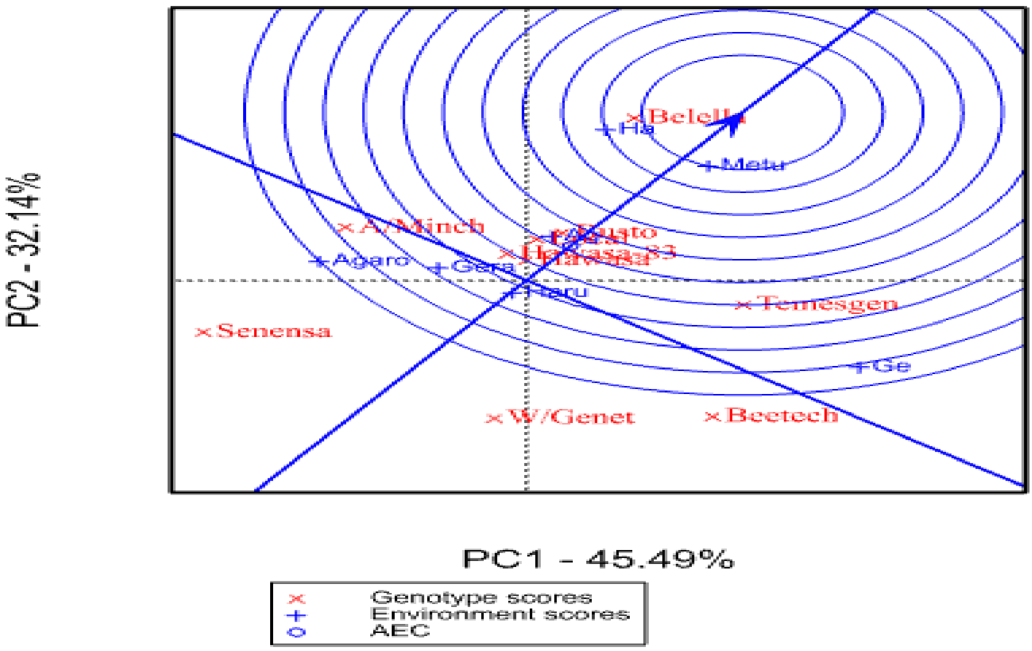

Figure 10.The root yield bi-plot for comparison of all environments with ideal environment

Concerning environmental ideality for root girth, the same environment as in case of storage root yield (Metu) was the ideal environment from MGE followed by Agaro (Figure 11).

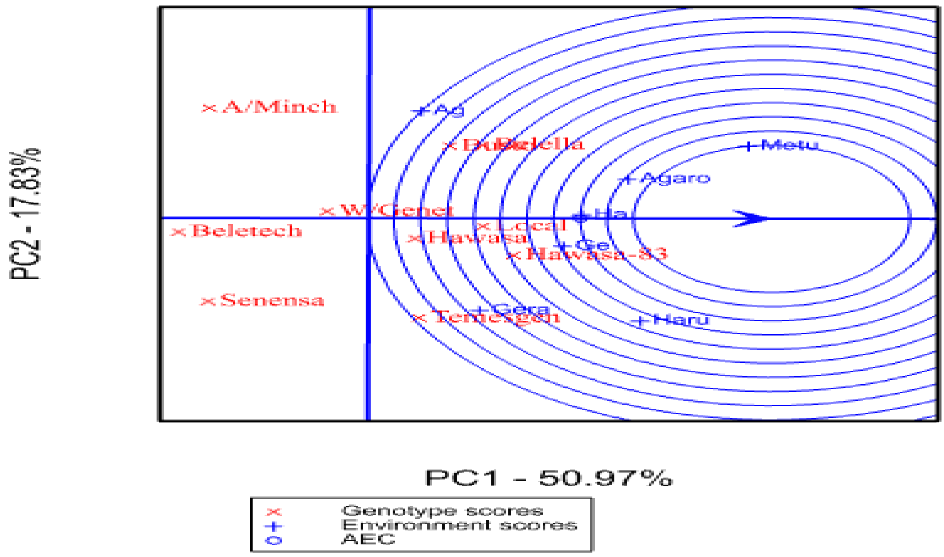

Figure 11.The storage root girth bi-plot comparison of all environments with ideal environment

In addition, for storage root length, Gera was indicated to be the most ideal of MGE while the ideal environment for root length was found to be Gera.

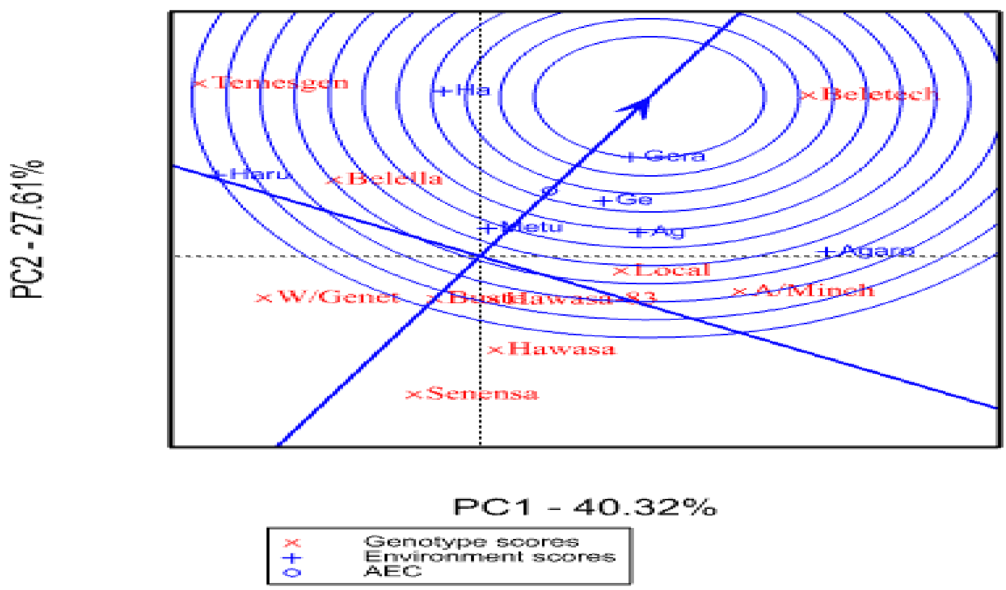

Figure 12.The storage root length bi-plot comparison of all environments with ideal environment

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Participatory Variety Selection for Enhanced Promotion and Adoption of Improved Potato (*Solanum tuberosum L.*) Varieties in Southwest Ethiopia

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Abstract

Participatory varietal selection has emerged as the best method to identify farmers' preferred crop varieties and enhances technology uptake as the method involves both scientific measurements and farmers assessments based on their evaluation criteria. This experiment was conducted during 2019 and 2020 cropping season at Jimma, Metu and Somodo research and farmers' training centers with the main objective of identifying adaptable, high yielding and diseases and pest tolerant potato varieties that meets farmer`s preference. The trial consisted of three potato varieties namely, Belete, Gera and Shenkola that were laid out in a single plot design. Both agronomic and farmers preferences data were collected and analyzed using SAS software and matrix ranking, respectively. The results revealed that varieties performed differently in different locations. Based on farmers' selection criteria, variety Belete, Gera and Shenkola ranked first to third in their order. However, matrix ranking of varieties based on farmers' preference criterion ranked Belete and Shenkola as first and second in all locations. Gera variety was not only low yielding, but also the least preferred variety by farmers in the study areas. Consequently, based on the findings, Belete variety could be recommended to potato growers in study area and similar agro-ecology for further promotion.

Introduction

Root and tuber are the main food security crops in developing countries in general and sub-Saharan Africa in particular (Tewodros *et al.*, 2019). These crops provide considerable amount of yield on marginal land where other crops do not perform well. Irish potato is an important root and tuber crop cultivated in almost all farmers' fields and being consumed daily by millions of people in the world (FAO, 2009). In Ethiopia, potato has promising prospect of improving the quality of basic diet in both rural and urban areas (Abebe *et al.*, 2017). It holds great promise for improving the livelihoods of millions of smallholder farmers in the highlands of Ethiopia (Asredie *et al.*, 2017). Potato's potential to producing high yield in a relatively short period of time, and its excellent food value give it great potential for improving food security, increasing household income, and reducing poverty (Devaux, *et al.*, 2014; Mohammed *et al.*, 2020). Furthermore, its short crop cycle which allowed double cropping by leave the land early and its utilization in different forms potato made it to be considered as the first priority crop for food security and income generation (Asredie *et al.*, 2017; Mohammed *et* *al*., 2020). However, its production is seriously constrained by biotic and a biotic stress (Asredie *et. al*., 2017) and low soil fertility (Shiferaw *et al*., 2019).

Currently, more than 30 potatoes varieties were released from different agricultural research centers to be produced in different agro-ecologies of Ethiopia (Gebremedhin *et al*., 2008; Mohammed *et al*., 2020). These varieties were selected based on major criteria like yield potential, tolerance to late blight, earliness in maturity period and wider adaptability (Asredie *et al*., 2017). In Southwestern part of Ethiopia, farmers produce potato mainly for household consumption and for market purposes. However, average yield low due to lack of adaptable technology for wide environments and poor promotion of these technologies in the area. Farmers' in the southwest Ethiopia grow potatoes using seed from market without improved agronomic practices, which resulted in the spread of devastating disease (Gebremedhin *et al*., 2001). Furthermore, in many cases, the involvement of stakeholders/farmers is neglected during variety development processes, and hence limited their uptake. Thus, understanding farmers' choices/needs across different agro-ecological growing areas are paramount importance to develop best technologies, identifying and understanding farmers' preference criteria disaggregated by gender (Asredie *et al*., 2017).

Cognizant of these facts, this study was conducted with the objectives to identifying adaptable, high yielding and diseases and pest tolerant /resistant potato varieties based on farmer`s selection criterion or farmer's preference.

Materials and Method

Experimental materials, locations and design

The experiment was conducted at Jimma, Metu and Somodo agricultural research and farmers' training centers during 2019/20 cropping season. These areas were selected based on their agro-ecological suitability for potato production and irrigation water availability. Three released potato varieties namely Belete, Gera and Shenkola, brought from Debre Berhan Agricultural Research Center were used as experimental materials. The experiment was laid out in single plot design with plot size of 3m x 4m ($12m^2$) for each variety at each location during the dry season using irrigation.

Experimental procedures and method of data collection

Farmers around the trial site participated starting site selection, land preparation and planting to harvesting. At planting, both local agronomic practices such as weeding, spacing (1m x 1m), earthing up frequency in one plot and following the recommended spacing of 75cm x 30cm inter and intra spacing and weed management in other plot of the same varieties were applied. Evaluation and selection of varieties were done twice: at vegetative stage and during harvesting together with farmers.

Data were collected based on farmers' selection criteria. Different farmers' selection criteria were recorded and participants were grouped in to two to three groups. Data on numbers of farmers that selected each variety and their selection criteria were recorded. Additionally, yield data of each variety, tuber size, shape and color was assessed and weighted. Besides, based on conventional cultivation they used and the improved agronomic practices, comparisons of yield were done. Data analysis was done using pairwise comparison method.

Results and Discussion

Farmers' variety selection criteria

Different selection criteria were mentioned by the participants in the study areas. These include disease and insect pest tolerance, maturity period, vigor and tiller development habit as well as yield performance (tuber size, shape and color). In the study areas, farmers' have selected late maturing, vigorous and thick stem potato varieties with more tiller at all locations. Additionally, varieties which showed disease symptom and early flowering were highly neglected by farmers. The reason was early flowering plant with short vegetative periods have low vegetative stature and low yield as reported by Machikowa and Laosuwan (2009) and stated that early maturing soybean varieties are low yielder due to their small plant vigor. Only few farmers selected early maturing variety for filling food gap during shortage of other crops. Results of participants selection and ranked is presented in Table 1 below. Based on these criteria, at Metu and Sombo, Belete and Gera ranked first and second at vegetative stage. At Somodo, variety Gera and Shankola were selected as first and second based on vegetative attributes (Table 1). Accordingly, based on maturity period, the early maturing variety was selected only for its earliness to fill the food gap. Otherwise, they suggested that late maturing varieties are expected to produce high yield. Additionally, these late maturing types had good vigor habit, thick stem, more tiller and lately flowering characteristics. They took such traits as indicator of high yielding habit (Table 2). At all locations, participants had almost similar view, but performances of each variety varied from location to location. This result was in parity with the achievement of (Wolie and Fentie, 2017) who suggested farmers' varieties preference differ at different locations based on their selection criteria.

Furthermore, at all locations, disease and insect pest tolerance and yield performance were the main criteria of potato selection used while maturity period, vigor, stem thickness and tillering were also the most crucial yield determinant factors (Table 1). Performance of varieties differed from location to location. Variety Gera provided highest yield than others only at Somodo trial site while

Belete performed best at Sombo and Somodo. However, no varieties fulfill all criteria (Table 2).

Table 1. Summary of selection criteria and number of participants ranking varieties in each location

T.No.	Farmers' criteria	Varieties			Rank of criteria
		Belete	Shenkola	Gera	
1	Stem and vigor	19	6	17	4
2	Tolerance to disease and insect	22	10	13	1
3	Lateness in maturity	14	13	18	3
4	Tuber size, shape and color	12	15	20	5
5	High yield	20	10	15	2
Score		87	54	83	-
Rank		1	3	2	-

At Metu based on disease and pest tolerance, tiller development, vigor, yield and related traits, Belete and Shenkola varieties ranked first and second, respectively. On the other hand, the same varieties ranked second for its early maturity whilst variety Gera preferred at Somodo in all parameters followed by Shenkola variety. Similarly, at Sombo, Belete variety preferred by most farmers as it performed best. However, Shenkola variety ranked third due to its poor performance than other varieties at this location (Table 2).

Table 2. The summary of selection criteria and the rank of varieties in each location

Farmers' criteria	Metu			Sombo			Somodo		
	Belete	Shenkola	Gera	Belete	Shenkola	Gera	Belete	Shenkola	Gera
Tiller and vigour	1	3	1	2	3	1	3	2	1
Tolerant to disease and insect	1	3	2	1	1	1	1	1	1
Lateness in maturity	2	2	1	2	2	1	3	2	1
Tuber size, shape and color	1	2	3	1	2	2	3	2	1
Yield	1	3	2	1	2	1	3	2	1

The second phase of evaluation was done during harvesting, where yield of each variety weighted, and the size and shapes of tubers were considered by farmers. Accordingly at Metu variety Belete provided the largest tuber yield followed by Gera 13.16 t/ha and 12.8 t/ha, respectively whereas the Shenkola gave the lowest tuber yield of 12.36 t/ha. Similarly, the same variety Belete gave the highest tuber yield of 32.44 t/ha at Sombo and the rest two varieties provided equal marketable tuber yield of 28.44 t/ha. But at Somodo, the variety Gera gave a highest tuber yield of 36 t/ha followed by Shenkola 33.78t/ha. At this location Belete gave the least 27.56 t/ha contrary to the other locations.

Table 3. The summary of yield performance of the three varieties at the three locations for cropping season of 2011 E.C

Location	Varieties	Tuber no./plant	Mark no./plot	Mark. Wt/ha (ton/ha)
Metu	Belete	5	213	13.16
	Gera	7.2	301	12.8
	Shenkola	4.5	224	12.36
Sombo	Belete	6.9	333	32.44
	Gera	5.7	300	28.44
	Shenkola	4.5	302	28.44
Somodo	Belete	7.2	260	27.56
	Gera	10.57	460	36.00
	Shenkola	8.125	327	33.78

Figure 1. Photo taken during participating farmers at vegetative and harvesting

During experimental period, in variety selection, the criteria considered by farmers and other stake holder differed from that of researchers'. Most farmers considered and preferred more vigorous but late maturity variety and marketable sized tubers ignoring very large sized and under sized tubers, since few of very large sized tubers weigh a kilogram. Besides, the shape, color and diseases reaction also taken into account as selection criteria. At different trial site, the performance and yield of each variety vary as reported by Wolie and Fentie (2017) who stated that grain yield of different varieties varied at different locations following selection criteria. In general, based on vegetative and yield attributes, at Metu, varieties Belete and Gera were ranked first and second whereas at Somodo Gera and Shenkola prioritized first and second at Somodo. But, at Sombo, Belete had been chosen as the best performing variety.

Conclusion and Recommendation

In variety selection farmers' different criteria mostly matched to researchers' selection criteria. Additionally, different varieties performed differently at different locations. The main considered criteria by farmers were vigor, resistant with late maturity. So, the probabilities of one variety to be selected at different locations depended on its performance observed at that location and fulfillment of producers' criteria. Based on these, at Sombo and Metu locations variety Belete ranked first while Gera and Shonkala ranked 2nd and 3rd, respectively. However at Somodo, Gera variety showed the best vegetative and yield performance and ranked first. Generally, this experiment was done up to yield but not evaluated at cooking stage since cooking quality is the main factor for consumption. So, future experiment and variety development should consider farmers' evaluation criteria from the stage of vegetative to consumption to increase adoption level and to ease their promotion.

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Genotype-By-Environment Interactions of Yam (*Dioscorea spp.*) Genotypes for Tuber Yield and Related Traits in Southwest Ethiopia

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Abstracts

The tuber yield of yam is affected by genotype, environment and genotype by environment (G×E) interactions. The objectives of the study were to assess the nature and magnitude of GxE interactions of yam genotypes based on multienvironment trials (METs) and to identify mega-environments (MGE) for future yam breeding program. The study was conducted across for two cropping seasons (2015-2017) in three locations, Jimma, Agaro and Gera, in southwestern parts of Ethiopia. A total of seven yam genotypes and one respective local check were evaluated in a randomized complete block design of three replications. Fresh tuber yield, tuber length and tuber diameter data were collected and analyzed using the additive main effect and multiplicative interaction (AMMI 2) and genotype main effect plus genotype by environment interaction (GGE) bi-plot analyses. A combined analysis of variance revealed the presence of significant variation among locations, years and their interactions for tuber fresh yield, tuber length and tuber diameter. Genotypes 2/87, 56/76 and 7/83 gave the highest mean tuber fresh yield across environments, whereas local genotypes, 1/75, 7/83 and 3/81 were superior for tuber length and tuber diameter. Environments 2 and 6, 1 and 3 and 1 and 5 were epitome for high tuber fresh yield, tuber length and tuber diameter, respectively and highly close to the ideal environment. Overall, environment 5 was the most suitable environment for discriminating genotypes and for being a representative test environment. Four MGE were identified for yam breeding; where environments, 5 and 6 combined into MGE-1, environments 1 and 4 combined into MGE-2 and environments 2 and 3 fell into a separate MGE-3 and MGE-4, respectively.

Introduction

Yam (*Dioscorea* species) belonging to the genus *Dioscorea* family *Dioscoreaceae* (Coursey, 1967). It is cultivated in Africa, Asia, South America, Caribbean and the South Pacific islands for its storage tuber and medicinal uses (Asieduand Alieu, 2010). The genus comprises over 600 species of which ten are cultivated for human food and economic importance for millions of people in tropical and sub-tropical regions (Girma *et al*. 2012; Dansi *et al*., 2013; Sisay *et al*., 2013). Guinea yam (*D. cayenensis and D. rotundata* complex) is the most widely cultivated species in Africa with greater economic significance (Lebot, 2009; Norman *et al*., 2012). Although, yams are cultivated in most tropical countries, most important species are widely adapted in Ethiopia as cultivated and wild relatives and believed to be the wild progenitor of the major species cultivated in Africa (Terauchi *et al*. 1992; Hildebrand *et al*., 2003). It is the third most important root crop in Ethiopia, after cassava (*Manihot esculenta* Crantz) and sweet potato (*Ipomoea batatas* (L.) Poir) (CSA, 2010). It is widely cultivated in South, Southwest and Western parts of Ethiopia and over 1.5 million people depend on it (Tewodros, 2016). In southwestern Ethiopia, yam is predominantly grown by smallholder farmers for food, traditional medicine and as a source of cash incomes. Women farmers are the main producers and traders of yam in southwest Ethiopia. Yam is increasingly showing high market value owing to consumer demand for food and medicine purposes making it an ideal candidate for market-driven production (Mulualem and Weldemichel, 2013). The most important feature of yam is its good adaptability and producuction of high yields under broad agro-ecology (Mesut and Ahmet, 2002), annual cycle of food availability through different species, diverse maturity and flexibility of harvest periods without the use of large amounts of agricultural inputs (Mulualem, 2012).

Yam productivity varies with the change in agro-climatic conditions, causing differences in the relative performance of the same landraces when evaluated across different environments due to genotype-by-environment interaction (GEI) (Yan *et al*., 2000). GEI refers to the inconsistent phenotypic performance of genotypes across environments. When it is associated with a significant genotypic rank change over environments, it presents limitations on selection and recommendation of varieties for target set of environments (Navabi *et al*., 2006). The presence of GEI result in low prediction of yield and interpretation of results based on genotype and environmental means alone (Ebdon and Gauch, 2002b; Voltas *et al*., 2002). The final state of a trait is the cumulative result of a number of causal interactions between the genetic make-up of the plant (the genotype) and the conditions in which that plant developed (the environment). Hence, biotic and abiotic factors contributes for GEI and yield instability in different crops including yams. Though not not fully, these factors can partly explain most of the GEI in multi-environment trials (Ferreira *et al*., 2006). Several statistical models have been proposed for studying the GEI effect (Zobel *et al*., 1988; Hussein *et al*., 2000). However, not all of them are always effective enough in analyzing the multi-environment data structure in breeding program (Zobel *et al*., 1988; Navobi *et al*., 2006). The additive main effects and multiplicative interactions (AMMI) and genotype plus genotype-by-environment interaction (GGE) models are defined powerful tools for effective analysis and interpretation of multi-environment data structure in different crop improvement programs (Yan *et al*., 2000; Ebdon and Gauch, 2002a; Samonte *et al*., 2005). AMMI is a statistical model that combines analysis of variance with multiplicative parameters of principal component analysis. It has both linear and bilinear component of GEI and hence very useful in visualizing multi-environments data and gaining accuracy (Gauch, 2006). The GGE bi-plot is a multiplicative model that absorbs the main effects of genotypes plus the environment interaction which are the two important factors in variety selection program (Yan *et al*., 2000; Yan and Tinker, 2006). GGE biplots are primary used to determine the relationship between genotypes and test environments graphically. These models provides valuable insights for assessing the extent of G×E interactions in multi-environmental trials. Therefore, this study was designed to assess the nature and magnitude of G x E interactions and determine mega-environments for yam trials in southwest Ethiopia.

Materials and Methods

Description of study areas

Field experiments were conducted at three locations namely; Jimma, Agaro and Gera Agricultural Research Centers/sub-centers, which are considered as the major yam growing areas of Southwest Ethiopia. The study was conducted for two cropping seasons (2015-2017) in all three locations. This made a total of six environments considering one location and one cropping season as one environment. Jimma Agricultural Research Center is located at 1753 meters above sea level (m.a.s.l.), 7^o 40.00' N latitude and 36^o 47'.00' E longitude. The area receives mean annual rainfall of 1432 mm with mean maximum and minimum temperatures of 29.2 ^{0}C and 8.90 ^{0}C, respectively. The soil of experimental plot is sandy loam. Agaro Agricultural Research Sub-center is situated at a distance of about 395 km to the Southwest of Addis Ababa. The site is located at 7°51′ .00' N latitude, 36°51′ 35' E longitude and an altitude of 1560 masl. The area receives mean annual rain fall of 1520 mm with mean maximum and minimum temperatures of 28.1^{0}C and 18.6^{0}C, respectively. The soil of Agaro is sandy loam. Gera Agricultural Research Sub-center is located at a distance of about 70 km to the west of Jimma. The site is located at 7^o31.60' N latitude, 36^o15'.00' E longitude and an altitude of 1900 meters above sea level. The area receives mean annual rain fall of 1877.8 mm with mean maximum and minimum temperatures of 26.3 ^{0}C and 10.9^{0}C, respectively.

Plant materials, experimental design and management

A total of eight yam genotypes were used for this study. The list of genotypes and areas of collection is presented in Table 1. The experiment was established in a randomized complete block design with three replications in each environment. Each yam genotype was assigned to one plot in each replication. The gross plot size for each treatment was 24m^2 (6m x 4m), using inter-row spacing of 1m and intra-rows spacing of 1m. Tubers of the same size and age were used as planting material. Planting was done at mid of April during the main growing season after the rain commenced and the soil was moist enough. One month after planting, seedlings were earthed up followed by frequent weeding. All other agronomic practices were followed according to the recommendations. Each yam plant was supported using dried coffee sticks of 3.5-4.5 m long for upright growth and induce good canopy and vine development. Five middle plants within a row were sampled and tagged for data collection and final harvest.

Table 1. List of eight yam genotypes and their areas of collection

Genotype	Zone	District	Latitude	Longitude	Altitude
3/81	Jimma	Manna	$07^0$40'58N	$036^0$48'75E	1731
56/76	Jimma	Manna	$07^0$41'89N	$036^0$48'06E	1837
57/76	Bench maji	Sheko	$07^0$02'88N	$035^0$29'74E	1654
1/75	Sheka	Yeki	$07^0$11'30N	$035^0$26'22E	1171
7/83	Jimma	Sekachekorsa	$07^0$35'06N	$036^0$41'91E	1898
6/83	Jimma	Dedo	$07^0$31'32N	$036^0$53'64E	1692
2/87	Jimma	Shebesombo	$07^0$26'76N	$036^0$24'12E	1365
Local*					

*Local materials were collected from respected tested locations of Jimma, Agaro and Gera areas.

Data collection

Data were collected from five plants on each plot and the average values were used for data analysis. The characters that are used for data collection were: tuber fresh yield (TFY, t/ha), tuber length (TL, cm), and tuber diameter (TDi, cm).

Data analysis

The collected data were subjected to analysis of variance (ANOVA) of each location and a combined ANOVA over environments following the standard procedure using SAS software version 9.0 (SAS, 2000) and Genstat version 17 (GenStat, 2007). Comparison of treatment means was done using the Fisher's protected least significant difference (LSD) test at 1% and 5% probability. A second ANOVA was conducted to determine the main and interaction effects of genotype, environment, and genotype by environmeny.

AMMI and stability analyses

The TFY was subjected to the combined analysis of variance and AMMI analysis, which is a combination of analysis of variance and interaction effect analysis. The analysis of variance was used to partition variance into three components: genotype deviations from the grand mean, environment deviations from the grand mean, and G×E deviations from the grand mean. Subsequently, multiplication effect analysis was used to partition G×E deviations into different interaction principal component axes (IPCA), which were tested for statistical significance through ANOVA. To determine the G × E interaction for yield parameters, AMMI and GGE bi-plot analyses were performed. The following AMMI model was used (Gauch, 1992). Genotypic stability parameter for each genotype was computed using GenStat software, 17th edition (GenStat, 2007). The additive main effects and multiplicative interactions (AMMI) statistical model reported by Gauch and Zobel (1996) was used to analyze yield data to obtain (AMMI) analysis of variance and (AMMI) mean estimates as follows:

$$Y_{ger} = \mu + \alpha_g + \beta_e + \sum \Lambda_n \gamma_{gn} \delta_{en} + \rho_{ge} + E_{ger}$$

Where: Y_{ger} = yield of genotype g in environment e at replicate r, μ = grand mean, α_g = genotype mean deviation (genotype means minus grand mean), β_e = environment mean deviation, n = number of principal component analysis (PCA) axes retained in the model, λ_n singular value for PCA axis n,y_{gn} = genotype eigenvector values for PCA axis n δ_{en} = environment eigenvector values for PCA axis n, ρ_{ge} = residuals, E_{ger} = error term.

The AMMI stability value (ASV) proposed by Purchase *et al*. (2000) was used to quantify and rank genotypes yield stability. The ASV has been defined as the distance from the coordinate point to the origin in a two dimensional scatter plot of first interaction principal component axis (IPCA1) scores against the second interaction principal component axis (IPCA2) (Adjebeng *et al*., 2017). Since IPCA1 accounts for most of the GEI variation, the IPCA1 scores are weighted by the ratio of IPCA1 SS (from AMMI ANOVA) to IPCA2 SS in the ASV were calculated by using the formula of Purchase *et al*. (2000) indicted below.

$$\mathbf{ASV} = \sqrt{\left[\frac{\text{SSIPCA1}}{\text{SSIPCA2}}(\text{IPCA1 score})\right]^2 + (\text{IPCA2 score})^2}$$

Where IPCA = Interaction principal component axis

Another important point was further reported by Yan *et al.* (2007) that genotype and genotype-by-environment effects must be considered simultaneously to make a meaningful decision in selection. Significant genotype by environment interaction was also analyzed by a GGE bi-plot which was useful in ranking genotypes based on their average performance and stability for farmer preferred traits in yam. The GGE bi-plot model was also used to determine the influence of GEI on total root yield, root dry weight and root diameter across test environments. The model for the GGE bi-plot based on singular value decomposition (SVD) of first two principal components was calculated by using the model, Yan *et al.* (2007).

$$Y_{ij}-\mu-\beta_j=\lambda_1\xi_{i1}\eta_{j1}+\lambda_2\xi_{i2}\eta_{j2}+\varepsilon_{ij}$$

Where: Y_{ij}= measured mean of genotype i in environment j, μ= grand mean, β_j = main effects of environment j, $\mu + \beta_j$ = the mean yield across all genotypes in environment j, λ_1 and λ_2= are the singular values (SV) for the first and second principle components axis (PCA 1 and PCA 2) respectively.ξ_{i1}andξ_{i2} = are eigenvectors of genotype i for PCA 1 and PCA 2, respectively, η_{j1} and η_{j2} = eigenvectors for environment j for PCA 1 and PCA 2, respectively.ε_{ij}= residual associated with genotype i in environment j.

Results and Discussion

The results of combined analysis of variance accomplished to determine the effects of year (Y), location (L) and genotype (G) is presented in Table 2. Year (Y) and Location (L) highly significantly ($p \leq 0.01$) affected TFY, TL and TDi of evaluated yam genotypes. Highly significant variance ($p<0.01$) among genotype (G) is observed in only TDi. The Y x L interactions effect was highly significant ($p<0.01$) for all the traits considered in this study. Likewise, the effect of G x L was highly significant ($p \leq 0.01$) on TDi while significant ($p<0.05$) on TFY and non-significant on TL of yam genotypes. Equally, a highly significant ($p \leq 0.01$) G x Y is observed on only TDi. The effect of triple interaction, GxYxL, was highly significant ($p \leq 0.01$) on TDi and significant on only at $p \leq 0.05$.

Table 2. Results of the combined analysis of variance on yield and yield related traits of eight yam genotypes tested for two cropping seasons (2015-2017) at Jimma, Agaro and Tepi.

Sources of variation	DF	TFY	TL	TDi
Location (L)	2	356.4**	372.04**	1052.79**
Genotype (G)	7	40.10	40.39	48.40**
Year (Y)	1	444.89**	2309.20**	26735.79**
Y*L	2	436.11**	243.16**	689.52**
G*L	16	179.94*	61.26	3.22**
G*Y	7	67.26	41.53	2.65**
G*Y*L	14	133.08	72.52*	3.24**
Error	94	87.05	38.85	15.23

*,
**significant at 0.05 and 0.01% of probability level.
TFY= tuber fresh yield; TL= tuber length, TDi= tuber diameter, Y = year, L = location, G = genotype, Rep= replication

The results further revealed that genotypes TFY was consistent across years and across years and locations hence had wide adaptability and high levels of genotype stability. G x E is a major problem when comparing the performance of crop genotypes across environments because it reduces the efficiency of the genetic gain through selection (Jandong *et al*., 2019). The significant effect of environment on TFY is reported in different crops (Agyeman *et al.*, 2015 and Tesfaye *et al.*, 2017). Aina *et al.* (2007) reported in multi-location yield trial, location accounted for about 92% of the total variation, whilst genotype and GEI combined contribute to 15–17% of the total variation.

Additive main effects and multiplicative interaction (AMMI 2) analysis of variance

The AMMI 2 analysis of variance revealed, highly significant effects ($p \leq 0.01$) of genotypes, environments, and GEI on yield and related traits of yam (Table 3). Genotype, environment, and GEI contributed 3.92%, 28.33% and 67.75%, respectively, to the total variation observed in TFY. Interaction principal component axis (IPCA 1 and IPCA 2) showed non-significant ($p > 0.05$) for IPCA 2 except for IPCA 1 which was highly significant at 1% level of probability, and explaining 53.32% and 24.99 % of the total GEI on TFY.

Table 3. AMMI analysis of variance for yam yield and related traits of eight genotypes tested across six environments in Southwest Ethiopia.

Source of variation		Tuber fresh yield (TFY)				Tuber length (TL)				Tuber diameter (TDi)			
	DF	SS	MS	Variation explained (%)	GxE Explained (%)	SS	MS	Variation explained (%)	GxE Explained (%)	SS	MS	Variation explained (%)	GxE Explained (%)
Treatments	47	7164	152.4*	32.25		5990	127.5**	63.88		70790	1506**	97.65	
Genotypes	7	281	40.1	3.92		287	41	4.79		339	48**	0.48	
Environment	5	2030	406**	28.33		3540	707.9**	59.09		68791	13758**	97.1	
Block	12	927	77.3	12.94		1803	150.2**	30.10		293	24	0.41	
Interactions	35	4853	138.7*	67.74		2164	61.8**	36.12		1660	47**	2.34	
IPCA-1	11	2588	235.3**		53.32	1196	108.7**		55.26	1300	118**		78.31
IPCA-2	9	1213	134.8		24.99	538	59.8*		24.86	282	31*		0.34
Residuals	15	1052	70.1		21.67	430	28.7		19.87	78	5		0.11
Error	84	7704	91.7			2371	28.2	39.58		1210	14	1.70	

DF: degrees of freedom, ns: non-significant ($P > 0.05$); *, ** significant at $p \leq 0.01$.

Performance of genotypes across individual locations

The mean performance of TFY, TL and TDi of eight yam genotypes across six environments is presented in Table 4-6. On average, genotypes 2/87, 56/76 and 7/83 gave the highest mean tuber fresh yield across environments.

Table 4. Mean fresh tuber yield (tons/ha) of eight genotypes across six environments.

Code	Genotype	Environments						Overall mean
		ENV-1	ENV-2	ENV-3	ENV-4	ENV-5	ENV-6	
G1	**3/81**	49.45	50.71	42.23	42.06	33.09	38.11	42.61
G2	**56/76**	31.48	53.03	41.38	40.41	53.30	49.27	**44.81**
G3	**57/76**	49.03	53.30	32.67	41.25	48.10	36.96	43.55
G4	**1/75**	52.59	51.81	39.95	42.67	35.48	36.73	43.21
G5	**7/83**	35.58	51.99	47.98	42.03	42.03	48.95	**44.76**
G6	**6/83**	30.03	49.96	41.14	38.28	46.66	46.61	42.11
G7	**2/87**	45.33	54.75	38.63	42.97	49.65	42.96	**45.72**
G8	**Local**	36.73	48.47	45.88	39.59	33.81	43.69	41.36
	Mean	41.28	**51.75**	41.23	41.16	**42.77**	**42.91**	43.52

On contrary, local genotype had lowest mean tuber fresh yield of all genotypes across environments (Table-4). Highest TL was observed in the environment-1, followed by environment-3 and environment-5 (Table 5). On average, genotypes local and 6/83 produced the longest and the shortest tuber length, respectively.

Table 5. Mean TL (cm) performance of 8 yam genotypes tested across six environments

Code	Genotypes	Environments						Overall mean
		ENV-1	ENV-2	ENV-3	ENV-4	ENV-5	ENV-6	
G1	**3/81**	52.44	35.79	44.48	35.04	32.36	33.22	38.89
G2	**56/76**	46.29	34.15	39.68	33.77	38.70	33.18	37.63
G3	**57/76**	45.02	34.42	43.22	32.99	35.99	33.39	37.51
G4	**1/75**	62.48	35.65	32.28	39.20	40.02	32.33	40.33
G5	**7/83**	48.90	36.98	47.05	35.36	35.71	35.42	39.90
G6	**6/83**	40.28	34.13	41.96	32.46	40.08	34.39	**37.22**
G7	**2/87**	47.91	34.41	36.36	35.09	42.82	33.68	38.38
G8	**Local**	45.34	38.09	44.42	36.94	45.87	38.30	**41.49**
	Mean	**48.58**	35.45	**41.18**	35.11	**38.94**	34.24	38.92

Similarly, the widest TDi was observed from genotypes 7/83, local, and 3/81 with a value of 46.65, 43.64 and 42.96 cm, respectively (Table 6). Environment-1 and environment-5 are the best environments for the TDi with mean value of 69.97 and 48.60 cm, respectively (Table-6). The

environments contributed significantly to the differential performance of genotypes across environments resulting in either cross over or non-cross over GxE. According to Malhotra et al. (2007) and Jandong *et al*. (2019), described the cross over effects as a significant change in performance from one environment to another, while in non-crossover interaction, a ranking of genotypes remains constant across the environment.

Table 6. Mean TDi (cm) performance of 8 yam genotypes tested across six environments

Code	Genotypes	Environments						Overall mean
		ENV-1	ENV-2	ENV-3	ENV-4	ENV-5	ENV-6	
G1	**3/81**	68.60	37.16	32.29	37.18	44.88	37.66	**42.96**
G2	**56/76**	57.67	35.80	36.08	35.58	48.31	36.59	41.67
G3	**57/76**	70.53	31.91	31.07	35.03	51.29	35.70	42.59
G4	**1/75**	76.28	35.29	27.51	35.55	45.53	35.79	42.66
G5	**7/83**	83.56	36.25	29.26	36.65	57.11	37.08	**46.65**
G6	**6/83**	63.24	35.30	32.52	35.23	45.44	35.93	41.28
G7	**2/87**	72.45	36.06	29.47	36.20	44.38	36.53	42.52
G8	**Local**	67.45	36.02	33.63	36.04	51.87	36.83	**43.64**
	Mean	**69.97**	35.47	31.48	35.93	**48.60**	36.51	**48.62**

AMMI stability value (ASV)

AMMI stability values revealed differences in TFY and related traits stability among the eight yam genotypes (Table 7). For TFY, genotype 2/87 was highly stable, due to lowest ASV value (1.64). On contrary, genotype 1/75 and 3/81 were among the least stable genotypes due to the highest ASV values. Other genotypes had intermediate stability. For TL, genotype 56/76 was highly stable with ASV values of 0.37; whereas genotype 1/75 remained the least stable among others. For TDi, genotypes 57/76, local and 3/81 were the most stable with ASV values of 1.01, 1.39 and 1.44, respectively; whereas genotypes 7/83 and 56/76 were the least stable. Further, the result in Table 8 exhibited, environments ENV-2 and ENV-6 had lowest ASV score for TFY and TL, and TDi, respectively; and these environments were considered as highly discriminating of genotypes.

The AMMI model does not make provision for a quantitative stability measure. Such a measure is essential in order to quantify and rank genotypes according to their TFY stability. The ASV measure was proposed by Yan *et al*. (2007) to manage with this problem. ASV is the distance from zero in a two-dimensional scatter gram of IPCA1 scores against IPCA2 scores. Since the IPCA1 score contributed more to G × E sum of square, it has to be weighted by the proportional difference between IPCA-1 and IPCA-2 scores to compensate for the relative contribution of IPCA1 and IPCA2 to the total G × E sum of squares. In the ASV method, a genotype with the least ASV score is the most stable. Accordingly, genotype 2/87 (TFY), 56/76 (TL) and 57/76 (TDi) were the most stable. Therefore, these genotypes can be used as checks in genotype evaluations.

Table 7. AMMI stability values (ASV) and IPCA scores for TFY, TL and TDi of eight yam genotypes tested six environments in SW Ethiopia

Code	Genotype	TFY				TL				TDi			
		Mean	IPCAg1	IPCAg2	ASV	Mean	IPCAg1	IPCAg2	ASV	Mean	IPCAg1	IPCAg2	ASV
G1	3/81	42.61	-2.2706	-1.2199	3.35	38.89	-0.4634	-2.2367	2.33	29.63	0.5190	1.2562	**1.44**
G2	56/57	44.81	2.2715	1.0656	3.30	37.66	0.1549	0.3003	**0.37**	28.34	2.7358	-0.7462	3.83
G3	57/76	43.55	-1.4249	2.6390	3.29	37.51	0.8246	-0.7061	1.34	29.75	-0.2769	-0.9352	**1.01**
G4	1/75	43.21	-2.7386	-0.3345	**3.78**	40.33	-3.7317	0.5053	5.16	29.32	-1.5752	1.1742	2.46
G5	7/83	44.76	1.3921	-1.5701	2.48	39.90	0.6645	-1.6149	1.86	33.32	-2.8191	-1.4346	4.13
G6	6/83	42.11	2.2965	0.1072	3.16	37.34	1.6742	0.8853	2.47	27.94	1.3411	0.3328	1.87
G7	2/87	45.72	-0.2075	1.6181	**1.64**	38.38	-0.4252	1.5938	1.70	29.18	-0.5770	1.4158	1.62
G8	Local	41.36	0.2372	-2.3045	2.33	41.49	1.3020	1.2697	2.19	30.31	0.6523	-1.0631	1.39

IPCAg = integrated principal component analysis, TFY= tuber fresh yield, TL = tuber length, TDi = tuber diameter

Table 8. AMMI stability values (ASV) and IPCA scores TFY, TL and TDi of six environments tested eight yam genotypes in southwest Ethiopia

Genotype	TFY				TL				TDi			
	Mean	IPCAg1	IPCAg2	ASV	Mean	IPCAg1	IPCAg2	ASV	Mean	IPCAg1	IPCAg2	ASV
ENV-1	41.28	-4.3164	0.5927	4.71	48.61	-3.4823	-1.0113	3.90	19.97	-3.8342	0.5697	4.19
ENV-2	51.75	-0.1923	0.4698	**0.51**	35.45	0.2878	-0.2301	**0.39**	15.85	0.7141	0.8232	1.13
ENV-3	41.23	0.7061	-2.8779	2.98	41.18	2.4845	-2.0124	3.36	11.48	2.1450	-0.1631	2.33
ENV-4	41.16	-0.6263	-0.3177	0.75	35.10	-0.7038	0.1512	0.78	15.93	0.6017	0.8201	1.05
ENV-5	42.77	2.1571	3.1732	3.94	39.03	0.4965	2.8603	2.91	18.60	-0.3482	-2.7410	2.77
ENV-6	42.91	2.2718	-1.0402	2.67	34.24	0.9171	0.2441	1.02	16.51	0.7216	0.6911	**1.04**

IPCAg = integrated principal component analysis, TFY= tuber fresh yield, TL = tuber length, TDi = tuber diameter

Additive main effect and multiplicative interaction (AMMI 2) bi-plot analysis

The performance of a genotype tested in an environment is considered better than the average performance in that environment if the angle between its vector and the environment is less than acute angle (90^0); near average if the angle is 90^0 (right angle) and below average if the angle is greater than 90^0 (obtuse angle) (Yan *et al.*, 2007). The AMMI 2 bi-plot analyses of TFY, TL, and TDi of the eight yam genotypes tested in six environments are shown in Figures 1, 2 and 3, respectively. For TFY, the percentage of variation accounted by the IPCA-1 and IPCA-2 axes was 53.33% and 24.99%, respectively (Figure 1). Genotypes 7 (2/87) and 3 (57/76) had broad adaptability as they were located closer to the center of the bi-plot. Genotypes 2 (56/76), 6 (6/83), and 1 (3/81) are placed furthest from the point of origin, showing specific adaptation to the environments within their proximity on the bi-plot.

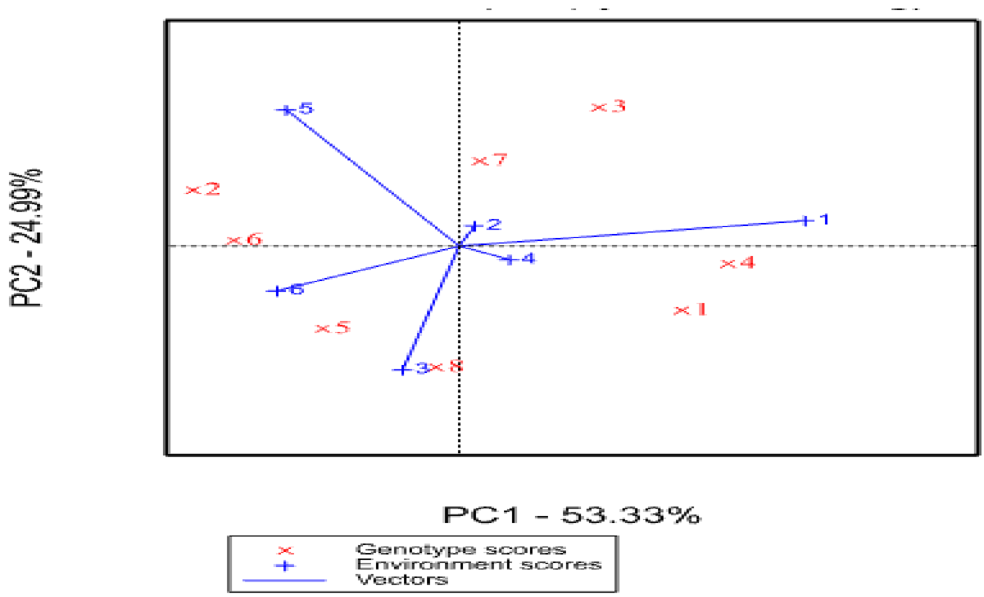

Figure 1. AMMI 2 bi-plot for IPCA 1 against IPCA 2 scores for eight yam genotypes and six environments on tuber fresh yield (TFY).

Furthermore, genotype 3 (57/76) had above-average yields and were located at the acute angle of PC1. Genotypes located on the right-hand side of the bi-plot were positively correlated with the environments on the same side. Based on this analysis, environment 3 was considered highly discriminating since it had longer vector. Environments 1, 2 and 4, were highly positively correlated, indicating that genotypes ranked similarly with respect to TFY in these environments. This suggested that these environments might form part of the same mega-environment, hence there is no need to test genotypes across all these environments indicating using one might serve the required interest.

For TL, the AMMI 2 bi-plot elucidated 80.14% of the total GEI (Figure 2). The percentage of variation accounted for by IPCA-1 and IPCA-2 was 55.27% and 24.87%, respectively. Genotypes 2 (56/76), 3 (57/76), and 5 (7/83) were close to the bi-plot origin; these genotypes had yields close to the overall mean yield. The following genotypes were positively correlated with environments closer to them: 5(3), 2(6) and 3(2). Genotypes located on the right-hand side of the bi-plot were positively correlated with the environments found on that side. Thus, environment 1_is highly discriminating in this study. This environment showed the high discriminating ability based on longer vector. Environment 3 and 1 had longer vectors, indicating the similar discriminating ability of the site at different right angles. Environment-2 had the shortest vector, suggesting poor genotype discriminating ability.

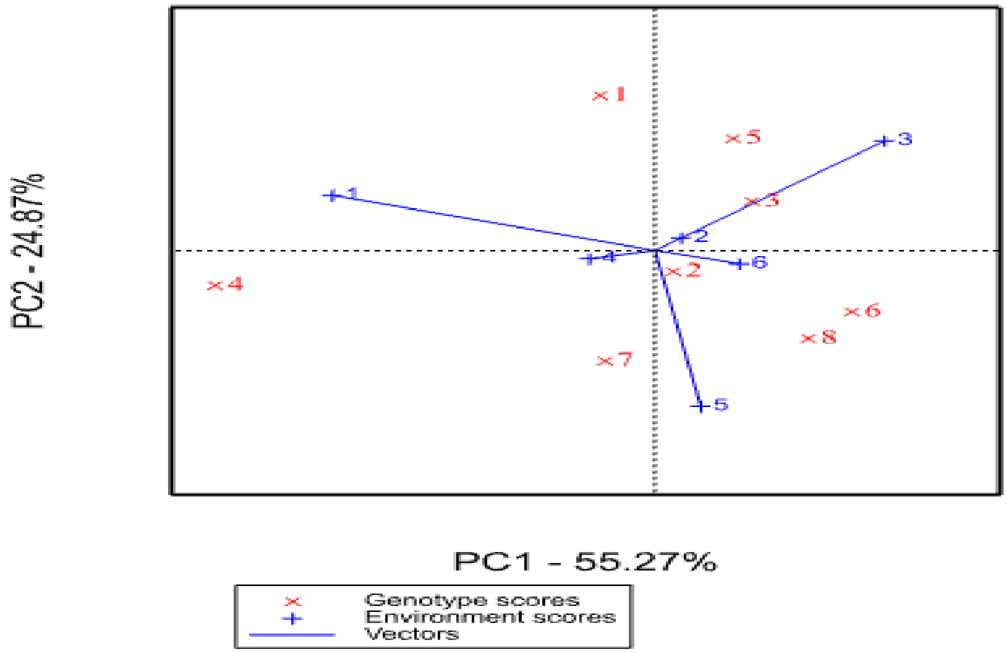

Figure 2. AMMI 2 bi-plot for IPCA 1 against IPCA 2 scores for eight yam genotypes and six environments on tuber length (TL).

The percentage of variation of AMMI 2 bi-plot for TDi accounted by IPCA 1 and IPCA 2 was 78.31% and 16.98%, respectively (Figure 3). Genotypes 1 (3/87), and 6 (6/83) were much closer to the origin of the bi-plot, indicating broader adaptability across the environments and had positively correlated with environments 2, 4 and 6 due to their location on the right-hand side of the bi-plot.

Genotype 6 (6/83) was positively correlated with environment 3 suggesting specific adaptation to this environment. Further, genotype 1 (3/81) was positively correlated with environments 2, 4 and 6.

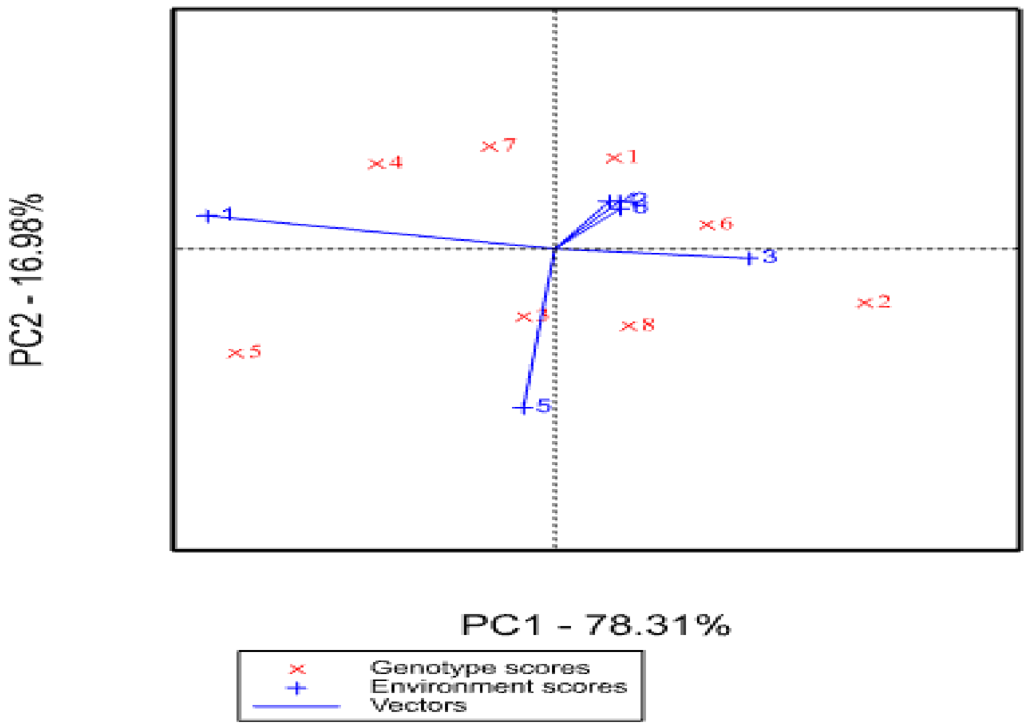

Figure 3. AMMI 2 bi-plot for IPCA 1 against IPCA 2 scores for eight yam genotypes and six environments on tuber diameter (TDi).

In this study, except environment 1, 5 and 3, other environments had shorter vectors, which imply the low discriminating ability of the sites. Most environments in this study had positive correlations. This was expected, since almost similar environmental conditions existed between environment 1 and 2, and 3, 4 and 5 and 6 (Table 1). The positive correlation obtained between test environments also suggests that indirect selection at either of these same environments for TFY can be applied across the sites_(Akinwale *et al.*, 2011). Combining these environments into a single test environment can give similar genotypic responses, thus reducing unnecessary costs and improving breeding efficiency_(Gauch and Zobel, 1997). For TFY, which is the trait of economic interest, environment PC1 had both positive and negative scores. Similar results were reported by Aina *et al.* (2007) indicating the existence of cross over G×E interactions. Genotypes with large PC1 scores can be easily recognized in environments with larger PC1 scores (Agyeman *et al.*, 2015).

Mega-environments analysis using GGE bi-plots

The polygon views of the GGE bi-plot for TFY, TL and TDi are shown in Figures 4, 5 and 6, respectively. In each bi-plot, diverse mega environments (MGEs) were grouped into sectors. Environments within the same MGE were presumed to have a similar effect on genotype performance and are considered uniform. Likewise, genotypes within the same MGE are assumed to have a similar response to the environments located in that MGE sector. The genotype located at the vertex of the sector is considered the best-performing variety in the MGE. For TFY (Figure 4), principal component-1 (PC-1) explained 50.63% of the total variation, whereas PC-2 explained 25.33%, with both axes accounting for 75.96% of the total variation. Perpendicular lines were drawn to each side of the polygon, all lines starting from the bi-plot origin.

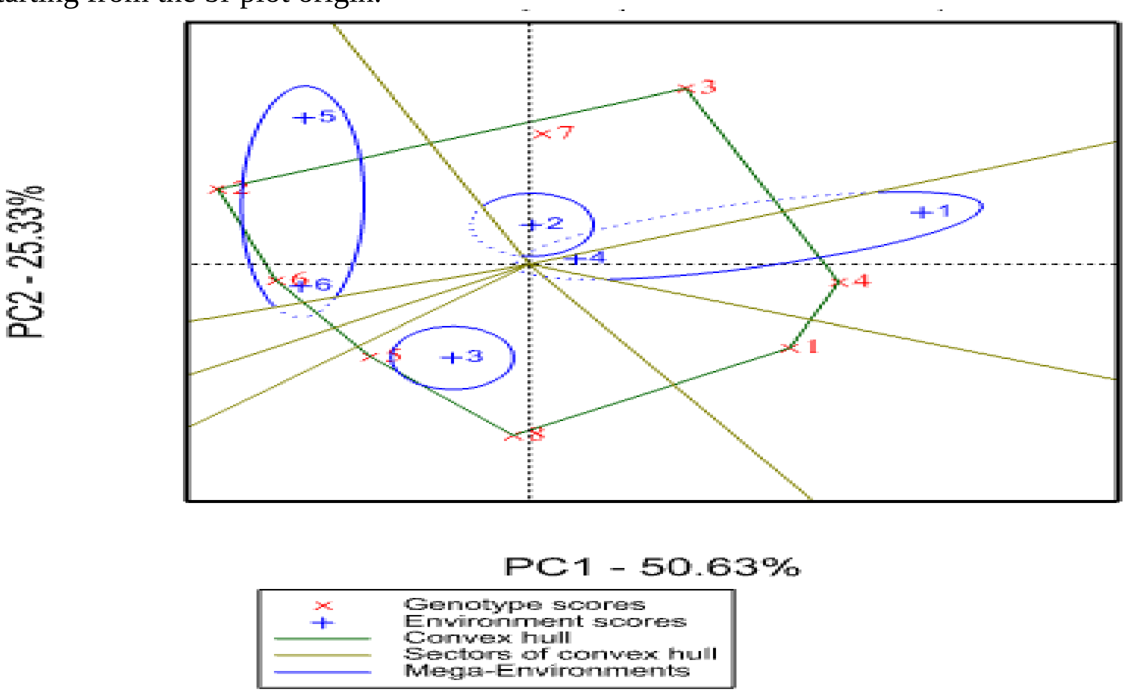

Figure 4. The "which-won-where" polygon view for TFY of the GGE bi-plot analysis representing the performance of eight yam genotypes tested across six environments

Analysis based on TFY identified four mega-environments, environments 5 and 6 combined into MGE-1, environments 1 and 4 pooled into MGE-2, environments 2 and 3 fell into a separate MGE-3 and MGE-4, respectively. Genotypes 2 (56/76) and 6 (6/83) positively correlated with environment 5 and 6 and were the winning genotypes in MGE-1. Genotype 4 (1/75) was the highest-yielding genotype in MGE-2. Genotype 7 (2/87) won in the MGE-3. Genotype 5 (7/83) was positively correlated with the environment 3 and was the winning genotypes in MGE-4.

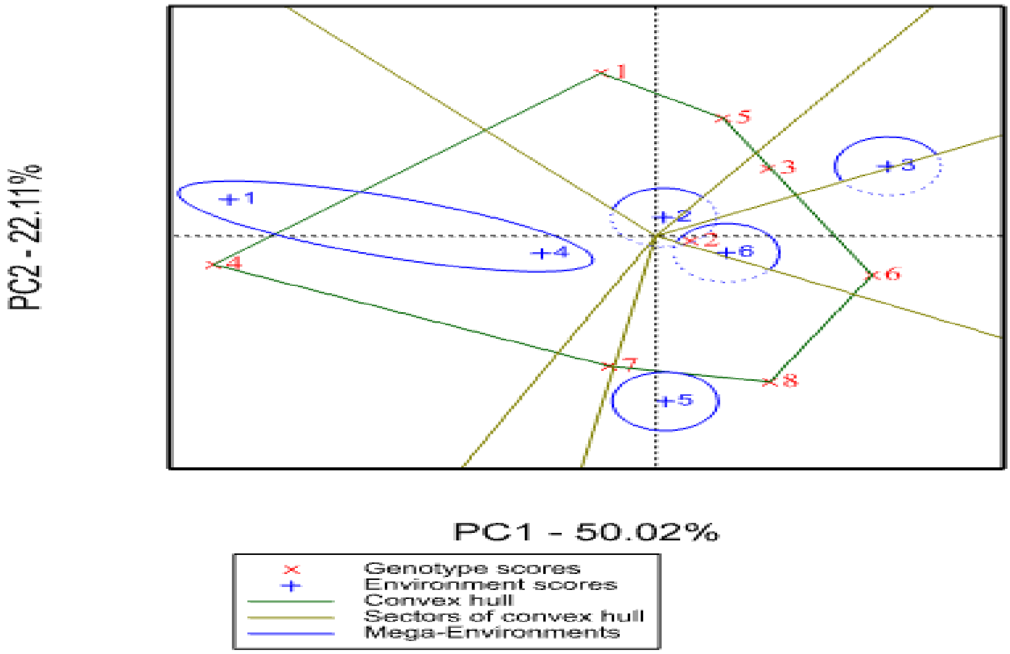

Figure 5. The "which-won-where" polygon view for TL of the GGE bi-plot analysis representing the performance of eight yam genotypes tested across six environments

For TL, the percentage of GGE explained by PC-1 and PC-2 was 50.02% and 22.11%, respectively (Figure 5). The bi-plot explained 72.13% of the total variation. The bi-plot consisted of five MGEs; where environments 1 and 4 are combined into MGE-1; environments 2, 3, 5 and 6 fell into a separate MGE-2, MGE-3, MGE-4 and MGE-5, respectively. Perpendicular lines were drawn to separate the respective sides of the polygon. Genotypes 1 (3/81) and 4 (1/75) positively correlated with the environment 1 and 4 and were the best genotypes in MGE-1.Genotype 7 (2/87) and 2 (56/76) were the highest yielding vertex genotype in MGE-4 and MGE-5.

Similarly, for TDi, the percentage of variation accounted by PC-1 and PC-2 was 76.02% and 18.16%, respectively; the total variation being 94.18%. In this bi-plot, three mega-environments were found; where environments 1 and 5 combined into MGE-1; environments 2, 4 and 6 were united into MGE-2 and environment 3 fell into a separate MGE-3, respectively. Most genotypes were highest-yielding vertex genotype in MGE-1, whereas genotypes 7 (2/87) and 4 (1/75) were the highest-yielding vertex genotypes in MGE-2.

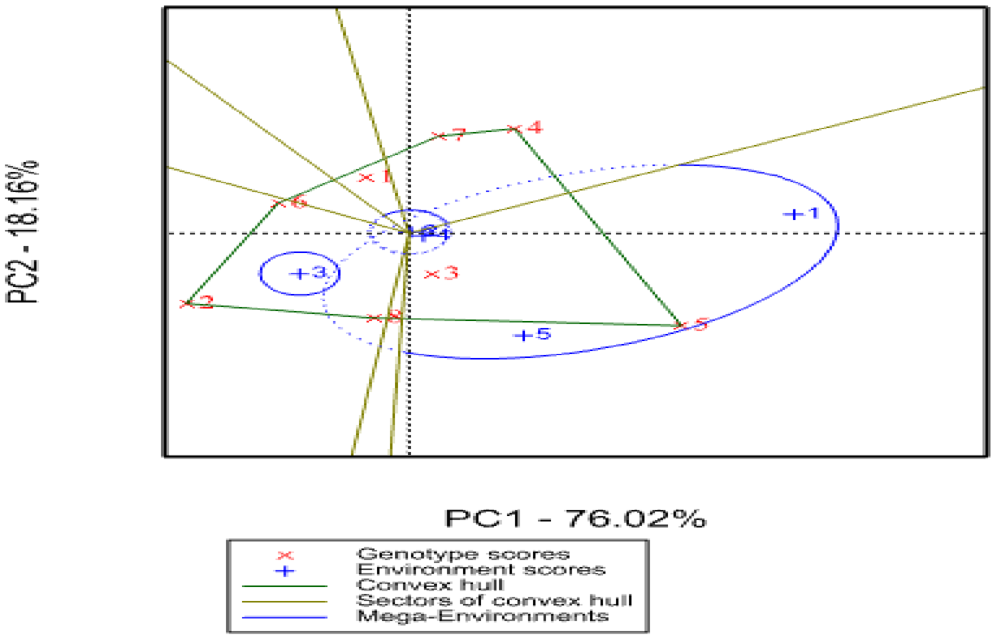

Figure 6. The "which-won-where" polygon view for TDi of the GGE bi-plot analysis representing the performance of eight yam genotypes tested across six environments

Genotype yield and stability using GGE bi-plots

For TFY, PC1 explained 50.63% of the variation and PC-2 explained 25.33% with two forming a total of 75.96% of the variation (Figure 7). Genotype 7 (2/87) was the ideal genotype and, therefore, it was considered the most desirable genotype of all the evaluated genotypes, followed by genotypes 3 (57/76) and 2 (56/76). The same interpretation is applicable to TL (Figure 8); the percentage of PC-1 and PC-2 were 50.02% and 22.11%, respectively both forming 72.13% of the total variation. Genotype 4 (1/75) had longest tuber and was more stable than other genotypes as confirmed by its closest position to the ideal genotype.

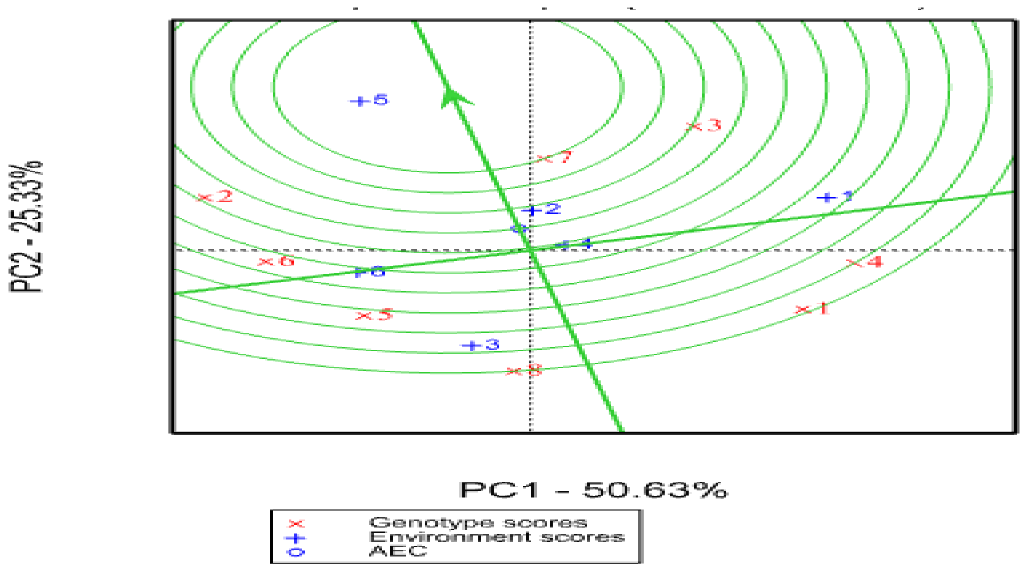

Figure 7. The average environment coordination (AEC) view showing mean performance and stability of eight yam genotypes tested in six environments on tuber fresh yield (TFY).

According to Yan (2001) definition, an “ideal” genotype can be identified based on both mean performance and stability, and the genotypes can be ranked based on their distance from the ideal genotype. In this study, genotypes 7 (2/87), 4 (1/75) and 5 (7/83) are ideal for TFY, TL and TDi, respectively (Figures 7, 8 and 9). These genotypes are high yielding and more stable as judged from their close proximity to the ideal genotype.

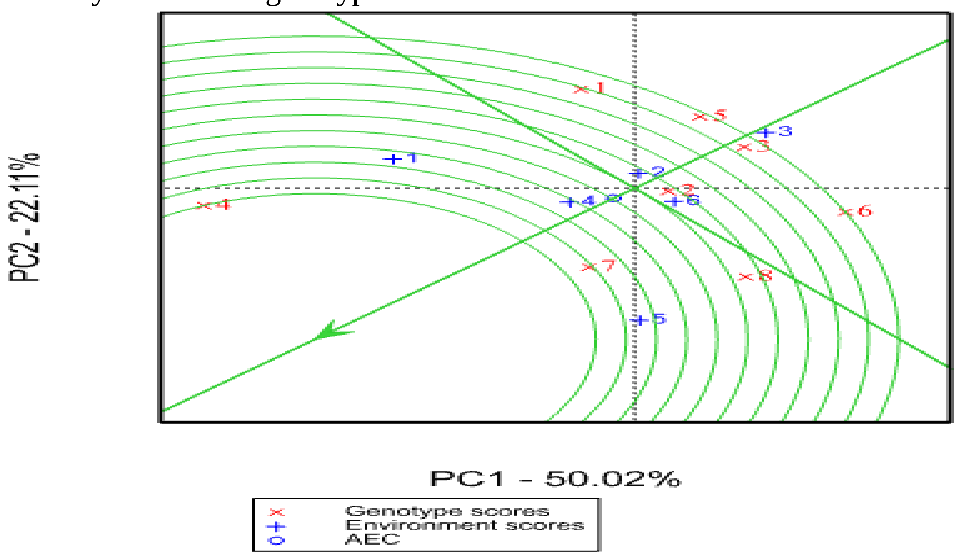

Figure 8. The average environment coordination (AEC) view showing mean performance and stability of eight yam genotypes tested in six environments on tuber length (TL).

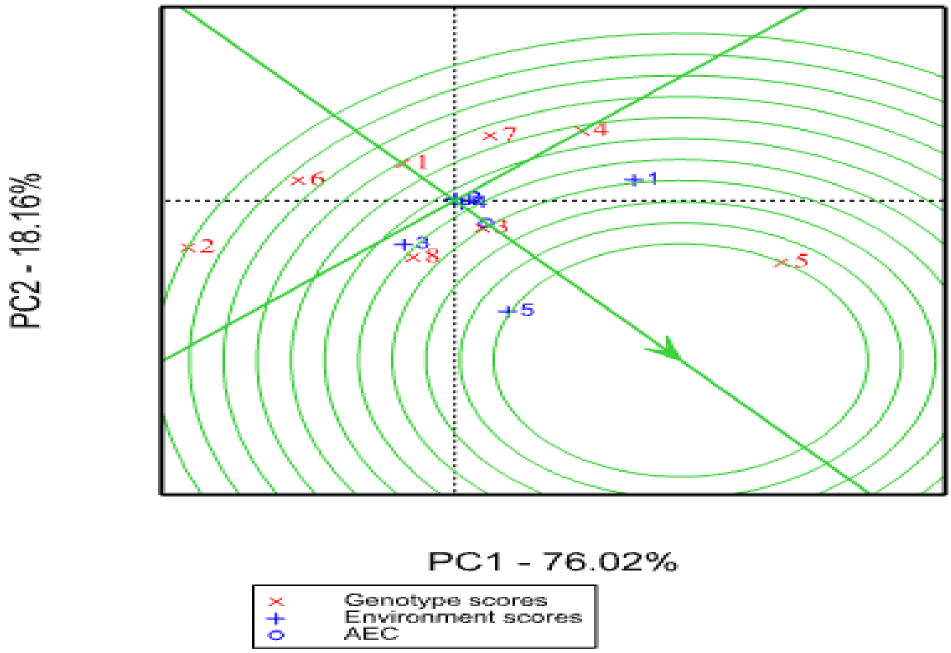

Figure 9. The average environment coordination (AEC) view showing mean performance and stability of eight yam genotypes tested in six environments on tuber diameter (TDi).

Environment discriminating ability and representativeness using GGE bi-plot

A similar analysis was applied for environment-focused bi-plots, which represents the ideal environment within a mega-environment. The ideal environment must have high discriminating ability and representativeness. For TFY, the ideal test environment was environment 5; whereas for TL and TDi, the ideal test environments were environments 2 and 1, owing to their closeness to the ideal environment (Figures 10–12).

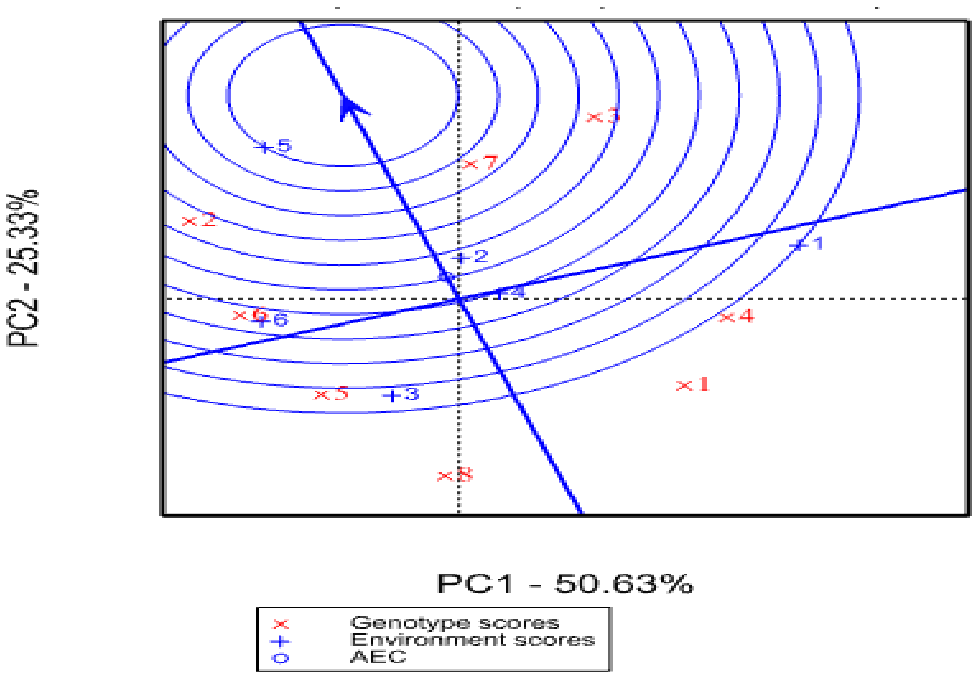

Figure 10. The bi-plot for comparison of all environments with the ideal environment on tuber fresh yield (TFY).

Test environments that had close proximity to the ideal environment on the AEC axis were positively correlated with genotypes closer to them. Environments that had less interaction with the genotypes were environment 1 for TFY and TL; and environment 1 and 5 for TDi. The purpose of validation of test-environment is to identify idea environments that effectively identify superior genotypes for a mega-environment.

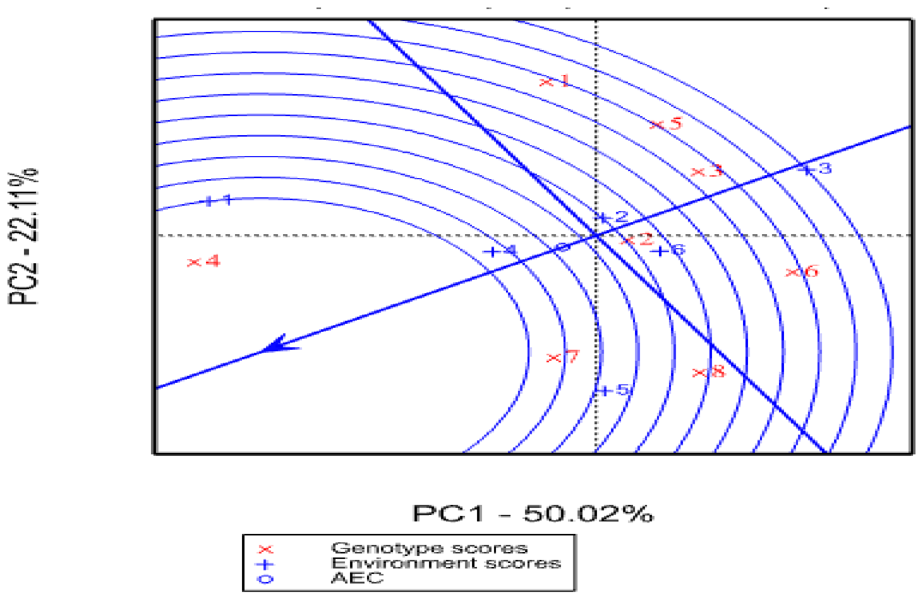

Figure 11. The bi-plot for comparison of all environments with the ideal environment on tuber length (TL).

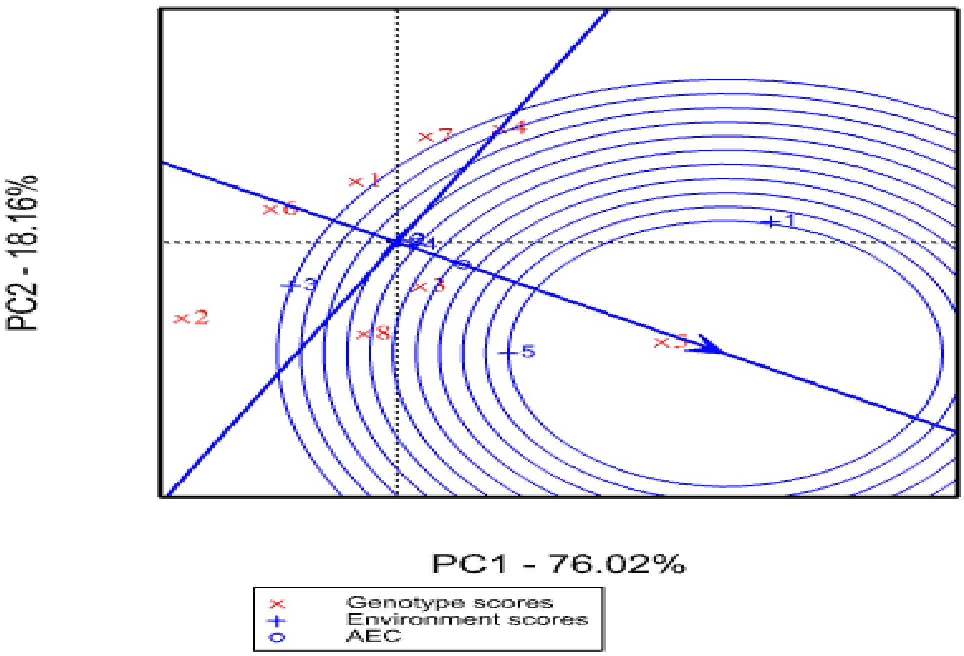

Figure 12. The bi-plot for comparison of all environments with the ideal environment on tuber diameter (TDi).

Ideal test environment should be highly discriminative of genotypes and representative of the mega-environment (Aina *et al*. 2007). This study showed that environment 5, 2 and 1 had a high discriminating ability and representativeness for evaluation of genotype for TFY, TL and TDi, respectively. The positive correlation existing between the genotypes and environments indicated that these genotypes possessed a specific adaptation. The tested environment markers fall close to the bi-plot origin because of their short vectors, it means that all genotypes performed similarly in those environments. This provides little or no information about the genotype differences, since the genotypes show broad adaptability.

Conclusions and Recommendation

Highly significant effects of genotypes, locations, years and their interactions observed for all traits considered in this study. The G×E analysis enabled identification of yam genotypes with narrow adaptation, which can significantly improve productivity in specific environments. Stable and high yielding genotypes were also identified and selected based on their relative response to a respective environment. Four mega-environments were identified as useful for genotype evaluation, production and breeding of yam. Based on the overall performance, two stable and high yielding genotypes G2 (56/76) and G7 (2/87) were identified and promoted for variety verification based on their relative response to a respective environment. The results obtained from this study will help yam breeders and producers recommend widely adapted genotype and its cultivation in unaddressed areas of the country. Accordingly, the study makes a significant contribution to food security and income generation of yam producing society in the country.

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Influence of Plant Spacing and Time of Harvesting on Yield and Tuber Size Distribution Of Potato (*Solanum tuberosum* L) Variety 'Belete' at Bekoji and Kofele Southeast Ethiopia

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Abstract

Potato is one of the most important crops in the farming system of Bekoji and Kofele cool highlands of Arsi. It is usually grown twice-yearly during the main and 'belg' seasons. 'Belete' has been the dominant potato variety in these areas for the last ten years and farmers prefer to grow this variety for its high productivity and resistance to late blight disease. Nevertheless, farmers have complaints on its big sized tubers, considered unmarketable, which costs them more seed to cover a given area of land and less suitable for cooking. Besides, farmers often use random population density and time of harvesting, which also contributed to this problem. The present study was therefore intended to manage the tubers' size distribution of this variety without negatively affecting the yield of the crop through modifying plant spacing and time of harvesting of previously recommended practices. Twelve combinations of four plant spacing and three time of harvesting were studied on variety "Belete" at Bekoji and *Kofele during the main seasons of 2018 and 2019. The experiment was laid out in a completely randomized block design of three replications with 4 x 3 factorial arrangements. The analysis of variance revealed that the interaction effect of spacing and time of harvesting significantly (p<0.001) affected the marketable tuber yields. Narrow spacing (60cm x 20cm) or high population treatment (83,333 plants/ha) combined with harvesting at 120 days after planting resulted in the highest marketable and total tuber yield compared to the rest. While the least yields were recorded from the wider spacing of 75cm x 30cm (44,444plants/ha) and early harvesting at 90 days after planting. The spacing 60cm x 20cm increased marketable tuber yield by 17.2% over the previously recommended spacing of potato (75cm x 30cm, 44,444plants/ha). From this study, therefore, 60cm x 20cm spacing and harvesting at 120 days after planting can be recommended as optimum spacing and time of harvesting for Belete to produce high marketable tuber yield. However, there is a need to study the cost benefit analysis of using the amount of seed tubers required to cover a hectare of land as using this spacing almost double the amount of seed required to plant a hectare of land compared to the previously recommended plant spacing of potato in Ethiopia.*

Introduction

Potato (*Solanum tuberosum* L.) is one of the most important agricultural crops in the world. In volume of production, it ranks fourth in the world after maize, rice and wheat, with an estimated production area of 18.9 million hectares (Naz *et.al.*

2011). Potato is regarded as a high-potential food security crop because of its ability to provide a high yield of high-quality product per unit input in a shorter crop cycle (mostly <120 days) than the major cereal crops (Adane *et al*., 2010).

The average composition of the potato tuber is about 80% water, 2% protein and 18% starch. As a food crop it is one of the cheapest and easily available sources of carbohydrates and protein and contains appreciable amount of vitamin B and C as well as some minerals. Moreover, the protein of potato is of high biological value (Woolfe, 1987; Ganapur, 1995).

Global production of potatoes was 388 million tons, led by China with 64% of the world total (FAOSTAT, 2019). China is now the biggest potato producer, and almost a third of all potatoes are harvested in China and India (FAOSTAT, 2019). Secondary producers were Algeria and Nigeria (FAO, 2019) while the current average potato productivity in Africa has been reported to be about 13.22 t ha^{-1} which is well below the world average productivity of 20.11 t ha^{-1} (FAOSTAT, 2019). The average yield of potato in Ethiopia ranges only between 8 to 13 t ha^{-1}, which is much lower than the yields obtained in Sudan (17 t ha^{-1}) and Egypt (26 t ha^{-1}) (Haverkort *et al*., 2012). In Ethiopia, during 2018/19 cropping season more than 1.2 million small holders are engaged in potato production. The total area allocated and total volume of production of potato during the rainy season of 2018/19 cropping season was 73,677.64 ha and 10,444,363.59 tons, respectively (CSA, 2018/19).

In Oromia Region potato production coverage was estimated about 38,925.67 ha from which 484,831.16 tons of potato was produced with an average yield of 12.46 t ha^{-1} (CSA, 2017/18). In Ethiopia, potato is a high potential food security crop due to its high yield potential per hectare and nutritious tubers. Potato production in Ethiopia is possible on about 70% of the arable land (FAO, 2008). In Ethiopia potato production serves as a bridge to pass food shortage periods during the ‘hungry months’, since it matures before the harvest of other food crops such as cereals (Sanginga *et al*., 2009). Despite this fact, the productivity of this crop in the country is very low (14.2 t $ha^{-1)}$ as compared to the world’s average yield of 19 tons ha^{-1} (CSA, 2017). The yield of potato is influenced by a number of factors, which include fertilizer input, cultivar, spacing, climatic conditions and geographic location (Barry *et al.*, 1990; Arsenault *et al.*, 2001). Plant spacing and time of harvesting are amongst the factors which could affect the yield as well as the size of tubers in potato. As plant density increases (closer spacing) there is a marked decrease in tuber size and yield per plant, while at lower plant density (wider spacing), the reverse could happen. This effect is due to inter-plant competition for water, light and nutrient. It is therefore, essential to understand how individual factors interact with each other and the environment and to possibly come up with the ideal crop density level to optimize yields and tuber sizes.

In Ethiopia a plant spacing of 75cm (inter row) x 30cm (intra row) and/or 60cm x 20cm to produce potato for table and seed purpose, respectively is a common practice for all varieties. However, growing the popular variety ‘Belete’ using this spacinghas resulted in production of large tubers, which are not usually acceptable by farmers, either for seed or table purposes. Besides, variations in tuber size distribution, seed rate to be used for a given area of land varies with varieties. Some varieties such as ‘Belete’ produces large tubers compared to other potato varieties and consequently, a higher seed rate is required to cover a hectare of land. Potato growers in Arsi area also have complaints that big sized potato tubers like that of ‘Belete’ could take longer time for cooking. In addition to plant spacing, time of harvesting also influences potato tuber sizes as tubers physiological developement time beginning tuber initiation to bulking stage is different. Most farmers harvest potatoes when its vine (haulm) is dead naturally, which could result in bigger sized tubers particularly for variety ‘Belete’. Therefore, the present study was carried out to study the tubers’ size distribution of variety ‘Belete’ in response to different plant spacing and times of harvesting.

Materials and Methods

Description of the study area

The experiment was conducted at Bekoji and Kofele, Southeastern Ethiopia during the main growing season of 2018 and 2019 main rain season. Bekoji and Kofele are the two major potato growing areas in Arsi zone of Oromia region which are about 52km apart and 227 and 250 km far from Addis Ababa, respectively. The study areas are located at an altitude of 2800 and 2650 meter above sea level, respectively. The maximum and minimum temperatures at Bekoji were 20.48 and 2.63 ^{0}C while 20.48 and 3.34^{0}C for Kofele. The study areas have acidic and loam soils and the agro- climatic condition of the areas is wet with 956.6 and 950.6 mm mean annual rain fall and both have a uni-modal rainfall pattern with extended rainy season from March to September. However, the peak rainy season is from June to August.

Experimental materials, design and procedure

The study was conducted on the improved variety ‘Belete', one of the dominant potato varieties in the production system in Ethiopia, that is released by Holeta Agricultural Research Center in 2009 (MoA-Crop variety register, 2010). Twelve treatment combinations of four plant spacing (75cm x 30cm, 75cm x 20cm, 60cm x 30cm and 60cm x 20cm) and three harvesting time (90, 105 and 120 days after planting) factorially combined in a 4 x 3 arrangement were laid out using

Randomized Complete Block Design (RCBD) in three replications. Medium sized seed tubers (35-55mm) were planted per plot ($9m^2$) for each treatment combination based on the spacing treatments combinations selected above. The required agronomic practices such as cultivation (weeding), ridging, fertilization, pesticide application, etc. were applied to all experimental units. Fertilizers were applied at the rate of 242kg ha^{-1} NPS and 150kg ha^{-1} urea, in which Urea is applied in split application, half dose at full emergence and the rest half after 45 days depending on the fertility level of the soil. Late blight disease (*Phytophtora infestans)* occurred on the experimental fields was managed with Redomil gold at 3.5kg ha^{-1}.

Data collected

Morpho-agronomic data such as number of main stem per hill, stem height, marketable tubers yield t ha^{-1}, and total tubers yield t ha^{-1} were collected

Data analysis

The collected data were subjected to Analysis of Variance (ANOVA) using statistical analysis Software (SAS version 9.2, 2008). The mean separation was done using (LSD) test at 5% probability level.

Results and Discussion

The combined analysis of variance revealed that stem number, plant height, marketable tuber yield, and total tuber yield were all significantly (P<0.05) influenced by the main effects of time of harvesting. However, spacing only affected marketable and total yields per hectare. While the interaction effect of the two factors brought about highly significant (P<0.01) effects on total marketable yields per hectare (Table 1).

Stem number at 50% flowering

The analysis of variance revealed that stem number of potato was significant (P<0.05) affected by the main effect of time of harvesting, but statistically not-significantly (P >0.05) influenced by the spacing treatments. Numerically the highest (3.94) stem number was recorded from plants harvested 105 days after planting, while lowest (3.28) was recordedplants harvested from 120 days after planting, but spacing did not significantly (P>0.05) affected stem number per hill. Generally stem numbers were reduced at high plant density level and increased with small numeraical value at lower densities. This might be due to population density and competition effect for resourse like sun light, nutrient and water. Some studies, for example in which the relation between plant spacing and growth were examined, the results showed an increase in plant spacing is accompanied by an increase in stem length. The increased branching at the wider spacing did not compensate for fewer plants/m^2. They attributed increased branching at wider spacing to the availability of more space at lower plant densities. More space meant that plants were able to exploit the available nutrients in the soil and the photosynthetic active radiation for growth than plants at close spacing (Allen, 1978). However, location very highly significantly affected (P<0.001) stem number per hill. The highest stem number was recorded at Bekoji, while the lowest was obtained at Kofele (Table 1). This could be due to environmental factors, such as soil variability, altitudes etc. At Bekoji, the soil is nitosol (red) and more acidic while at Kofele the soil was clay loam soil.

Table 1. Results of ANOVA of the main effect of spacing and harvesting time on morpho-agronomic traits of Belete potato variety at Bekoji and Kofele, Southeast Ethiopia, 2018 and 2019.

Spacing	Stem number at 50% flowering	Stem height at flowering	Marketable tuber yield, t ha^{-1}	Total tuber yield, t ha^{-1}
75cm*30cm	3.57	81.67	44.23b	53.31b
75cm*20cm	3.72	84.06	46.39b	57.07b
60cm*30cm	3.38	81.27	45.60b	55.94ab
60cm*20cm	3.53	81.71	53.43a	63.97a
LSD (5%)	NS	NS	8.01	9.39
Harvesting time				
90	3.44b	79.48b	42.36b	55.33b
105	3.94a	82.10ab	49.03a	56.26b
120	3.28b	84.95a	50.84a	61.07a
LSD (5%)	0.38	3.45	7.17	3.73
Locations				
Bekoji	3.93a	79.57b	45.71b	59.21
Kofele	3.17b	84.78a	49.12a	55.91
LSD (5%)	0.31	2.82	2.69	NS
CV (%)	26.62	10.41	18.97	18.79

LSD0.05 = least significant difference at 5%, CV (%) = Coefficient of variation. Means in the same column followed by the same letter(s) are not significantly different.

Stem height at 50% flowering

The combined analysis of variance revealed that stem height of potato was significantly (P <0.05) affected by main effect of time of harvesting but not statistically affected by both spacing and their interaction.

Numerically the highest (84.95cm) stem height was recorded at 120 days after planting. The shortest (79.48cm) stem height was obtained from 90 days after planting. But spacing did not significantly (P>0.05) affected stem height. This contradicting result could be due to soil variability, planting season, moisture levels, and variety response to location, light energy, biotic factors or other environmental factors affecting the influence of plant spacing. On the other hand, location very highly significantly affected (P<0.01) stem height. Numerically the highest (84.78cm) stem height was recorded from Kofele; while the shortest (79.57cm) was obtained at Bekoji (Table 1). This could be due to differences in environmental factors, soil variability, altitudes and amount of rainfall between the locations. At Bekoji the soil was nito soil (red) or more acidic, high rain fall and nutrient availability.

Marketable tuber yield t ha^{-1}

The combined analysis of variance revealed that marketable tuber yield of potato were significantly affected (P<0.05) by the main effects of both time of harvesting and spacing (Table 1), and very highly significantly influenced (P<0.001) marketable tuber yield t ha^{-1}by the interaction of of spacing and days to harvesting. The highest (50.84 t ha^{-1}) marketable tuber yield was obtained from 120 days after planting, while lowest (42.361 t ha^{-1}) marketable tuber yield was recorded from 90 days after planting. This might be due to the fact that at full physiological maturity, small size tubers will develop into medium size tubers size category through increased photoassimilation, metabolic processes including cell division, cell expansion, respiration and photosynthesis. Time of harvesting in potato have significant influence on tuber sizes as tubers develop in different physiological time space starting from tuber initiation to bulking stage. However, an experiment conducted at Bekoji in 2017 showed that, there was a tendency that marketable tuber yield was declining with delayed harvesting. This could be for the very reason that potato tubers could increase bulking and increased large sized tubers towards late harvesting (Figure 1). This was also in line with the decreasing numbers of small sized tubers towards late maturity (Figure 2).

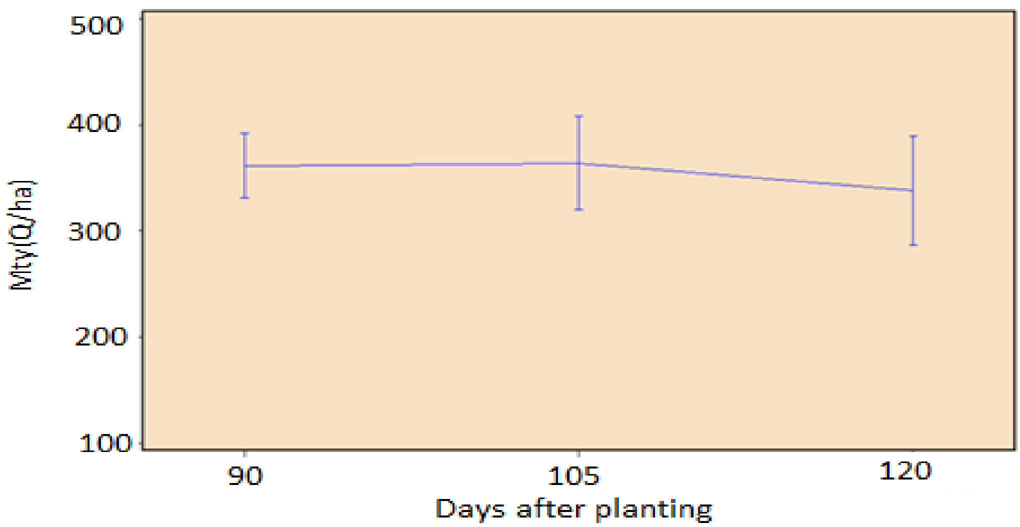

Figure 1. Response of marketable tuber yield to time of harvesting at Bekoji, 2017.

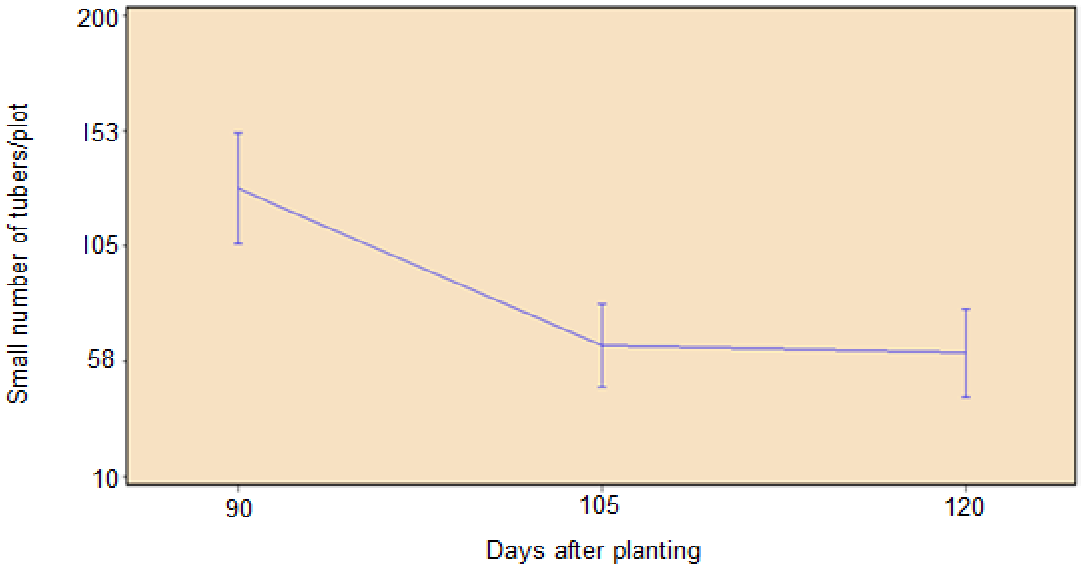

Figure 2. Response of small number of tubers (unmarketable) to time of harvesting at Bekoji, 2017.

Similarly the marketable tuber yield t ha^{-1} was affected by spacing. Numerically the highest (53.43 t ha^{-1}) marketable tuber yield was obtained at the narrow spacing of 60cm x 20cm, while lowest value (44.28 t ha^{-1}) marketable tuber yield was recorded at the wider spacing of 75cm x 30cm. The highest marketable yield recorded at closer spacing is attributed to more number of tubers produced at the higher plant population per hectare. The result is analogous with the findings of Somanin *et.al*. (2010) who reported that increasing plant density increases the tuber yield per plant. The findings of Harnet *et.al*. (2013) also reported that the combination of inter and intra spacing had significant effect on number of marketable yield. In a related study Burton (1989) reported that wider spacing produced few tubers as it gave rise to few stems that could lead to few large sized tubers, but closer spacing improved quality and saleable yield. The present result is contradicts with Tesfaye *et al*., (2013) result who reported highest marketable yield at the wider intra row spacing of 30 cm whereas the lowest was obtained at closer spacing of 10 cm. Our results are in line with what was found by Alemayeu *et al*. (2015) in that increasing the planting density from 4.44 to 6.67 plants m^{-2} significantly increased total and marketable tuber yield by 5.21 and 4.67t ha^{-1}. Our result showed that increasing plant population from 75cm x 30cm (4.4 plants/m^2) to 60cm x 20cm (8.33plants/m^2) increased marketable tuber yield from 44.23 to 53.43 t/ha^{-1}). As mentioned above on the effect of time of harvesting on marketable yields, the study in 2017 at Bekoji explained that increasing plant population significantly increased marketable tuber yields to until an optimum point where marketable tuber yield started to decline due to increased number of small number of tubers (Figure 3 and 4).

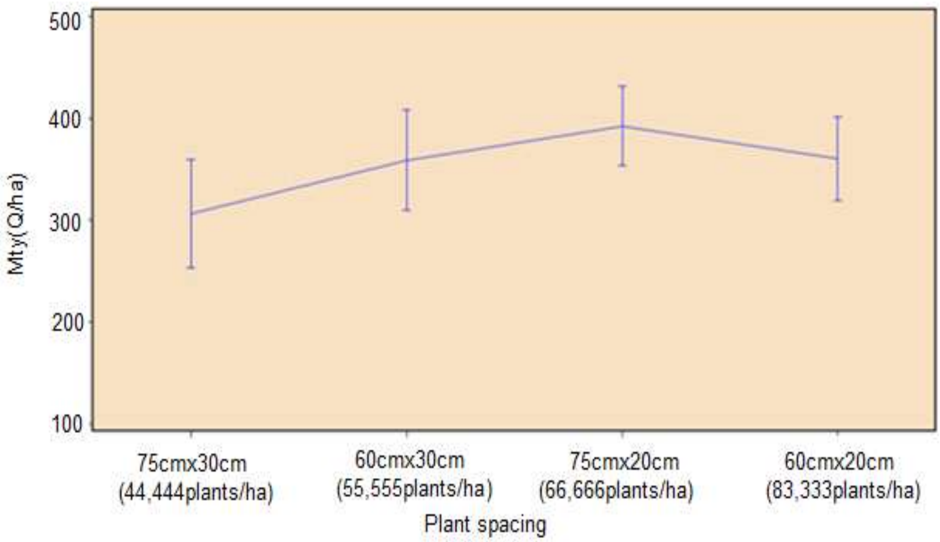

Figure 3. Response of marketable tuber yield to plant spacing (plant population) at Bekoji, 2017.

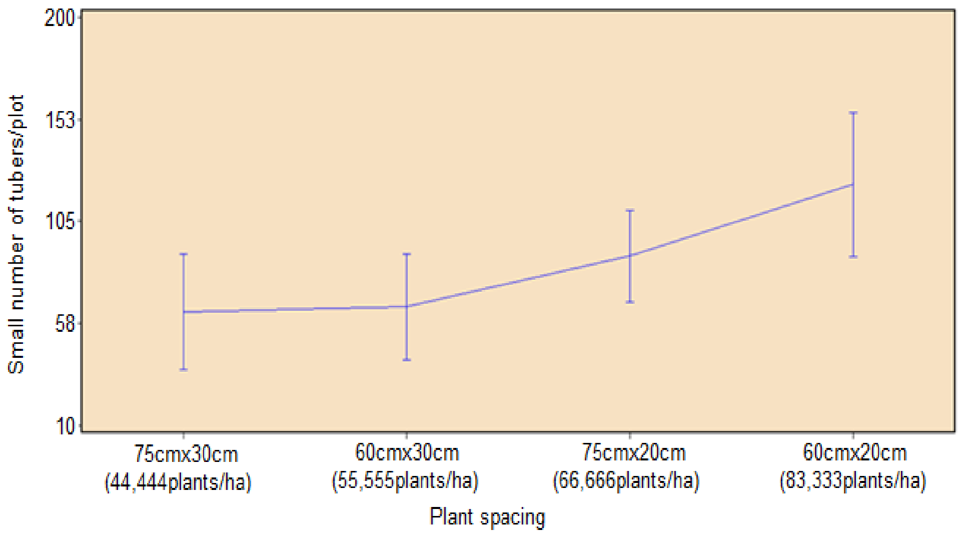

Figure 4. Response of small number of tubers to plant spacing (plant population) at Bekoji, 2017.

The combinations of spacing (60cm x 20cm) and harvesting after 120 days after planting resulted in better marketable potato yield per hectare. The lowest mean marketable yield was recorded from treatment combination of 60 x 30cm spacing and plant harvesting after 90 days of planting. The combinations of 60cm x 20cm spacing and time of harvesting of after 120 days brought about 17.2% increments in marketable yield per hectare over the treatment combination of 70cm x 30cm spacing and early harvesting at 90 days after planting (Table 2). The increased yield at higher densities may be attributed to the higher ground covered with green leaves earlier in the season and light is intercepted used for assimilation, fewer lateral branches being formed and starting of tuber growth earlier. Consistent with this suggestion, increased plant population density increased yield due to more tubers being harvested per unit area of land (Beukema and Van der Zaag, 1990). However, total tuber yields decreased as a result of wider spacing owing in part by increased production of large-sized tubers and decreased production of small-sized tuber. This is apparently a result of reduced interplant competition, which leads to increased production of total tuber numbers per plant and increased average tuber size with wider spacing (Rex *et al*, 1987). This result is analogous with Tesfaye *et al.* (2013) who obtained highest marketable yield at the wider intra-row spacing of 20 cm whereas the lowest was obtained at closer spacing of 10 cm. Contrarily, Alemayeu *et al.* (2015) reported increasing planting density from 4.44 to 6.67 plants m^{-2} significantly increased total and marketable tuber yield by 5.21 and 4.67t ha^{-1}.

On the other hand location had very highly significantly affected (P<0.001) marketable tuber yield. Numerically the highest (49.12 t ha^{-1}) marketable tuber yield was obtained from Kofele location; while the lowest (45.71 t ha^{-1}) was recorded from Bekoji location (Table 1 and Fig.1). This may be due to differences in environment and edaphic factors such as amount of rainfall and soil type and fertility gradient.

Table 2. The interaction effect of days after harvesting and spacing on marketable yields grown at Bekoji and Kofele in 2018 and 2019.

DAH	Spacing	Marketable yield t ha^{-1}
90	75cm x 30cm	41.94^{de}
	75cm x 20cm	41.94^{de}
	60cm x 30cm	38.38^{e}
	60cm x 20cm	47.17b^{cd}
105	75cm x 30cm	44.86^{cde}
	75cm x 20cm	47.29^{bcd}
	60cm x 30cm	50.18^{bc}
	60cm x 20cm	53.81^{ab}
120	75cm x 30cm	45.88^{cd}
	75cm x 20cm	49.92^{bc}
	60cm x 30cm	48.25^{bcd}
	60cm x 20cm	59.31^{a}
Mean	474.12	
LSD(0.05)	17.73	
CV (%)	18.60	

LSD0.05 = least significant difference at 5%, CV (%) = Coefficient of variation, DAH = days after harvesting. Means in the same column followed by the same letter(s) are not significantly different.

Total tuber yield t ha^{-1}

The main effect of harvesting time and spacing showed a very highly significant ($P<0.001$) influence on total tuber yield per hectare (Table 1). The highest (61.07 t ha^{-1}) total tuber yield was obtained from 120 days after planting, while lowest value (55.33 t ha^{-1}) was recorded from 90 days after planting. This might be due to the fact that at full physiological maturity, small size tubers get bulked to medium/ large sized tubers which could increase the total tuber yield. On the other hand, the low tuber yields at early harvesting time could be attributed to more number of under sized and immature tubers.

Similarly the highest total tuber yield (63.97 t ha^{-1}) was obtained from the narrowly spaced (60cm x 20cm) high plant population treatment whereas the lowest (53.30 t ha^{-1}) was recorded at the widely (75cm x 30cm) spaced lower plant population density (Table 1). In other words, it was clearly evident from the results that the total tuber yield ha^{-1} was increased with decreasing plant spacing. These results are completely in agreement with Alemayeu *et al.* (2015) who reported a significantly marketable and total tuber yield increase by 5.21 and 4.67 t ha^{-1}, respectively due to planting density increase from 4.44 to 6.67 plants m^{-2}.

Conclusion and Recommendations

In conclusion, plant spacing of 60cm x 20 cm (83,333plants/ha) and harvesting plants 120 days after planting resulted in the production of the highest marketable and total tuber yields of Belete variety than any other treatments studied. The spacing 60cm x 20cm (83,333plants ha^{-1}) brought about 17.2% marketable yield per hectare increments over the generally recommended spacing of potato (75cm x 30cm, 44,444plants/ha). From this study, therefore, it is found optimum and can be recommended to use narrow spacing of 60cm x 20cm and harvesting 120 days after planting of Belete variety to produce higher marketable tuber yields. However, there is a need to study the cost benefit analysis of using the amount of seed tubers required to cover a hectare of land as using this spacing almost double the amount of seed required to plant a hectare of land compared to the previously recommended plant spacing of potato in Ethiopia.

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Effect of Intercropping Enset with Maize, Common Bean and Taro on the Yield of Enset and Component Crops

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Abstract

Field experiment was conducted at Areka Agricultural Research Centre during 2014-2017 cropping seasons to evaluate different intercropping patterns on yield and yield components of enset and component crops. There were three experiments: enset intercropped with maize, common bean and taro. The experiments were laid out in randomized complete block design with three replications. One year old enset suckers were planted using the recommended spacing and time of planting for each experiment. Maize, common bean and taro were grown with in three enset rows. The number of rows between enset rows for taro and maize were 8, 6 and 4, while for common bean it was 14, 10 and 6. The statistical analysis of variance showed that most of the yield and yield components of enset were not significantly affected when intercropped with maize, common bean and taro. In enset/maize intercropping maize yield and yield components were not significantly affected except 1000 seed weight and biomass yield. In enset /common bean intercropping all parameters except pseudostem height were not affected significantly by the intercropping. Common bean yield and yield components were not affected by the intercropping. In enset/ taro intercropping all parameters of both crops were not affected significantly by the intercropping. The land equivalent ratio (LER) of the three experiments were more than one. This indicates that all intercropping combinations were better in resource use efficiency compared to sole growing each crops.

Introduction

Enset [*Ensete ventricosum (Welw.) Cheesman]*, a plant which looks like banana, is a multi-use crop domesticated and grown as food crop only in Ethiopia. It is one of the most important perennial food security crop of Southern Nations Nationalities and Peoples Regional State (SNNPR) of Ethiopia. Due to its multi-use and high economic returns it is referred to as a plant for everything (Valentina, 2015).

Enset serves as a staple food for about 20% of the Ethiopian population, over 20 million people, mainly in the South and Southwest of the country (Borrell *et al*., 2018). Enset is perceived to be relatively tolerant of drought (Zerfu, et al., 2018), withstand heavy rain, tolerate flooding, and endure frost damage (Degu and Workayehu, 1990). Enset is most abundant in northern and eastern zones of SNNPR. It is important for household food security and livestock feed. Many enset-based farms are derived from forest, whereby farmers clear away the undergrowth to plant enset, coffee, and other crops, leaving the upper story trees, resulting in multi-story agroforestry systems which are thought to have remained relatively stable for centuries (Kippe, 2002).

Intercropping is the practice of growing two or more crops at the same time during the same cropping season in the same piece of land (Willey, 1979). The system has been shown not only to be more efficient than sole cropping (Willey, 1979) but also to improve the overall ecology (Adelana, 1984). It is mostly practiced by smallholder farmers in developing countries. Yields of intercropping are often higher than sole cropping systems (Lithourgidis *et al*., 2006) due to the reason that resources such as water, light and nutrients can be utilized more effectively than in the respective sole cropping systems (Li *et al*., 2006).

Intercropping, double cropping and other mixed cropping practices that allow more efficient uses of on-farm resources are among the agricultural practices associated with sustainable crop production (Tolera, 2003). In general, intercropping has been shown to be more productive than mono cropping (Carruthers *et al*., 2000). In areas where intercropping is practiced, crop yield is enhanced simply by growing two or more compatible crops without using costly agricultural inputs. The persistent exploitation of agricultural land and fast growth of population in Ethiopia have made land an extremely expensive natural resource (CSA, 2013). Such population growth causes diminishing of arable land that in turn forced farmer to practices multiple cropping system (Ricker-Gilbert *et al.*, 2014) in which two or more crops are produced in space and time combination (Abera *et al.*, 2005).

Enset is a very competitive and a crop with dense canopy hence at early stage of enset combining annual and perennial legume crops are also a possible and could contribute to improve soil nitrogen and produce additional protein foods from that piece of land. Winged beans, climbing cowpeas and beans and local forage legumes could be adapted to benefit enset plantation without reducing but hopefully increasing enset growth and development. Enset production system involves intercropping with diverse crop species as well as landrace mixtures. Young enset plants are commonly intercropped with annuals crops such as maize, common bean, cabbage, taro, and Irish potato, and older *Enset* plants with perennials such as avocado, coffee, and citrus (Tsegaye and Struik, 2000). To improve this production system and increase productivity per unit area, compatible crops for intercropping and the best mixtures of enset landraces need to be investigated. However, there is no sufficient scientific information that help to maximize farmers benefit from this traditional practice of intercropping enset/annual crop in the study areas. Therefore, this study envisaged to investigate the effect of maize, common bean and taro intercropping with enset and recommend the best intercropping combinatins.

Materials and Methods

Description of the study area

A field experiment was conducted at Areka Agricultural Research Center which is located at about 300 km Southwest of Addis Ababa, at 7 04'N latitude and 37 41'E longitude and altitude of 1790 meters above sea level. The soil of the Research Center is formed from pyroclastic rocks, and is clayey in texture (Abayneh Esayas, 2003). The soils at Areka are deep, highly weathered with a pH of 5.2. The climate is tropical, with mean annual rainfall of about 1500 mm. The daily mean maximum and minimum temperature of the area is 25 0^c and 13 0^c, respectively. The main soil type in the area is Nitisols.

Experimental design and experimental procedures

There were three experiments: enset intercropped with maize, common bean and taro. Maize, common bean and taro were grown at three different numbers of rows between enset rows. Four, six and eight rows for maize and taro. Six, ten and fourteen rows for common bean. One year of enset sucker was planted at a recommended intra and inter-row spacing of 1.5 m X 3m, respectively. Maize, common bean and taro were intercropped with enset at the same time using the recommended spacing of 75 cm x 30 cm, 40 cm x 10 cm, and 75 cm x 50 cm, respectively. Net plot size of the experiment was 12 m x 8 m (96 m^2)**.** The experiments were established in randomized complete block design with three replications.

The plants were fertilized with DAP and Urea following the respective component crop recommendation. For maize it was applied near the maize rows at the rate of 100 kg/ha based on their respective plant population density. All DAP and 50% of urea was applied at sowing. The other 50% of urea was applied 30 days after emergence. For common bean 150 kg ha^{-1} DAP was applied at planting time. To keep the trial free from weeds, hand weeding was done equally and at the same time for the entire experimental units as required.

Data collection and analysis

At harvest, cobs of maize were picked, air dried before it was shelled. Five maize cobs were randomly selected from each plot to determine average cob weight, average number of seeds/cob, average cob length, 1000-seed weight and plant height. For common bean, plant height, number of pods $plant^{-1}$ number of seeds $plant^{-1}$, 1000 seed weight and grain yield data were collected. Number of roots $plant^{-1}$, root weight $plant^{-1}$, root diameter, root length, marketable, unmarketable and total yield data were collected for taro.

Analysis of variance and comparison of treatment

Analysis of variance and comparison of treatment means at 5% significant level of probability was carried out on all collected data using general linear model (GLM) procedure of SAS Institute (2000). The productivity of the intercropping system was evaluated following the land equivalent ratio (LER) procedure (Fisher, 1977; Mead and Willey, 1980), i.e., the sum of the ratios of the yields of the intercrops to those of the sole crops.

Results and Discussion

Enset yield and yield components in Enset/maize intercropping

The statistical analysis of variance showed that yield and yield components of enset were not significantly affected when intercropped with maize (Table 1). This result was in agreement with the result obtained by Fisseha Negash and Tewodros Mulualem (2014) that growing maize with different arrangements between rows of cassava did not cause significant difference on cassava root yield and yield components. The non-significant effect of maize on yield and yield component of enset could be due to early maturity of maize crop and absence of crops competition with enset for resources.

Table 1. Enset yield and yield components in Enset/maize intercropping

Number of maize rows	Pseudo Stem Height (m)	Pseudo stem Circumference (m)	Fiber length (m)	Fiber Yield (kg/ha/yr	Corm Yield (kg/h/yr	Bulla yield (kg/ha/yr	Kocho yield (kg/ha/yr
4 rows	1.19	1.12	1.15	243	32568	1277	24198
6 rows	1.29	1.22	1.22	290	43456	1535	34552
8 rows	1.18	1.15	1.17	262	38025	1088	26420
Sole enset	1.16	1.08	1.18	254	36545	1312	27397
CV (%)	7.6	8.6	7.4	30.3	14.2	6.6	26.8
P	NS	NS	NS	NS	NS	NS	NS

Means within a column followed by the same letter(s) are not significantly different at 5% level of significance. *= significant;** = Highly significant; ns = non- significant

Maize yield and yield components in Enset/maize intercropping

The statistical analysis of variance showed that enset-maize intercropping caused significant ($P<0.05$) influence on maize biomass yield and thousand seed weight (Table 2). Significantly the highest biomass yield of (8025 kg ha^{-1}) was obtained from sole maize growing. The biomass yield was increased with the number of rows in maize. The highest maize thousand seed weight of (285 g) was recorded at 8 rows of maize. There were not significant difference in thousand seed weight among intercropped maize. Sole cropping maize recorded significantly the lowest thousand seed weight. In line with this result, Niringiye *et al*. (2005) reported that intercropping of maize with different population density of bean resulted more yield and economic advantage than sole cropping of the component crops. Intercropping could result in competition for growth resources when the component crops are in intimate contact, especially with increasing planting density of any of or all the crops in mixture (Muoneke and Asiegbu, 1997). The LER of enset with maize intercrops were all above 1.00 and the yield advantages ranged from 68 to 118 %. (Table 3). This indicates that all intercropping combinations were better in resource use efficiency compared to growing the two crops separately. The highest LER of 2.12 was obtained when 6 rows of maize was intercropped between two enset rows (Table 3).

Table 2. Maize yield and yield components in enset/maize intercropping

Number of maize rows	Plant Height (m)	Stand % at harvest	Biomass yield (kg/ha)	No of rows /cob	No of Seeds /rows	Cob Length (cm)	Cob wt. (g)	No of Seeds /Cob	Seeds weight /Cob (g)	1000 Seed Wt. (g)	Grain Yield kg/ha
4 rows	2.37	61	4815c	12	35	19	139	391	115	275 a	1488
6 rows	2.18	54	6420b	13	38	19	154	369	128	284 a	1605
8 rows	2.37	59	7778a	12	36	18	133	428	135	285 a	2109
Sole maize	2.38	55	8025a	13	35	17	112	420	108	241 b	1858
CV (%)	6.1	13.5	8.8	7.4	8.6	15.8	10.8	9.0	16.4	6.3	16.7
P	NS	NS	0.001	NS	NS	NS	NS	NS	NS	0.05	NS

Means within a column followed by the same letter(s) are not significantly different at 5% level of significance. *= significant;** = Highly significant; ns = non- significant

Table 3. LER in enset/maize intercropping

Number of maize rows	Sole enset yield (kg/ha/yr)	Intercropped enset yield (kg/ha/yr)	LER of enset	Sole yield of maize (kg/ha/yr	Intercrop Yield of maize (kg/ha/yr)	LER of maize	Total LER
4 rows	27397	24198	0.88	1858	1488	0.80	1.68
6 rows	27397	34552	1.26	1858	1605	0.86	2.12
8 rows	27397	26420	0.96	1858	2109	1.14	2.10

Enset yield and yield components in enset/ common bean intercropping

In enset/common bean intercropping only pseudostem height of enset was significantly affected (P<0.01) by intercropped common bean. All other yield and yield components were not affected significantly by the intercropped common bean. Although their difference were not significantly different sole enset gave better value in all parameters. The highest pseudostem height was obtained by sole enset followed by six rows of common bean between enset rows (Table 4).

Common bean yield and yield components were not affected significantly by intercropping with enset. The land equivalent ratio indicated that the yield advantages ranged from 22 to 47 % (Table 6). The highest land equivalent ratio was observed when 6 rows of common bean was intercropped between enset rows.

Table 4. Enset yield and yield components in Enset/ common bean intercropping

Number of bean rows	Pseudo Stem Height (m)	Pseudo stem Circumference (m)	Fiber length (m)	FiberYield (kg/ha/yr)	Corm yield (kg/ha/yr)	Bulla yield (kg/ha/yr)	Kocho yield (kg/ha/yr)
6 rows	1.27 a	1.12	1.13	265	33381	1513	30619
10 rows	1.10 b	1.02	1.04	200	27848	1233	20487
14 rows	1.24 a	1.13	1.18	269	35796	1405	30368
Sole enset	1.33 a	1.19	1.19	348	37034	1664	40989
Cv (%)	5.0	7.0	6.3	26.0	19.4	14.7	35.8
P	0.01	NS	NS	NS	NS	NS	NS

Means within a column followed by the same letter(s) are not significantly different at 5% level of significance. *= significant;** = Highly significant; ns = non- significant

Table 5. Common bean yield and yield components in Enset/ Common bean intercropping

Number of Common bean rows	Days to maturity	Plant Height (cm)	No of Pods plant^{-1}	No of Seeds plant^{-1}	1000 seed weight (g)	Grain yield (kg ha^{-1})
6 rows	92	73.000	15	6	15	1291
10 rows	93	61.667	15	6	14	1282
14 rows	91	69.600	18	6	14	1005
sole Bean	89	62.800	16	6	15	1778
CV (%)	3.5	7.0	9.8	9.0	7.1	24.1
P	NS	NS	NS	NS	NS	NS

Means within a column followed by the same letter(s) are not significantly different at 5% level of significance. *= significant;** = Highly significant; ns = non- significant

Table 6. LER in Enset/common bean intercropping

Number of taro rows	Enset sole yield (kg/ha/yr)	Enset intercrop yield (kg/ha/yr)	LER of Enset	Sole common bean yield (kg ha^{-1})	Intercrop common bean yield (kg/ha)	LER Common bean	Total LER
6 rows	40989	30619	0.75	1778	1291	0.73	1.47
10 rows	40989	20487	0.50	1778	1282	0.72	1.22
14rows	40989	30368	0.74	1778	1005	0.57	1.31

Enset yield and yield components in Enset/ taro intercropping

All yield and yield components of enset were not significantly affected by the intercropped taro. Decreasing trend were observed in Kocho yield with increasing number of rows of taro, though it was statically not significant (Table 7).

Table 7. Enset yield and yield components in Enset/ taro intercropping

Number of taro rows	Pseudo Stem Height (m)	Pseudo stem Circumference (m)	Fiber length (m)	Fiber Yield (kg/ha/yr)	Corm Yield (kg/ha/yr)	Bulla yield (kg/ha/yr)	Kocho yield (kg/ha/yr)
4 rows	1.11	1.05	0.92	212	29870	951	35057
6 rows	1.03	1.02	0.93	214	26657	1036	34812
8 rows	1.14	1.06	1.03	224	32590	1086	34812
Sole enset	1.07	0.98	0.90	193	28397	915	29130
CV (%)	9.0	7.8	12.8	21.5	10.9	11.8	23.1
P	NS	NS	NS	NS	NS	NS	NS

Means within a column followed by the same letter(s) are not significantly different at 5% level of significance. *= significant;** = Highly significant; ns = non- significant

Taro yield and yield components in Enset/ taro intercropping

Based on the results of the experiment, sole Taro and treatment with eight rows of Taro significantly gave the highest marketable corm yield (27 037 kg/ha^{-1}) and (24 321 kg/ha^{-1}), respectively. In enset /taro intercropping only marketable taro yield was significantly affected (P<0.05). It increased with increased number of taro rows. Total yield of taro was not significantly affected by the intercropping. This was in agreement with the finding of Silva *et al*. (2008) who reported that intercropping of taro did also reported the non-significant effect of *Crotalaria juncea on* taro yield. Tafadzwanashe Mabhaudhi and Modi (2014) also reported that intercropping taro with *Bambara Groundnut* did not affect taro yield significantly. Though not significantly different, taro yield also increased with increased number of taro rows (Table 8). Contrary to our findings, Momoko (2018) reported significant difference of intercropping taro with cowpea turmeric and common bean.

Table 8. Taro yield and yield components in Enset/ taro intercropping

Number of taro rows	No of Corms / plant	Corm weight / plant kg	Corm diameter (cm)	Corm Length (cm)	Marketable kg/ha	Un-marketable (kg/ha)	Total Yield (kg/ha)
4 rows	12.667	1.8667	22.3	14.5	16296 b	803	17099
6 rows	12.133	1.8667	20.8	14.0	20617 ab	1222	21840
8 rows	11.267	1.8667	22.3	12.5	24321 a	1086	25407
Soletaro	9.750	1.4567	21.2	13.0	27037 a	1420	28457
CV (%)	16.8	19.6	3.3	8.7	17.0	36.4	17.8
P	NS	Ns	NS	NS	0.05	NS	NS

Means within a column followed by the same letter(s) are not significantly different at 5% level of significance. *= significant;** = Highly significant; ns = non- significant

Table 9. LER in Enset/Taro intercropping

Number of bean rows	Sole yield of enset (kg/ha/yr)	Intercrop yield of enset (kg/ha/yr)	LER Enset	Sole yield of taro (kg/ha¹)	Intercrop yield of taro (kg/ha)	LER Taro	Total LER
6 rows	29130	17099	0.59	28457	17099	0.60	1.19
10 rows	29130	21840	0.75	28457	21840	0.77	1.52
14 rows	29130	25407	0.87	28457	25407	0.89	1.77

Land equivalent ratio (LER)

Evaluation of LER value of different treatments of intercropping showed that in all the treatments the value of LER was more than one, since all intercrop systems had LER > 1, and indicated that intercropping was more advantageous to sole-cropping. This is due to better use of environmental resource. LER of these intercropping patterns of enset and different annual crops indicated that intercropping has advantages over sole cropping (Table 3, 6 and 9). Less value of intercropping was observed in enset/ common bean intercropping (Table 9) while in all other intercropping except in enset/ common bean intercropping showed increasing trend of LER with increased number of annual crops rows. In enset/ Maize intercropping the highest LER value (2.12 and 2.10) was obtained at 6 and 8 row planting of annual crops in enset rows. In enset/ common bean intercropping the highest LER value (1.47) was obtained when 6 rows of common bean was planted between enset rows. Needs to consult more LR & study conducted on intercropping

Summary and Conclusion

The annual crops did not affect significantly enset yield and yield components when they were grown for one year in enset rows. The yield and yield components of the annual crops were also not significantly affected when they were grown in enset rows. In all the treatments the value of LER was more than one. Thus, intercropping annual crops is advantageous than growing these crops separately. In general, maize, common bean and taro can be advantageously grown with enset in intercrop in early stage of enset, at least for one year, without affecting enset yield and but higher yield per that parcel plot of land since had higher LER value.

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Development and Sensory Evaluation of Bulla Based Food Products Formulated with OFSP and Field Pea

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Abstract

Bulla is white starchy enset product obtained by squeezing decorticated mass. It is mainly consumed in form of soup, flat bread and as mucho. The objective of this was to enrich bulla nutrients by fortifying bulla with orange fleshed sweet potato and field pea especially when it is solely consumed. Products were developed using different formulation ratios and their acceptance level was evaluated with selected panellists. The result indicated that the developed products were equally liked with control samples without affecting sensory quality attributes for flat bread and soup. Hence, it can safely recommended that bulla can also be utilized with other component crops with additional advantage of nutrient if eaten fortified with orange flesh and field pea..

Introduction

Enset (*Ensete ventricosum*, Musaceae) is a staple root crop consumed by about 20 million Ethiopians. Enset is basically an energy food source, low in protein and vitamins. Bulla is white starchy enset product extracted by squeezing freshly decorticated and chopped enset manually or using presser. It is separated from kocho during processing by squeezing and decanting the liquid. After decanting, the bulla is left to dry and fermented in a way similar to kocho or can be directly cooked without fermentation (Birhanu *et al*., 2016). Sometimes water is added to aid the extraction process. Microorganisms are active in bulla fermentation for starch hydrolysis, proteolysis and lipolysis that determine odour, colour and flavour of the final product. Fermentation time can affect the chemical composition, physico-chemical characteristics, microbial proliferation and sensory attributes of enset's products (Yirmaga, 2013).

In enset consuming areas, bulla is a common food product used to prepare porridges mainly for lactating women. Though bulla is considered as best quality enset product, it lacks Vitamins and protein. Food based fortification approach is an ideal technique to alleviate nutrient deficiencies in the daily nutrient requirement of the body to (Mitra S, 2012). Besides alleviating malnutrition, food fortification will also improve product quality and utilization.

Incorporation of a relatively low cost protein and vitamin sources might potentially improve nutrition security in areas that use enset as a staple food. Field pea is one among important pulse crops utilized in form of split or ground form. It is a good source of protein. On the other hand orange flashed sweet potato is a root crop mainly composed of starch and rich in beta-carotene which is precursor of vitamin A. The two fortificants were selected accordingly due to their availability and nutritional perspective. Therefore, the aim of this research was to develop and evaluate food products developed by blending bulla, orange fleshed sweet potato (OFSP) and field pea.

Material and Methods

Ingredients and formulation

Bulla and OFSP were obtained from Areka Agricultural Research Centre and field pea was purchased from local market. Bulla was processed by following the usual bulla processing steps in the area: harvesting matured enset plant, decortication and chopping, squeezing, decantation, and drying. Orange fleshed sweet potato tubers were harvested, sorted, washed, peeled, sliced, dried and milled to obtain flour. Similarly field pea flour was obtained by soaking, removing water, drying and milling the samples.

Table 1. Formulation ratio for fortification of bulla with field pea and orange fleshed sweet potato

Bulla (%)	Field pea (%)	Orange fleshed sweet potato (%)
50	25	25
50	10	40

Product development

After raw material processing, thin porridge (soup), flat bread and cake were prepared using the ingredients accordingly with different mixing ratio and sole bulla soup, flat bread and cake from wheat flour was used for comparison. Preparation procedure: 1) soup: - ingredient collection, weighing and mixing, introduction into pre boiled water, boiling, cooling. 2) Flat bread: - ingredient collection, weighing and mixing, dough, spreading the dough on enset leaf, roasting.

Sensory evaluation

The acceptance level of the products was evaluated with panelists using sensory attributes (color, texture/mouth feel, flavor, taste and overall acceptability) of the developed products. During evaluation, 30 untrained panelists were participated.

Data analysis

The collected data was analysed using SPSS (16.0 version) software. Mean separation was performed among the products to detect their equally accepted or not.

Result and Discussion

Result

Table 2. Sensory results of bulla based products

Products	Proportions	Color	Texture	Flavor	Taste	OA
Soup (thin porridge)	50:25:25	3.67±0.8^b	3.63±0.9	3.10±1.2	3.13±1.2	3.77±1.0
	50:10:40	3.27±0.9^b	3.20±1.0	3.53±1.0	3.30±1.1	3.70±0.7
	100% bulla	4.37±0.9^a	3.73±0.9	3.50±1.2	3.37±1.1	4.03±0.8
	LSD	1.10	NS	NS	NS	NS
Flat bread	50:25:25	3.87±1.0^a	3.67±1.1	3.87±0.9	3.43±1	3.70±0.9
	50:10:40	3.80±0.9^b	3.48±0.9	3.60±1.0	3.57±1	3.97±0.8
	100% bulla	3.33±0.9^b	3.57±0.9	3.53±1.0	3.67±1	3.47±1.0
	LSD	0.5	NS	NS	NS	NS
Cake	50:25:25	3.80±0.9^b	3.40±1.0^b	3.40±1.0^b	3.13±0.8^b	3.97±0.7^a
	50:10:40	4.60±0.7^a	3.43±0.9^b	3.07±1.0^b	4.30±1.1^a	3.80±0.8^a
	wheat	3.57±0.6^b	4.53±0.8^a	4.23±1.0^a	3.33±0.9^b	4.43±0.9^b
	LSD	0.80	1.13	1.20	1.16	0.63

Proportions (Bulla: field pea: orange fleshed sweet potato)
Means followed by different superscript letter within the column shows significant difference at α=0.05, NS= non-significant, OA= overall acceptability

Discussion

Mean separation result of the samples showed no differences compared to the control (Table 2). The samples can be used equally or as alternative formula with control. One advantage of this fortification is complementation of nutrients (i.e. protein from field pea and vitamin from sweet potato). Except color differences in soup and flat bread, the other sensory attributes were equally accepted as that of control sample (Table 2). Contrarily, statistical differences among newly developed samples and control declare that the developed new products were not liked as control. This might be due to the fact that cake consumption pattern in the study area is u common. It implies cake production was not effective by blending bulla, field pea and orange fleshed sweet potato as main ingredient.

Conclusion and Recommendation

Incorporation of missing nutrients from possible sources is the best approach in alleviating malnutrition. Blending of the three ingredients (bulla, field pea and orange fleshed sweet potato) can ideally mitigate the nutrient deficiency. In general bulla can also be utilized with other nutrients without affecting its sensory acceptance level. The products (soup and flat bread) are common and accepted by the users except their colour deviation. The authors recommend further nutritional analysis of each formulation to satisfy the daily requirement of the target users.

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