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Wheat Production and Consumption Trends and Prospects in Ethiopia

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Abstract

National wheat research and development efforts mainly focus on enhancement of production and productivity to ensure wheat food security and self-sufficiency. Wheat production and productivity growth can be achieved using irrigation, adoption of improved agricultural technologies and farm mechanization. Currently, federal and regional governments have extensively focused on increasing wheat production and productivity to achieve wheat self-sufficiency and further generate exportable production. These entail policy and production decisions based on the analyses of historical wheat production and consumption growth rates and trends as well as their future prospects in relation to current production practices. To examine issues on policy and production decision, this article provides information on wheat production and consumption trends, and future prospects in line with the current wheat production interventions. Historical wheat production and consumption data were used to achieve the objective of the study. The study finds out that wheat production increases, on average, by 6.2% per annum while annual wheat consumption increases on average by 261,120 tons if past production and consumption practices continue with no major and continuous production and productivity enhancement interventions. Production and consumption gap, and price increase if there are no major yield and production improvements. To offset the gap, national average wheat yield need to increase annually by 1.58 quintals per hectare with current wheat production area. Ensuring wheat self-sufficiency and import substitution need continuous and sustainable current wheat production interventions in lowland areas using irrigation, and focus on yield increment of major food commodities. Private sector involvement and investment in wheat production, processing, and marketing is decisive for the success of interventions to ensure wheat self-sufficiency and export need.

Keywords: Wheat, production & consumption, growth rates, irrigated wheat, wheat prospects

Introduction

Global climatic changes, agricultural productivity vis-à-vis population growth, rising demand for food as well as soaring food prices have given rise to concerns for ensuring food security. To address these concerns, the Second United Nations Sustainable Development Goal (SDG) of 2030 aims at mitigating hunger, food insecurity, and malnutrition (FAO, 2018). The same report indicates that though great efforts have been carried out to address the challenge of food insecurity, still billions of world population are in extreme poverty and food insecurity. World food demand projections indicate that global food demand may increase by 70 percent by 2050 (Alexandratos and Bruinsma, 2012; FAO, 2019). This will be a major challenge unless productivity of major food crops is increased to feed the increasing urban and rural population of the world.

Wheat is one of the major food crops that has potential impact on food security. It is the second most produced grain after maize in the world (FAOSTAT, 2022). In developing countries, especially Sub Saharan African countries, wheat has low productivity with rising demand and prices. Increasing wheat production and productivity is crucial for meeting global wheat food demand, and thereby mitigate the impacts of food shortage and rising food prices.

In view of this, since last few years, Ethiopia has given a high priority to wheat production to achieve food self-sufficiency and generate exportable wheat surplus. To achieve this goal, Ethiopian government has supported and promoted irrigated wheat production in lowland areas in addition to wheat production in the main rainy season. Moreover, offseason wheat production has become a common practice in highland and midland agro-ecologies where irrigation facilities are available.

The national development plan in wheat production is to ensure wheat food self-sufficiency, import substitution, and mitigate increasing wheat prices, and enhance export earnings. However, formulating short- and long-term plans and strategies require assessment of current wheat production and demand situations as well as its future outlook. The development of the wheat sector will depend on underlying long-run trends in production and demand that will continue to determine national wheat food status. Therefore, this article is intended to assess the current wheat production, productivity, and consumption to determine the future prospects of national wheat production and consumption at the times of population growth and increased demand, climatic changes, natural resource degradations, and soaring food prices.

The objective of this article is to provide information on the current national wheat production, consumption and future prospects as well as its implications on national wheat self-sufficiency in the course of promoting new domestic wheat production interventions.

Materials and Methods

Data sources

This article is mainly based on secondary data and information collected from several sources including FAOSTAT, USDA, Ethiopian Statistical Service (CSA/ESS), NBE, EGT, Ethiopian Custom Authority and various published and unpublished documents of government and non-government organizations. To adequately address the objective of the study, blends of techniques and approaches were employed that included extensive desk reviews of secondary data/information, multidisciplinary team reflection sessions, and key informant interviews (wheat researchers, extension workers, wheat processors and traders). In general, time series aggregated data were collected on national wheat production, yield, supply and demand, imports and prices. Time series data were used for analyzing historical growth rates and trends, and making forecast to see changes over years. For this purpose, minimum of 20 years production and consumption data were used.

Data analysis

Data analysis involved both descriptive statistics (means, percentages) and log-linear trend models. Time series data were analyzed using log-linear trend models to estimate annual growth rates and project future prospects of wheat production and consumption in Ethiopia The trend models generally assume that the same underlying causal relationship that existed in the past will remain unchanged in the future. Following Gujarati (2004), forecasting was made using historical data on wheat production and consumption, yield and price. The base year for estimating the trend of wheat production and consumption in Ethiopia was set at 2020/2021 while projection was made to the year of 2030/2031.

Measuring trends of wheat production and consumption

A log-linear trend model is commonly used in econometrics to estimate growth rates and analyze trends in some economic variables such as GDP, inflation, trade, agricultural and food production, etc. In this model, the dependent variable is assumed to follow a log-linear trend over time which indicates that the percentage change in the dependent variable remains constant over time. Therefore, the growth rates and trends of wheat production and consumption were estimated using the following log-linear model.

Let Y_t denotes real wheat production or consumption at time t, and Y_0 the initial value of production or consumption in the base year. Based on Gujarati (2004), we can have compound interest formula:

$$Y_t = Y_0 (1 + r)^t \quad (1)$$

Where r is the compound growth rate of Y over time. Taking the natural logarithms of equation (1),

$$ln\, Y_t = ln\, Y_0 + t\, ln\, (1+r) \quad (2)$$

Letting $\beta_1 = ln\, Y_0$ and $\beta_2 = ln\, (1+r)$

Equation (2) can be written as

$$ln\, Y_t = \beta_1 + \beta_2 t \quad (3)$$

Adding disturbance term to equation (3), we get

$$\ln Y_t = \beta_1 + \beta_2 t + U_t \qquad (4)$$

The model becomes a log-linear regression model with parameters β_1 and β_2. The dependent variable is the log values of Y and the independent variable is time "t" which takes the values 1, 2, 3 … t.

The slope coefficient in the log-linear model, β_2, measures the average growth rate of the dependent variable, Y, over time "t".

In addition to model (4), a linear trend model can be used to estimate absolute change in wheat production or consumption:

$$Y_t = \beta_1 + \beta_2 t + U_t \qquad (5)$$

Model in equation (5) is called linear trend model and the time variable t is called trend variable. The slope coefficient, β_2, determines the upward or downward trend in Y depending on the sign of β_2 i.e. positive or negative value of β_2. However, the choice between growth rate (log-linear) model and linear trend model depends up on whether the interest is in the relative or absolute change in Y (wheat production or consumption). But for comparative purposes, relative change is generally more relevant (Gujarati, 2004).

Generally, both growth rate and linear trend models were used to find out the relative and absolute changes in wheat production and consumption over the time period considered for the analysis. Historical data of wheat production and consumption for the time period 1999-2021 were used for measuring growth rate and projections.

Results and Discussion

Wheat Production and Consumption

Wheat is one of the major food and cash crops in Ethiopia. It is produced by over 4.8 million smallholders on about 1.89 million hectares of land with annual volume of production of over 5.78 million tons and yield of 30.46 quintals per hectare (CSA, 2022). Wheat production and productivity have been improved over the last couples of decades in Ethiopia, grew, on average, 6.21% per annum during the period between 1999 and 2021 which is equivalent to an average annual increment of 190.31 thousands metric tons (Figure 1).

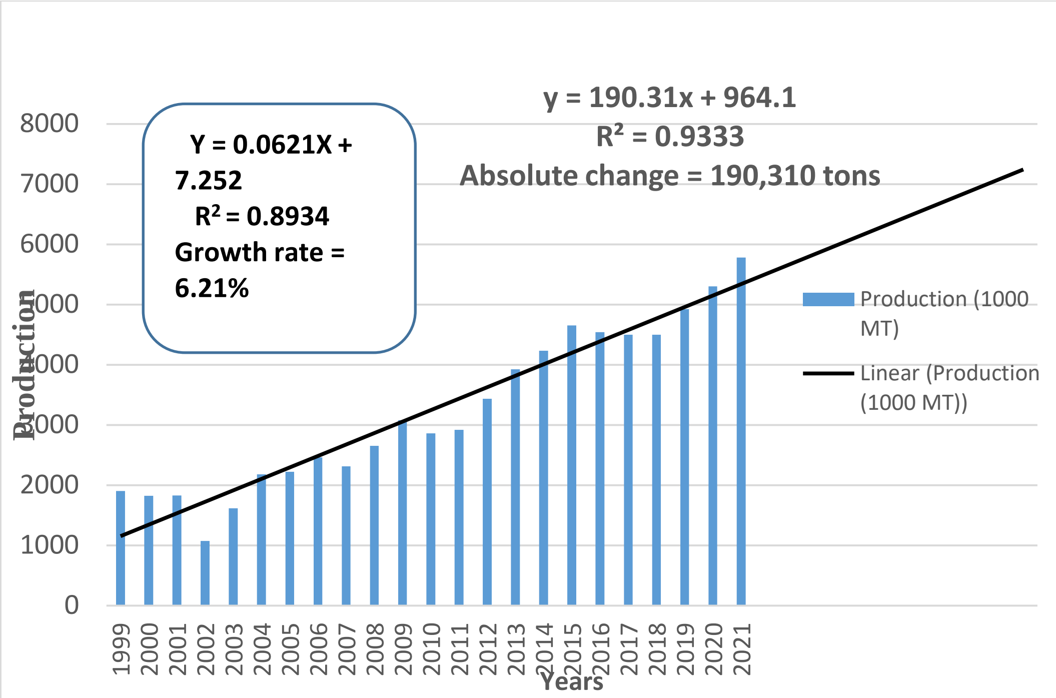

Figure 1 Wheat production in Ethiopia in 1000 MT
Source: CSA/ESS, 2020/21

Government reports, e.g. Ministry of agriculture, indicate that the total wheat area in Ethiopia has been expanded to 2.3 million hectares in 2022/23 which is 18 percent higher than in 2021/22 resulting in growth in domestic wheat production amounted to 7.0 MMT. The increment by 1.3 million metric tons was reported, and it was mainly due to the focus on wheat production in lowland areas and off-season using irrigation.

Wheat productivity has been increasing over the past couple of decades. Model results showed that national wheat yield has increased, on average, by 0.114 ton/ha annually from 2010 to 2021 (Figure 2).

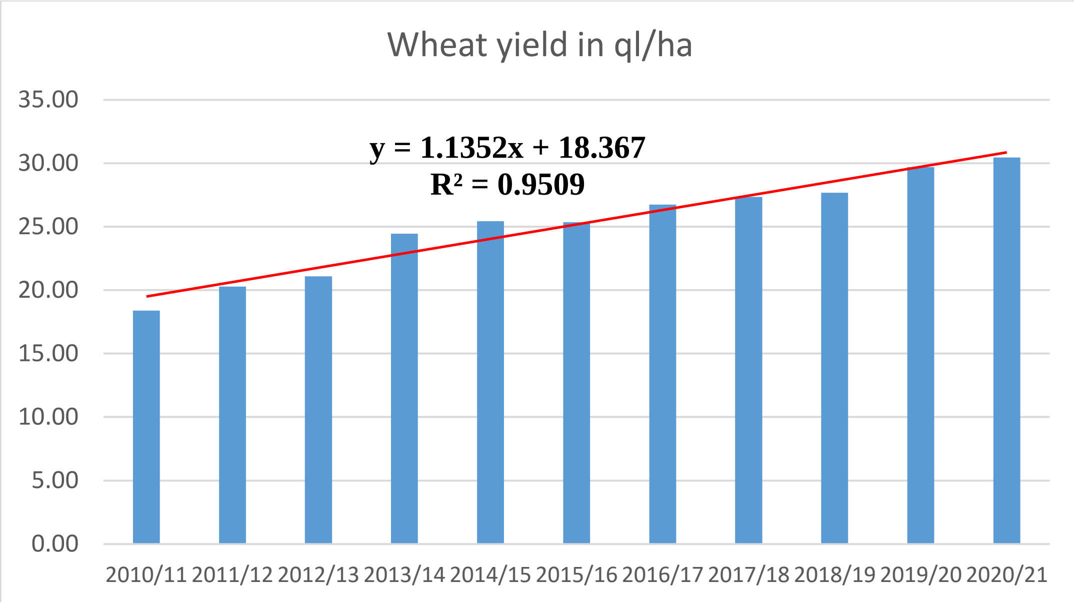

Figure 2 Wheat Yield trends in quintal per hectare from 2010/11 to 2020/21 cropping years.
Source: CSA report of 2011 to 2022.

The major regional states that produce wheat are Oromia, Amhara, South regional state, and Tigray. Larger wheat producing administrative zones in the country include Arsi, West Arsi, Bale, the whole Shewa zones, Gojam, South wollo, and Hadiya zones (CSA, 2021). Figure 3 shows the distribution of wheat production area among Regions during the 2020/21 cropping season.

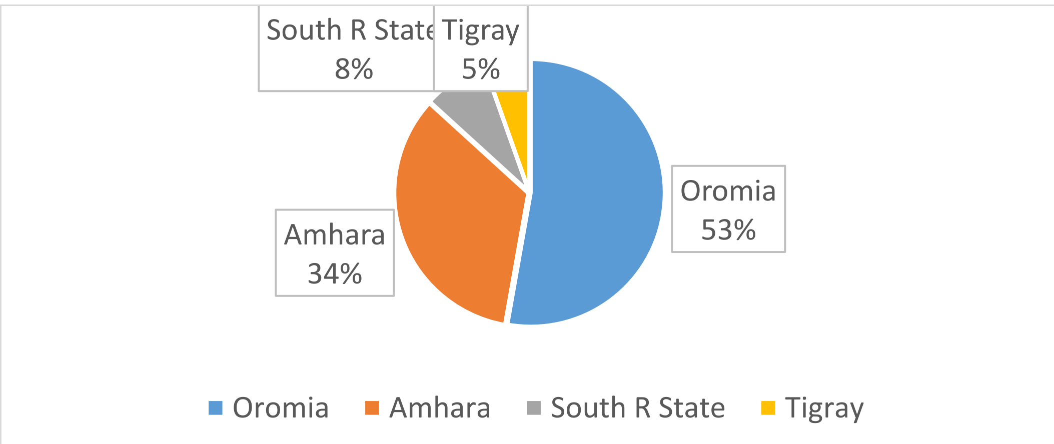

Figure 3. Percentage share of wheat area (ha) among Regions during 2020/21 cropping season
Source: Computed from CSA 2022 report.

Regional states comparison of wheat volume of production shows that Oromia regional state accounts for 57% of the total volume of wheat production. Similarly, Amhara regional state comprise 32% of wheat output in 2020/21 production year. The two regional states produced 89% of the total wheat output in the same year indicating that the two regional states are the major and larger wheat producing states in the country.

Evidences show that there has been an increasing trend in the gap between wheat production and consumption during 1999-2021 (Figure 4). Consumption data were calculated by adding annual domestic wheat production and import from abroad. The increasing wheat production and consumption gap indicates the need for more efforts in improving domestic production and productivity of wheat in Ethiopia.

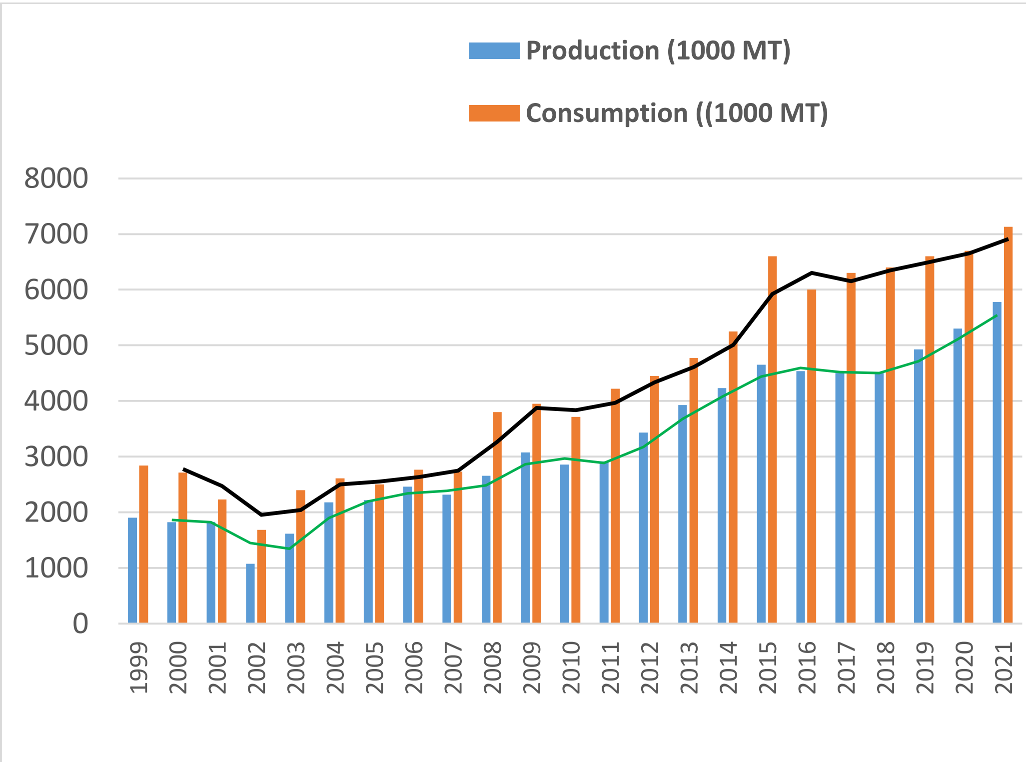

Figure 4 Wheat production and consumption trends in Ethiopia
Source: Data of CSA, FAOSTAT, and Ethiopian Customs Commission (ECC)

The demand for wheat has been increasing (Figure 4). The increasing demand for wheat and low domestic production has forced the country to import wheat every year or every other year from abroad. This challenge has forced the government to give due attention on wheat self-sufficiency through improving production and productivity of wheat. To achieve this, government plan and strategies focus on wheat production in lowland areas using irrigation, clustering wheat farming, enhancing agricultural mechanization, and improving farm input supply and crop management practices.

Wheat Import and prices

There is a gap between the level of wheat production and consumption in the country. This gap has been bridged through imports. Figure 5 shows wheat production, consumption, and import trends during 2000-2021.

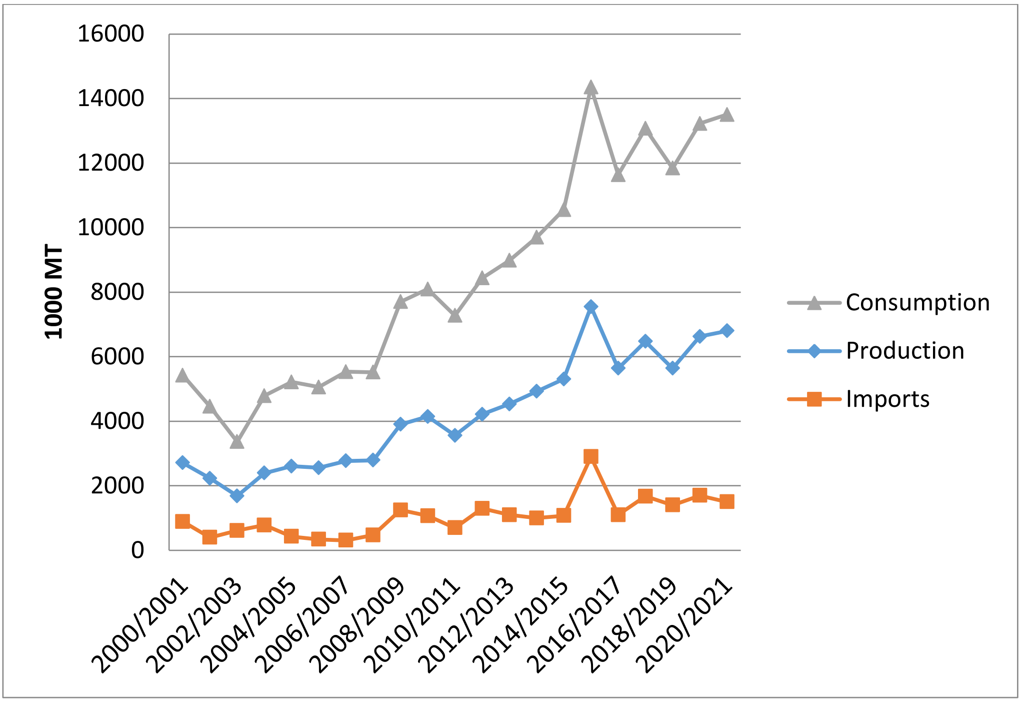

Figure 5 Trends of Wheat production, consumption and import, Ethiopia (2000/01- 2020/21)
Source: CSA, ECC, and FAOSTAT data

Generally, there have been soaring prices on food grains in Ethiopia since recent years due to the apparent inflation. Inflation, low domestic wheat production, and higher demand caused a high wheat price. Figure 6 depicts wheat price situations over the last 16 years. It can be seen that the nominal domestic producer and wholesale prices have been increasing despite the distribution of imported wheat to urban consumers at subsidized prices. A sharp rise in wheat price was observed during the period 2018 and 2023.

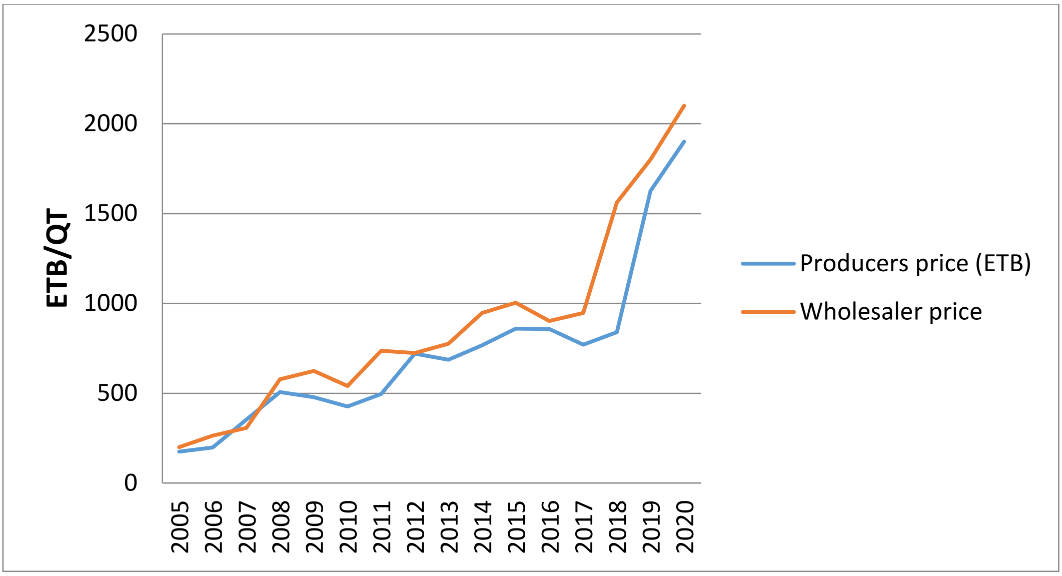

Figure 6 Trend of Wheat Price (2005-2020)
Source: Based on data of CSA and FAOSTAT data

Future prospects in wheat production

Projections on wheat production and consumption were made based on historical data on current situations. The projection shows that wheat production has to reach 8.2 million tons to meet local consumption in 2022 in the absence of imported wheat. But if the past trends on wheat production remain unchanged, total wheat production is projected to reach 6.06 million tons in 2024 and 7.32 million tons in 2030. Likewise if the current wheat import trend continues, total consumption i.e. production plus import reaches 7.99 million tons in 2024 and 9.75 million tons in 2030. Figure 7 shows projections of wheat production and consumption based on the current trends on wheat production and import. The projections are based on linear forecast of production and consumption of past 20 years. This implies that there will be gap of 2.43 million tons between domestic production and consumption in 2030 if the past 20 years production and consumption trends continue till 2030. However, major continuous interventions by regional states and federal government to enhance wheat production and productivity in different agro-ecologies using irrigation and adoption of technologies may shift the forecasted production trend and offset the gap between production and consumption.

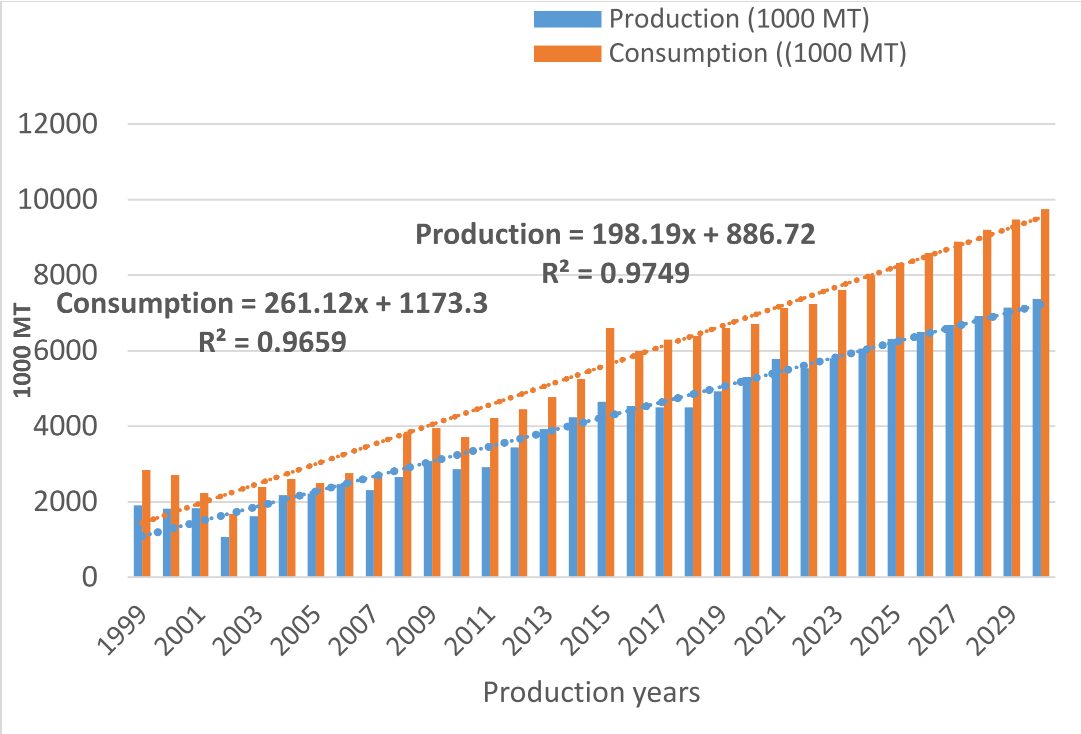

Figure 7 Linear trend projection of wheat production & consumption (2022 to 2030)
Source: Based on data of CSA, ECC, and FAOSTAT.

Figure 8 shows projected yield to offset the gap between wheat production and consumption given the current wheat cultivated land of 1.89 million hectares of 2021 (CSA, 2022) remains constant. To offset production and consumption gap of 2023, the national average yield of wheat needs to be 4.03 tons/ha. Likewise, the current trend of production and consumption gap can be avoided if average national yield will reach 4.4 tons/ha in 2025, and 5.16 tons/ha in 2030 provided that the 2021 wheat area coverage of 1.89 million hectares is maintained constant. However, as per the reports of government, wheat area coverage has been increased due to expansion of wheat cultivation in lowland areas and in off seasons using irrigation. This could affect the trend of domestic production and consumption gaps that has been based on historical data. Therefore, it has to be noted that government intervention strategies to enhance wheat production and productivity could change the forecasted production, consumption and yield values of future years.

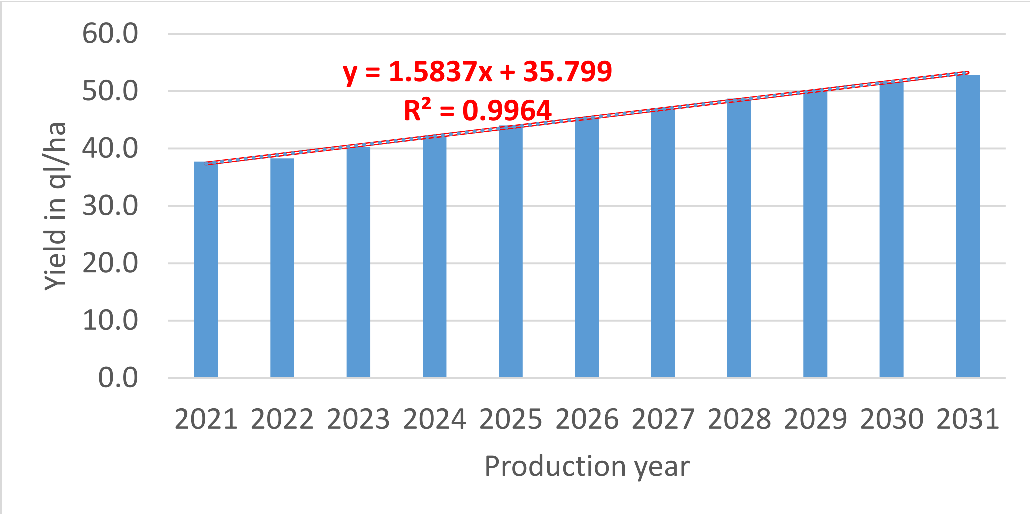

Figure 8 Yield (ql/ha) trend to offset production & consumption gap
Source: Computed from CSA data of various years

Investment options

Wheat production has been given due attention by federal and regional governments of Ethiopia. The government encourages both small and large wheat producers to increase production and productivity to ensure wheat food self-sufficiency and stop wheat imports. Smallholders' land consolidation in the form of cluster and contract farming, and expansion of irrigated wheat production in the lowland areas are the key government strategies and focus areas to enhance wheat production and productivity. Farm input provisions, extension services, and credit provision for irrigated and mechanized wheat production are some of government support areas to increase wheat production.

Moreover, the government has agricultural sector policy and investment, and development plan that ranges from 2021 to 2030. Development policy, strategy and plan focus on rural commercialization, and improvement of productivity and competitiveness through involvement of private sectors. As stated in government's 10 year plan, the government "Creates conducive investment climate and incentivize domestic investors in key sectors, builds strong and market-led public-private partnerships in order to ensure the establishment of inclusive and pragmatic market economy, enhances access and quality of infrastructure to attract quality foreign direct investment, identifies new sources of growth, empower and stimulate the private sector, and supplements the private sector in strategic areas, and gives emphasis to public-private partnership on problem solving innovations and research activities."

Though the current private sector investment on wheat production is limited, the Ethiopian government gives a high priority on the wheat sector through creation of enabling policy environment for investment. In addition, the current growing local and global demands for wheat are great opportunities for private sector investment in large commercial irrigated farms.

Agro-processing

The current growing urbanization and the high local demand for wheat food products are great market opportunities for private investment in agro-processing industries in Ethiopia. Wheat agro-processing is one of the investment options in wheat sector. Survey reports showed that there were over 400 cereal and/or wheat processing factories all over the country (FBIRD, 2022). About 92.5% of the factories were reported to be wheat flour. Most of the factories are located along main roads and their production is for local markets (Figure 9). They produce only single product (83.3% of the factories). About 43.3 % of the factories have no internal quality control laboratories.

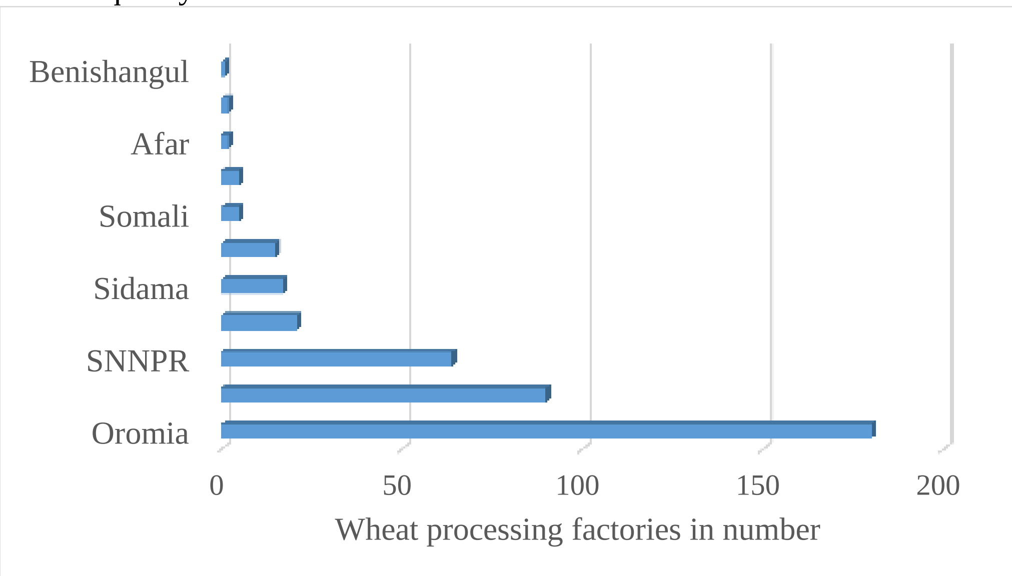

Figure 9 Distribution of Wheat processing factories in Ethiopia
Source: FBIRDC, 2022

Figure 9 shows that the majority of wheat processing factories (45%) are located in Oromia and followed by Amhara (22%). This shows that there is a potential for both wheat production and processing investment options in the regions. Even though there is investment opportunities in wheat processing, there are various constraints and challenges that affect smooth and full capacity functioning of the factories. The report of FBIRDC (2022) indicate that 70% of the factories have shortage of raw material (wheat), 42.2% of the factories have shortage of electric power supply, 28.4% have constraint of working capital, 24.7% of the factories have foreign exchange challenge, and 23.7% have water supply constraint. The challenges hinder and limit the functions and expansions of existing and new factories.

Investment in wheat agro-processing is carried out by private limited companies, sole proprietorship, share companies, cooperatives, and partnerships (Figure 10).

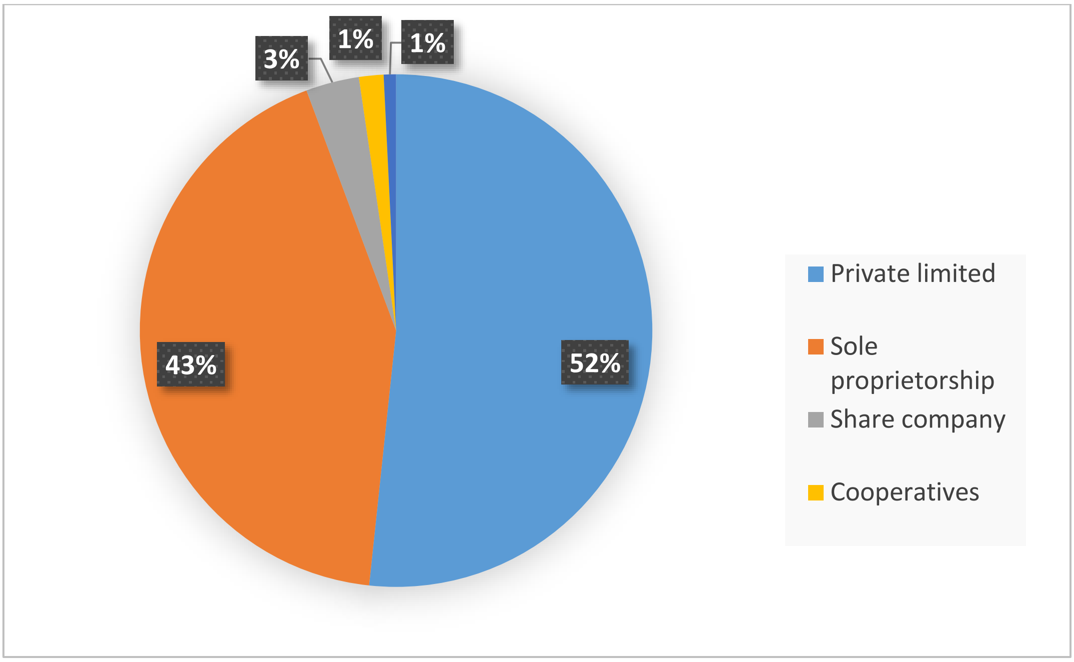

Figure 10 Ownership of wheat processing factories
Source: Compiled from FBIRDC, 2022

Majority of wheat processing factories (52%) are owned by private limited companies, and 43% are owned by sole proprietorship. Small proportion (5%) of factories are owned by Share Company, Cooperatives and Partnership. This shows that 95% of ownership status of wheat processing factories are held by private limited companies and sole proprietorship. These wheat processing factories have investment capital that ranges from 6 million to 43 million birr, and working capital of 5 million to 30 million birr (FBIRDC, 2022). They have also 21,306 permanent workers over 7,200 daily laborers in 2022. There were also a total of 215 expatriates in the wheat processing factories. This shows that wheat processing has great employment opportunities. However, there is a significant difference between factories actual processing capacity and initial installed capacity as well as between annual production plan and actual amount produced. The agro-processing factories are generally observed to have capacity utilization problems where they function under their full capacity (FBIRDC, 2022).Therefore, wheat agro-industries need to be strengthened and expanded by solving their challenges and constraints that are related to supply of raw material, electric power, working capital, foreign exchange, and adequate water.

Conclusion

National agricultural production efforts increasingly focus on enhancement of production and productivity to ensure food security, increase export revenues, and substitute imports. Wheat is one of the major food and cash crops with low production and productivity, and increasing consumption demand. The gap between domestic production and consumption demand has been increasing. This gap will be increasing if past wheat production and management practices continue in the future. Bridging production and consumption gap requires enhancement of wheat production and productivity. Enhancing wheat production and productivity needs involvement of all stakeholders including private sector to jointly plan and take coordinate actions along wheat value chain. It is through increased production and productivity that objectives of ensuring wheat food self-sufficiency, reduced wheat prices and generating export revenues can be achieved. However, enhanced production and productivity entails adoption of improved agricultural technologies and favorable agricultural investment policy environment as well as development of infrastructures including irrigation facilities, roads, and energy supply.

Therefore, to ensure domestic wheat food self-sufficiency and generate marketable surplus for export market, there is a need to focus on enhancing wheat yield per unit area or productivity to offset the gap between production and consumption demand. Yield improvement needs proper use of improved technologies (seeds, production & management practices), high inputs utilizations (fertilizers, chemicals, irrigation), mechanized farming, disease & pest control mechanisms, soils & natural resources management, and support mechanisms (finance, and extension services). Encouraging private sector investments in wheat production & agro-processing is crucial to develop wheat sector. This needs development of infrastructure and provision of services that include irrigation, use of machinery for mechanized farming, working capital, and credit services. Improving wheat marketing is also critical to enhance production and productivity. This involves efficient inputs and outputs marketing, and solving constraints along wheat value chain. Establishing conducive policy & legal environments to invest on wheat production, processing, marketing, and export are crucial elements for the development of Ethiopian wheat sector.

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Heat-induced Toughening in the *Semitendinosus* Muscle of Beef Carcasses Held at Pre-rigor Room Temperature in Ethiopia

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Abstract

Carcasses from some Ethiopian public abattoirs are stored at room temperature for six to twelve hours before being sent to butcher shops where they are sold. The purpose of this study was to examine the effects of age, breed, and pre-rigor room temperature on the instrumental properties of the semitendinosus muscle. The blood samples, pH, and meat samples (48) were collected from 24 carcasses obtained from four cattle breeds under two age categories. The samples were held at pre-rigor room (24) and chill (24) temperatures for 24 hours and aged for 7 days to evaluate tenderness using Warner Bratzler-Shear Force, water holding capacity, cooking loss, thawing loss, and color (L, a*, b*). The results of the study revealed that the post-slaughter 6-hour mean temperature and pH of samples held in the pre-rigor room and chill temperatures were 29.5 ± 0.79 °C, 6.09 ± 0.05, and 25.35 ± 0.97°C, 6.02 ± 0.04, respectively. The proportion of heat-induced toughening for semitendinosus muscle held at pre-rigor room and chill temperature were 12.5% and 4.2%, respectively. Heat induced toughening differed between breeds and age categories. Tenderness of muscle samples held at pre-rigor chill temperature was tender (36.05±1.22 N) while samples held at pre-rigor room temperature were intermediate (40.38±1.42 N). The water holding capacity of the muscle samples held at pre-rigor room temperature ranged from 62.83 to 73.2% while for samples held at pre-rigor chill temperature water holding capacity increased from 69.2 to 73.33%. Higher thawing and cooking losses were observed for samples held at pre-rigor room temperature compared to chilled one. In conclusion, keeping carcasses at pre-rigor room temperature has contributed to lowering the quality of beef produced at public abattoirs. It was recommended that a good practice of keeping carcasses at pre-rigor chill temperature until rigor mortis resolute need to be introduced in public abattoirs before being dispatched to butcher shops.*

Keywords: Pre-rigor temperature, Warner Bratzler-Shear Force, water holding capacity, color

Introduction

Africa's largest cattle population is found in Ethiopia. It was estimated that there were roughly 68 million cattle in the nation (CSA, 2022). More than 70% of the red meat produced in the nation was made up of beef (Issack et al., 2017). One of the main obstacles to Ethiopian beef exports is quality (Mummed, 2023).

A number of factors affect the quality of beef namely, pre-slaughter animal handling (nutrition, health status, age, sex, breed, level of stress), slaughter method, and post-slaughter carcass handling (Rodríguez-Vázquez et al., 2020). Among carcass handling, the temperature in which carcasses are managed and the rates of decline in pH affect quality parameters such as tenderness, color, and water-holding capacity of beef (Kim et al., 2014). The combination of rapid glycolysis (rapid pH fall) and slow cooling leads to high rigor temperatures there by heat toughening (CSIRO, 2002).

The core body temperature of grazing and feedlot cattle animals is about 38–39 °C (Cafe *et al*., 2011), but the interfacial seam between the semimembranosus (SM) and semitendinosus (ST) muscles can reach 42–44 °C post-mortem due to metabolic heat production (Jacob *et al*., 2014). Exposing pre-rigor muscle to high temperatures (> 35 °C), accompanied by a rapid pH decline, affects the quality of meat (Devine et al., 1999). Locker and Hagyard (1963) reported the presence of minimal shortening for pre-rigor muscles exposed to temperatures between 15 and 20 °C and substantial shortening for muscles exposed to pre-rigor temperatures above 20 °C. Similarly, Devine et al. (1999) reported the production of tender beef for muscle held at 15 °C during rigor development and resolution and the toughening of meat as the temperature increased beyond 20 °C. These researchers suggested the two main reasons for the toughening of meat: muscle shortening and inactivation of the calpain enzyme, both of which are dictated by pre-rigor temperature. Higher shear force values were reported for beef loins held at a high pre-rigor temperature of 38 °C (Kim et al., 2014) due to the effect of heat toughening. The same researchers reported the negative influence of heat toughening on the tenderness of aged and unaged meat. The influence is greater in the deep muscle compared to the intermediate and outer muscles. Pre-rigor temperature and pH were reported as one of the major factors responsible for meat toughness in the musculus longissimus thoracicum et lumborum, musculus semimembranosus, and musculus semitendinosus muscles (Devine et al., 1999). Differences in the quality of beef from bulls of Arsi, Bale, Borana, and Harar cattle breeds were reported in some studies conducted before (Gadisa et al., 2019; Birhanu et al., 2019; Dagne et al., 2021). The effects of production system, breed, and age were implicated as some of the reasons for the difference in the quality of beef between these breeds (Mummed, 2023). However, the effect of the breed of cattle on the quality of beef was minimized by finishing them under similar feeding conditions (Mummed, 2023). The management practices in public abattoirs were reported to contribute partly to the lower quality of beef produced in Ethiopia (Mummed and Webb, 2015). The researchers reported the rare practice of chilling carcasses in public abattoirs.

Abattoirs fabricate carcasses to be quartered on the slaughter floor and transported to butcher's shops. It took 4–10 hours from bleeding animals to transporting carcasses to the shops. Most butchers keep carcasses at room temperature until they finish selling the whole carcass, which usually takes 1-3 days. The time period between slaughter of cattle and transport of carcass to butcher's shops might not be enough for rigor to resolute, as rigor resolution needs 6–12 hours for the pH to fall from 5.4 to 5.8 and attain a carcass temperature of about 15 °C. This carcass temperature and pH are attained by keeping the carcass at 4°C in the chilling room for 24 hours.

The rare practice of keeping carcasses in the chilling room post-sale for 24-hours and the limited time for rigor to resolute suggested the possible negative contribution of heat-induced toughening to the lower qualities of beef (particularly on the interior portion of muscle such as semitendinosus) produced in the public abattoirs in Ethiopia.

However, there is no documented information on the degree of heat-induced toughening of beef in Ethiopia. This study was therefore conducted with the aim to determine the contribution of pre-rigor room temperature in heat induced toughening in *semitendinosus muscle* of beef in Ethiopia.

Materials and Methods

Animal management, feed composition and analysis

The study was conducted based on cattle fattened for 90 days at the Beef Farm of Haramaya University. A total of 24 intact bulls, which represented four breeds of cattle (Arsi, Borena, Harar, Holstein Frisian crossbreds six from each breed) under two age categories (2–3 and 4–5 years, 12 from each age category), were finished under similar feeding conditions composed of 60% roughage (grass hay and wheat straw) and 40% concentrate (34.78% wheat bran, 33.14% maize grain, 27.8% Guzotia Abyssinica cake, 1.7% limestone, 1.7% salt, and 0.88% ruminant premix). The chemical composition of the feed ingredients is presented in table 1.

Table 1. Chemical composition of experimental feed ingredients

	% of items on DM					
Feed type	**DM**	**Ash**	**CP**	**NDF**	**ADF**	**ADL**
Maize grain	87.35	1.80	10.06	42.68	6.64	3.79
Nuge cake	90.46	8.48	45.74	42.91	27.94	10.07
Wheat brane	88.81	5.24	17.19	54.44	9.92	4.22
Total mixed ration	89.81	9.99	21.69	51.28	14.54	6.93
Grass hay	89.29	8.59	5.83	77.05	44.14	8.41
Wheat straw	94.49	5.94	3.14	80.64	45.32	6.14

DM= dry matter, CP= Crude protein, NDF= neutral detergent fiber, ADF= acid detergent fiber, ADL= acid detergent lignin

For chemical analysis 100 grams of samples of feeds were dried at 65 °C for 48 h. Then dried samples were then ground (1 mm screen) and stored for subsequent analyses of dry matter (DM), crude protein (CP), ash, neutral detergent fire (NDF) and acid detergent fire (ADF). DM, N and total ash were determined according to the official methods of (AOAC, 1990) and NDF and ADF according to (Soest *etal*., 1991). Dry matter content of the feed was determined by drying the samples in an oven at 105 °C overnight while ash content was determined by burning the samples at 550 °C for 5 h in a muff furnace. Nitrogen (N) was determined by Kjeldahl method (CP = N × 6.25).

Three percent of their body weight per day for total mixed ration was given in two equal meals at 8:00 AM in the morning and 3:00 PM in afternoon of the day and the amount were adjusted based on body weight once per every week. Clean water was available all the time. The amount of concentrate and roughage offered and refused were recorded daily to derive feed intake.

The study animals were slaughtered at Elfora, Bishoftu export abattoir, Bishoftu, Ethiopia, following the standard procedure of the abattoir. Carcasses were suspended at Achilles tendon and were not electrically stimulated.

Data collection

Temperature and pH

A wall thermometer in the abattoir was used to record room temperature. Room temperature on the day of slaughter, from bleeding time to post-sale 24-hours, was on average 25 °C (min 22.5 °C and max 27.5°C). Moreover, the temperature and pH of the meat samples (*Semitendinosus* muscle) kept at chill and room temperature were measured using a portable pH/ORP/Temp meter at 45 minutes, 3, 6, 12, and 24 hours post-sale. To calibrate the pH meter, a probe was inserted into distilled water and a buffer solution (pH 4, pH 7, and pH 10) after each reading. The pH value was read about 30 seconds after inserting the probe into the incised semitendinosus muscle (ESVLDM, 2005).

Blood and carcass sampling

Blood samples were collected in heparinized tubes at exsanguination from the 24 bulls and immediately placed in an icebox for plasma and serum separation.

The carcass samples were collected from *semitendinosus* (part of round) muscle from 24 carcasses. Duplicate samples, each sample weighting 200 gm was collected and kept at chill (48 samples) and room temperature (48 samples) for 24 hours. Then after the collected samples were packed into the plastic bag, sealed, stored in the icebox and then transported to meat processing technology laboratory at Oda Bultum University located at West Hararghe, Oromia Regional State. The samples were kept at 4 °C for 7 days to determine WBSF, color, WHC, TL and CL.

Evaluation of carcass quality parameters

Heat induced toughening

The percentage of heat-induced toughening was calculated by dividing heat-toughened meat by the total number of meat samples and multiplying by 100. Heat-induced toughening of meat samples was evaluated based on two models. The first model was the Meat Standard Australia model, which considered heat-induced toughening for those meat samples that had a pH less than 6 and a temperature above 35 °C at 6 hours post-sale (Meat Technology Update, 2011a). The second model was one used by Devine et al. (1999), which considered heat-induced toughening for those meat samples that had a pH less than 6 and a temperature of 20–25 °C at 6 hours post-sale.

Glucose and insulin

The plasma was separated by centrifugation at 2000 rpm for 10 minutes at room temperature. The serum was decanted into Eppendorf tubes and frozen at -20 °C until analysis for insulin and glucose at the Public Health Institute, Addis Ababa. The insulin resistance score (HOMA-IR) was computed with the formula: fasting plasma glucose (mmol/L) times fasting serum insulin (µu/mL) divided by the constant number 22.5. HOMA-IR = {[glucose (mmol/L) × insulin (µu/mL)] / 22.5} (Muniyappa *et al*., 2008).

Warner Bratzler-Shear Force, thawing and cooking losses

Instrumental tenderness was determined using the WBSF device. The device is a G-P*P* shear machine model (No. GR-151; serial number 1612021) produced by G-P-Electrical Manufacturing Company LLC. The beef samples aged for 7 days at 4 °C were exposed to room temperature for 12 hours before determining WBSF. The steak preparation procedure of AMSA (2015) was followed. The cooking pan was heated for about 205 °C before placing the steak on the pan. The steak, which was cooked at 70 °C, was allowed to cool down to room temperature for about an hour to evaluate instrumental tenderness using WBSF. After cooling, heavy connective tissue was cut across the long axis of the steak to determine the fiber direction by using a knife. The steak was cut to 1 inch (2.5 cm) in thickness perpendicular to the long axis of the semitendinosus (ST) muscle, and six cores parallel with the muscle fibers were removed from the steak. Each core was cut across the middle (center) and expressed by Newton (N). The values for each core were averaged for the determination of a single value for each steak (AMSA, 2015). Thawing and cooking losses were determined based on the steak used to determine WBSF. The difference in the weight of beef samples before and after thawing, divided by the weight before thawing and multiplied by 100, was used to determine thawing loss. The difference between the weight of the steak before and after cooking, divided by the weight before cooking multiplied by 100, was used to determine cooking loss.

Color

The color of the meat samples was determined using a Mini Scan EZ machine (model number MSEZ-4500L, Serial No. MSEZ1547, 45°) with a 20 mm diameter measurement area, illumination/viewing system, D65 light source, and 10˚ standard observer angle. The machine was calibrated before taking measurements using the black and white standardized tile samples provided for this purpose.

A 3 cm-thick meat sample was taken from round muscle, particularly *semitendinosus* muscle, that was removed from the sirloin area of the carcass in the free fat area. Measurements were made after 30-minute exposure to air (bloom time) at the different locations of the surface of the muscle. Three readings were taken on each sample by rotating the Color Guide 90˚ between measurements so as to obtain the average value for the color. The meat color was expressed using the CIELAB color space (L* = lightness, a* = redness, and b* = yellowness) according to the CIE system (Chulayo and Muchenje, 2016).

Water holding capacity

The water holding capacity of the samples was measured in triplicate using the method suggested by Whiting and Jenkins (1981) after removing the samples from the refrigerator overnight. Two Whatman number-1 filter papers were weighed (A), and 0.5 gram of meat sample (C) was placed between two filter papers, which in turn were placed between two glass sheets. Over it, an object weighing 2.015 kg was placed, while the glass sheet weighed 0.8278 kg, giving a total compression weight of 2.8428 kg for 5 minutes. Then the weight was removed, the meat was separated from the filter papers, and it was weighed (D). At the end, the filter paper was dried, and the weight was recorded (B). After that, the amount of protein attached to the filter paper and the actual weight of the meat after pressure treatment was determined.

Amount of protein attached to the filter paper (E) = B - A
Actual weight of meat after pressure treatment (F) = E + D
% Water holding capacity of the meat (WHC) = (C-F)/2*100

Statistical Analysis

The qualities of beef from four breeds, namely Harar, Borena, Arsi, and Holstein Friesian cross, under the two age categories (2–3, 4–5 years), which contained meat samples from chilled and not chilled, were analyzed using the General

Leaner Model (GLM) procedure of SAS 9.1 software. Where a significant difference between effects was observed, mean separation was done by Tukey Test at $P < 0.05$. Besides the correlation between carcass temperature, pH and WBSF were evaluated using Pearson correlation.

Different models were used to see the effect of breed, age and pre-rigor temperature on instrumental qualities of *semitendinosus* muscle.

Model 1. $Y_{ij\gamma t} = \mu + \alpha_i + \beta_j + \gamma_k + (\alpha*\beta*\gamma)_l + e_{ijkl}$ used for analysis of effects of breed, age and pre-rigor temperature on *semitendinosus* muscle temperature, pH, WBSF, WHC, CL, TL and color, where; $Y_{ij\gamma}$ = the response variable

μ = Overall mean
α_i = Effect of breeds
β_j = Effect of age
γ_k = Effects of pre-rigor temperature
$(\alpha*\beta*\gamma)_{ijk}$ = Interaction effect
e_{ijkl} = Random error

Model 2. $Y_{ij\gamma} = \mu + \alpha_i + \beta_j + (\alpha*\beta)_{k\gamma} + e_{ij\gamma}$ used for analysis of effects of breed and age on glucose, insulin, insulin resistance, p8 fat thickness where, $Y_{ij\gamma}$ = the response variables,

μ = Over all mean
α_i = Effects of breeds
β_j = Effects of age
$(\alpha*\beta)_{k\gamma}$ = Interaction effect
$e_{ij\gamma}$ = Random error

Results and Discussion

Temperature and pH of *Semitendinosus* Muscle Held at Pre-Rigor Room and Chilled Temperature

Mean temperature of *semitendinosus* muscle held at pre-rigor room and chilled temperature for breeds of cattle under two age categories is shown in Table 2. The overall mean temperature post slaughter 45 minute for all samples (pre-rigor room and chilled temperatures) was 33.91 °C. The overall mean *semitendinosus* muscle temperature post slaughter 24-hours for samples held under pre-rigor chill temperature was 15.85 °C while for those samples held under pre-rigor room temperature was 22.36 °C. Post slaughter 24-hour temperatures of *semitendinosus* muscle in the range from 10 to 15 °C were reported to be associated with highest degree of tenderness, while above this range, heat induced toughening may occur that can increase toughness of the meat (Devine et al., 1999). Post slaughter 6-

hour average temperature of *semitendinosus* muscle samples held under pre-rigor room temperature was about 29.5 ± 0.79 ℃ while those held under pre-rigor chill temperature was about 25.35 ± 0.97 ℃ in the present study. High temperature accelerated glycolysis (pH decline; Kim et al. 2012). Substantial shortening of muscle fibers was observed in muscles when exposed to higher than 20 ℃ pre-rigor temperatures (Locker and Hagyard, 1963). The post slaughter 6-hour temperature of *semitendinosus* muscle varied ($p < 0.01$) across breeds and ages in the present study. Meat sample from Arsi and HF-Cross breeds that was held at pre-rigor room temperature had attained relatively higher temperature (31.98, 30.55 ℃) compared to meat samples of the same breeds held at pre-rigor chill temperature (26.55, 28.16). The temperature in which the muscle managed might implicate to the difference in the ultimate temperature. The slow cooling of muscle was reported to lead to high rigor temperatures (CSIRO, 2002). Meat samples from bulls slaughtered at 4-5 years of age had exhibited higher carcass temperature for both categories of meat samples held under pre-rigor room (31.55 ℃) and chill temperature (27.3 ℃), compared to meat samples from bulls slaughtered at 2-3 years of age. The amount fat and weight of carcass might be implicated for difference in the temperature between the two age groups. The heavier the carcass and fat stored, the higher the temperature of carcasses was reported by Warner et al. (2014). Six-hours post slaughter pH and temperature are important to determine the degree of heat toughening in meat. According to Meat Standard Australia, heat induced toughening occur at temperature above 35℃ and pH less than 6 at 6 hours post slaughter (Meat technology update, 2011a). Some other studies suggest the possibilities of heat induced toughening at lower temperature. For instance, Locker and Hagyard (1963) and Devine et al. (1999) reported the incidence of heat toughening at temperature 20-25℃ and pH less than 6 at 6-hours post slaughter. The justification according to these researchers were the breakdown of actino-myosin muscle bondage at the specified temperature by calpain enzyme contributing positively to tenderization of the meat. This is because elevated pre-rigor temperature inactivated calpain enzyme activities there by toughness of the meat. According to the report by Wahlgren et al. (1997), carcasses kept at constant pre-rigor temperature of 35 ℃ for 5 h after slaughter lost about 80% of the m-calpain activity while only about 20% of the activity lost when exposed to a constant rigor temperature of 15 ℃ for 27 h post slaughter. Devine et al. (1999) reported that muscles held at 15 ℃ showed the least shortening while for those held at 30-35℃ maximum shortening of 25% occurred. The average 6 and 24-hour post slaughter temperature (29.5 ± 0.79; 22.36 ± 0.46) in the present study suggest the possibilities of loss of some of the activities of m-calpain which may trigger heat toughening incidence.

Table 2. Effects of breed, age and pre-rigor temperature on *semitendinosus* muscle temperature

	Temp 45 minute Mean ± SE	Temp 3 hour Mean ± SE	Temp 6 hour Mean ± SE	Temp12 hour Mean ± SE	Temp 24 hour Mean ± SE
Overall Temp	33.91 ± 0.56	30.48 ± 0.77	27.43 ± 0.68	23.65 ± 0.70	19.11 ± 0.54
Breed					
Arsi	37.4^{a} ± 0.81	32^{a} ± 1.13	29.27^{a} ± 1.67	25.483^{a} ± 1.91	19.81 ± 1.3
Borena	31.9^{b} ± 0.70	28.15^{bc} ± 0.69	25.86^{b} ± 0.79	22.592^{ab} ± 0.95	18.63 ± 0.87
HF-Cross	34.35^{b} ± 1.49	30.76^{ab} ± 1.56	29.36^{a} ± 1.60	24.675^{ab} ± 1.46	19.69 ± 1.24
Harar	31.95^{b} ± 0.43	26.76^{c} ± 0.79	25.24^{b} ± 0.90	21.879^{b} ± 1.04	18.31 ± 0.91
P - Value	***	***	**	**	NS
Age (year)					
2-3	32.32^{b} ± 0.64	28.46^{b} ± 0.60	25.43^{b} ± 0.62	22.17^{b} ± 0.75	18.58^{b} ± 0.65
4-5	35.49^{a} ± 0.81	32.5^{a} ± 1.3	29.43^{a} ± 1.09	25.15^{a} ± 1.13	19.64^{a} ± 0.87
P - Value	***	***	***	**	*
Pre-rigor temperature					
Room	33.90 ± 0.80	31.55^{a} ± 0.86	29.51^{a} ± 0.79	26.83^{a} ± 0.84	22.36^{a} ± 0.46
Chill	33.90 ± 0.80	29.42^{b} ± 0.88	25.36^{b} ± 0.97	20.49^{b} ± 0.68	15.86^{b} ± 0.28
P - Value	NS	**	***	***	***
Breed*Age	***	***	***	*	*
Age * Pre-rigor temp	NS	NS	NS	NS	NS
Breed *Pre-rigor temp	*	*	*	*	*
Breed*Age * Pre-rigor temp	*	*	*	*	*

Mean values under the same category that bear different superscript letters are significantly different, ***= P<0.001, **= P<0.01, *= P<0.05, SE= standard error of mean, HF-cross= Holstein Frisian cross breed, Temp = temperature, NS= not significant

Mean pH of meat samples held at pre-rigor room and chilled temperature for breeds of cattle under two age categories is presented in Table 3. The overall mean post slaughter 45 minutes pH of meat samples held under pre-rigor room and chilled temperature was 6.73 ± 0.06 ℃. The overall mean post slaughter 24-hour pH of meat samples held under pre- rigor room and chilled temperature was 5.6 ± 0.02 ℃. The average post slaughter 6-hour pH of meat samples held under pre-rigor room and chilled temperature were almost similar (6.09 ± 0.05 and 6.02 ± 0.04, respectively). Meat samples which attained pH less than 6 at 6-hours post slaughter are expected to exhibit heat toughening (Locker and Hagyard (1963); Devine *et al*., 1999). With respect to this criterion, meat samples from Arsi cattle breed (held under pre-rigor room temperature), meat samples from Boran and HF-Cross (managed under pre-rigor chilled temperature) and meat samples from bulls slaughtered at 4-5 years of age (held under both pre-rigor room and chilled temperatures) exhibited heat toughening. Devine *et al*. (1999) reported heat induced toughening for carcass which had post slaughter 6-hour pH less than 6 and temperature above 20 ℃ while MSA anticipate the presence of heat toughening for carcass above 35 ℃ (Meat technology update, 2011a).

Table 3. Effects of breed, age and pre-rigor temperature on *semitendinosus* muscle temperature

	Temp 45 minute Mean ± SE	Temp 3 hour Mean ± SE	Temp 6 hour Mean ± SE	Temp12 hour Mean ± SE	Temp 24 hour Mean ± SE
Overall Temp	6.73 ± 0.04	6.41 ± 0.04	6.05 ± 0.03	5.8 ± 0.02	5.6 ± 0.01
Breed					
Arsi	6.80^{ab} ± 0.03	6.44^{a} ± 0.04	6.02^{ab} ± 0.06	5.78^{a} ± 0.04	5.59 ± 0.03
Borena	6.52^{b} ± 0.13	6.29^{a} ± 0.12	5.96^{b} ± 0.08	5.76^{ab} ± 0.05	5.58 ± 0.02
HF-Cross	6.73^{ab} ± 0.05	6.33^{a} ± 0.08	6.01^{ab} ± 0.07	5.75^{ab} ± 0.07	5.59 ± 0.05
Harar	6.88^{a} ± 0.03	6.60^{a} ± 0.03	6.22^{a} ± 0.03	5.89^{b} ± 0.03	5.66 ± 0.01
P - Value	*	NS	*	NS	NS
Age (year)					
2-3	6.76^{a} ± 0.05	6.46^{a} ± 0.05	6.14^{a} ± 0.05	5.86^{a} ± 0.03	5.64^{a} ± 0.02
4-5	6.71^{a} ± 0.05	6.37^{a} ± 0.06	5.97^{b} ± 0.04	5.74^{b} ± 0.03	5.57^{b} ± 0.02
P - Value	NS	NS	*	*	*
Pre-rigor temperature					
Room	6.73 ± 0.06	6.45 ± 0.05	6.09 ± 0.05	5.8 ± 0.04	5.60 ± 0.02
Chill	6.73 ± 0.06	6.38 ± 0.06	6.02 ± 0.04	5.79 ± 0.03	5.61 ± 0.02
P - Value	NS	NS	NS	NS	NS
Breed*Age	NS	NS	NS	NS	NS
Age * Pre-rigor temp	NS	NS	NS	NS	*
Breed *Pre-rigor temp	NS	NS	NS	NS	NS
Breed*Age * Pre-rigor temp	NS	NS	NS	NS	*

Mean values under the same category that bear different superscript letters are significantly different, ***= P<0.001, **= P<0.01, *= P<0.05, SE= standard error of mean, HF-cross= Holstein Frisian cross breed, Temp =Temperature, NS= not significant

Percentage of heat induced toughening for meat samples held under pre-rigor room and chilled temperature are presented in Table 4. The table shows that percentage of heat induced toughening for meat samples held at pre-rigor room and chilled temperature were 12.5% and 4.2%, respectively, based on the criteria for Meat Standard Australia (Meat technology update, 2011a). Based on this model, meat samples from Arsi breed carcass held at pre-rigor room scored relatively higher percentage (8.3%), followed by HF Crossbred (4.2%) while no heat induced toughening was anticipated for samples from Borena and Harar cattle carcasses. Based on the same criteria, no heat toughening was occurred for all meat samples (held at pre-rigor room and chilled temperature) from bulls slaughtered at 2 - 3 years of age while 12.5% heat toughening observed in beef samples from bulls slaughtered at 4 - 5 years of age. Based on the second model (Locker and Hagyard 1963; Devine *et al*. 1999) carcasses managed under pre-rigor chilled temperature exhibited a total 29.2% heat induced toughening with carcasses from Arsi breed (4.2%), Borena and HF cross 12.5% each and Harar 0%. Relatively lower percentage of heat toughening for age group 2 - 3 years (8.3%) compared to age group 4 - 5 years of age (12.5%). The difference in percentage of heat toughening between breeds and age categories in the present study might be associated with difference in proteolytic potential, level and rate of glycolysis, weight and fat deposition on the carcasses (CSIRO, 2002; Warner et al. 2014).

Table 4. Percentage of heat induced toughening for *semitendinosus* muscle managed under pre-rigor room and chilled temperature

Heat Toughening Models	Semitendinosus muscle	Breed					Age group (years)		
		Arsi	Borana	HF cross	Harar	Total	2 -3	4 - 5	Total
MSA	Pre-rigor room	8.3	0	4.2	0	12.5	0	12.5	12.5
	Pre-rigor chilled	0	0	4.2	0	4.2	0	4.2	4.2
Devine et al. (1999)	Pre-rigor room	12.5	8.3	8.3	0	29.2	8.3	20.83	29.2
	Pre-rigor chilled	4.2	12.5	12.5	0	29.2	8.3	12.5	29.2

The occurrence of high rigor temperature across beef processing plants in Australia ranges from 56 to 94% (Warner *et al*., 2014). The lower incidence of heat toughening in the present study compared to the report by the former researchers might be associated with the difference in the weights of the carcasses. The average hot carcass weight of bulls under the present study was about 86.8 kg (Musa et al., 2021). Carcasses evaluated by Warner et al. (2014) in the Australia were heavy (243- 432 kg). The same researchers reported strong correlation between heavy carcass weight and higher rigor temperature. The likely occurrence of heat toughening in modern processing plants was reported by Meat technology update, (2011a). Chilling carcass had minimized the rate of heat toughening in the present study. However, the incidence of heat toughening in chilled *semitendinosus* muscle in the present study suggest the need to adjust the slaughter and other management practice at abattoirs so that incidence of heat toughening would be minimized. Minimizing number of hour carcass stay in the slaughter floor, providing high thermal conductivity path using ‘heat tubes,’ and vascular infusion of cold solution to beef carcass can be considered as some of the alternatives strategies to minimize the temperature in the deep muscle of beef carcasses (Meat technology update, 2011b).

Fat thickness, glucose and Insulin resistance among cattle breeds under study

Least square means of glucose, insulin, insulin resistance and p8 fat thickness of cattle breeds under the study are presented in Table 5. The value of glucose, insulin and insulin resistance (IR) of the studied cattle breeds were significantly ($p < 0.05$) different between breeds under the study. Age groups had affected the level of glucose. Bulls from Arsi and Boran cattle breed had higher glucose in their blood at slaughter compared to HF-cross and Harar cattle breeds under the present study. Bulls slaughtered at older age contained more glucose level in their blood compared to their young counterpart in the present study. Meat technology update, (2011a) reported lower incidence of heat toughening (46%) for cattle feed 60-70-day pre-slaughter, with the increase in the incidence as the number of feeding periods increased to 340-350 days (94%). The higher incidence of heat toughening in the latter case might be associated with heavier weight, and faster fall of pH of carcass compared to lighter cattle (Meat technology update, 2011a). Arsi and Harar cattle had relatively higher insulin and insulin resistance over Borena and HF crossbreds in the present study. Higher plasma insulin levels at slaughter were associated with a higher temperature at pH 6 (Warner et al., 2014). The same researchers further suggest the compromise of high insulin resistance to thermoregulation ability which can exacerbate stress. The higher concentration of insulin resistance in Arsi breed might contribute to higher level of heat toughening of the muscle in this breed. Fat thickness didn’t significantly differ between breed and age categories in the present study. The average fat thickness of carcasses in the present study was 4.59 ± 0.5mm. P8 fat thickness is a good indicator for overall carcass fat content (Taylor *et al*., 1996). Grass-fed lean cattle P8 fat thickness of 5 mm had a relatively low incidence of heat toughening (54%) compared to cattle P8 fat thickness of 30 mm with higher (87%) incidence of heat toughening. The higher concentration of plasma glucose, insulin and insulin resistance in bulls from Arsi cattle breed might be contributed to relatively higher incidence of heat toughening in the *semitendinosus* muscle from the breed.

Table **5**. Least square means of glucose, insulin, insulin resistance and p8 fat thickness

Variables	Glucose (mg/dL)	Insulin (µu/ml)	IR (mg/dL/µu/ml)	P8 fat thickness (mm)
Breeds	**Mean ± SE**	**Mean ± SE**	**Mean ± SE**	**Mean ± SE**
Arsi	$72.92^{a} \pm 1.16$	$0.92^{a} \pm 0.08$	$2.97^{a} \pm 0.32$	5.55 ± 1.2
Boran	$74.71^{a} \pm 3.14$	$0.45^{b} \pm 0.08$	$1.48^{b} \pm 0.26$	4.04 ± 1.3
HF-Cross	$60.59^{b} \pm 6.53$	$0.62^{b} \pm 0.1$	$1.77^{b} \pm 0.46$	3.91 ± 0.84
Harar	$67.8^{ab} \pm 2.72$	$0.73^{ab} \pm 0.12$	$2.15^{ab} \pm 0.31$	4.85 ± 0.65
P - Value	*	*	*	NS
Age (year)				
2-3	$64.64^{b} \pm 3.3$	$0.67^{a} \pm 0.06$	$1.97^{a} \pm 0.22$	3.62 ± 0.45
4-5	$73.37^{a} \pm 2.23$	$0.69^{a} \pm 0.1$	$2.22^{a} \pm 0.33$	5.56 ± 0.83
P - Value	*	NS	NS	NS
Overall	69.008 ± 2.15	0.68 ± 0.05	2.098 ± 0.20	4.59 ± 0.5
A * B	NS	NS	*	NS
CV	10.67	33.15	33.31	53.23

R=insulin resistance; Mean values under the same category that bear different superscript letters are significantly different, A* B = age and breed interaction, ***= P < 0.001, **= P < 0.01, *= P < 0.05, SE= standard error of mean, CV= coefficient of variation, HF-cross= Holstein Frisian cross breed, NS= not significant

Effect of Breed, Age and Pre-Rigor Temperature on WBSF value of *Semitendinosus* muscle

The effect of breed, age and pre-rigor temperature of carcass on WBSF value of *Semitendinosus* muscle aged for 7 days is presented in Table 6. Breed, age and pre-rigor temperature significantly affected the WBSF tenderness. *Semitendinosus* muscle from Borena and Harar bulls were more tender than the muscle from Arsi and crossbred of HF cross. In the previous part of the manuscript, beef from Arsi and HF cross exhibited heat toughening (MSA model) while Boran and Harar didn’t. Similarly, the relatively higher value of WBSF for cattle slaughtered at 4-5 years of age compared to those slaughtered at 2-3 years might be associated with the heat toughening condition exhibited by cattle slaughtered in the former age categories compared to the later. The finding further indicated the effect of the pre-rigor temperature on the WBSF value, with pre-rigor chilled muscle yielded tender beef while meat samples held at pre-rigor room temperature yielded intermediate tender. The adverse impacts heat induced toughening in beef was reported by a number of studies (Devine et al. 1999; Rosenvold et al. 2008; Thomson et al. 2008). Devine et al. (1999) reported lower values of WBSF (10N) for beef at held at 15 ºC which increased to WBSF above 40N as the rigor temperature increased from 20 to 30 ºC. Citing a number of studies, Jian et al. (2023) reported the effect of high pre-rigor temperature coupled with a fast pH decline that led to toughened meat. The possible cause for the toughening might be associated with heat-induced sarcomere shortening or reduced postmortem proteolysis of calpain activities (Kim et al., 2014).

Table **6**. Effects of breed, age and pre-rigor temperature on WBSF (Mean±SE) of *semitendinosus* muscle aged for 7 days

Category		WBSF (N)
Breed		
	Arsi	41.29±1.38[a]
	Borana	32.76±1.22[b]
	HF cross	42.63±2.25[a]
	Harar	36.19±1.50[b]
p-value		***
Age		
	2 - 3	34.71 ±1.02[b]
	4 - 5	41.73±1.35[a]
p-value		***
Breed*Age		NS
Pre-rigor temperature		
	Chill	36.05±1.22[b]
	Room	40.38±1.42[a]
p-value		***
Breed* Pre-rigor temperature		NS
Age* Pre-rigor temperature		NS
Breed*Age*Pre-rigor temperature		NS

Mean values under the same category that bear different superscript letters are significantly different, ***= P<0.001, **= P<0.01, *= P<0.05, SE= standard error of mean, HF-cross= Holstein Frisian cross breed, WBSF= Warner - Bratzler Shear Force,, NS= not significant

Influence of Pre-Rigor Temperature on Color of Semitendinosus Muscle

Color is the primary attribute by which meats are judged by the consumer before purchase. The desirable color of meat is usually reddish-pink (or bright cherry red), which make the purchaser assume that the product is wholesome and edible (Kim et al., 2014). Influence of pre-rigor temperature on color of *semitendinosus* muscle is presented in Table 7. Lightness (L*) of meat of color was not affected by breed, age and pre-rigor temperature in the present study. Depite the absence of significant difference in L* value, sample held under chill pre-rigor temperature was relatively lighter (35.01 ± 0.82) compared to samples held under pre-rigor room temperature (32.8 ± 1.27). Farouk and Swan (1998) reported higher L* value for semitendinosus muscle held 35 ºC. The rapid pH decline at high muscle temperature condition is a well-known fact that affects both meat color and stability at grading. Pre-rigor higher temperature yields paler color and reduce color stability of meat which can be primary attributed to protein denaturation (particularly myoglobin and/or myofibrillar), and possibly to altered oxygen consumption by endogenous enzymes and/or metmyoglobin reducing ability (Kim et al., 2014). The paler color due to higher muscle temperature can be attributed to light scattering. PSE-like qualities in semitendinosus muscle was reported by (Hunt and Hedrick 1977). The redness (a*) was influenced by breed and pre-rigor temperature. and yellowness (b*) of semitendinosus muscle. The *semitendinosus* muscle from Boran was relatively redder (P<0.05) compared to the muscle from Harar cattle breed. The redness (a*) and yellowness (b*) of semitendinosus muscle kept at room and chilled pre-rigor temperature were significantly different.

The values of a* and b* were lower for muscle kept at pre-rigor chill temperature. Similar to the present study, Farouk and Swan (1998) reported higher value at higher temperature. Pre-rigor chilling temperatures of carcasses improve meat color and color stability. However, stepwise chilling temperature needs to be optimum to benefit the industry further in the future (Kim et al., 2014).

Table 7. Effects of breed, age and pre-rigor temperature on color of semitendinosus muscle aged for 7 days

Category	L* Mean ± SE	a* Mean ± SE	b* Mean ± SE
Overall	33.90 ± 1.27	10.87 ± 1.49	12.91 ± 0.56
Breed			
Arsi	33.54 ± 1.32	10.56 ± 0.43^{ab}	12.05 ± 0.46
Borena	35.13 ± 1.40	12.10 ± 0.59^{a}	13.76 ± 0.60
HF-Cross	33.11 ± 1.02	10.77 ± 0.37^{ab}	12.75 ± 0.98
Harar	33.83 ± 2.19	10.03 ± 0.38^{b}	13.07 ± 0.70
P - Value	**NS**	*	**NS**
Age			
2-3	32.91 ± 1.28	10.81 ± 0.39	12.62 ± 0.54
4-5	34.89 ± 0.81	10.92 ± 0.30	13.19 ± 0.46
P - Value	NS	NS	NS
Pre-rigor temperature			
Room	32.80 ± 1.20	11.45 ± 0.38^{a}	14.21^{a} ± 0.48
Chill	35.01 ± 0.82	10.28 ± 0.25^{b}	11.60^{b} ± 0.37
P - Value	NS	*	***
Breed*Age	NS	NS	NS
Age * Pre-rigor temp	NS	NS	*
Breed *Pre-rigor temp	NS	*	*
Breed*Age * Pre-rigor temp	NS	*	*

Mean values under the same category that bear different superscript letters are significantly different, ***= P<0.001, **= P<0.01, *= P<0.05, SE= standard error of mean, HF-cross= Holstein Frisian cross breed, NS = not significant, L*- lightness, a*- redness, b* yellowness

Influence of Pre-Rigor Temperature on Water Holding Capacity, Cooking and Thawing Loss of *Semitendinosus* Muscle

Influence of pre-rigor temperature on water holding capacity (WHC), cooking (CL) and thawing loss (TL) of *semitendinosus* muscle is presented in Table 8. The WHC, CL and TL of the *semitendinosus* muscle were significantly influenced by pre-rigor temperature. Keeping muscle under pre-rigor chill temperature significantly (P<0.001) reduce thawing loss. The influence of pre-rigor temperature similarly influenced the WHC and CL. The WHC of muscle held under pre-rigor room temperature was 67.38 ± 1.19 while for those samples held at chilling pre-rigor temperature was 72.98 ± 2.0. Similarly, the CL was remarkably reduced by keeping the meat sampled under chilling condition at pre-rigor period. This confirm the importance of keeping beef carcass under pre-rigor chilling condition which was not widely practiced for fresh meat supplying abattoirs and butcher shops in Ethiopia. Similar to the present finding, Jian et al. (2023) reported the effect of high pre-rigor temperature in decreasing water holding capacity. The same authors reported the higher purge and cooking loss for meat sample kept at high temperature. Similar to the present finding, Warner et al. (2014) reported higher purge, surface exudate and cooking loss for *semitendinosus* muscle held at 37ºC. Decrease in proteolysis due to lower m-calpain activities because of higher temperature might induces an increased shrinkage of the muscle cell, creating channels for dripping moisture out of muscle bundles and thus results in greater drip loss (Huff-Lonergan and Lonergan 2007). Poor WHC results in high drip and purge loss, which can represent significant loss of weight from carcasses which may affect the yield and quality of processed meat. In addition, inferior WHC can negatively affect the appearance of meat, and this can influence consumer willingness to purchase the product.

Table 8. Effects of breed, age and pre-rigor temperature on TL, CL and WHC muscle aged for 7 days

Category		TL Mean ± SE	CL Mean ± SE	WHC Mean ± SE
Overall		11.24 ± 1.57	28.07 ± 1.37	70.23 ± 0.16
Breed				
	Arsi	14.09 ± 3.02	30.47 ± 2.92	68.56 ± 0.33
	Borena	13.99 ± 3.98	29.08 ± 3.09	72.70 ± 0.29
	HF-Cross	8.37 ± 2.13	25.66 ± 1.88	68.08 ± 0.31
	Harar	8.52 ± 3.11	25.08 ± 2.93	73.54 ± 0.34
	P - Value	**NS**	**NS**	**NS**
Age				
	2-3	11.25 ± 2.24	24.84 ± 2.20	70.27 ± 0.23
	4-5	11.23 ± 2.24	25.31 ± 1.71	69.18 ± 0.23
	P - Value	**NS**	**NS**	**NS**
Pre-rigor temperature				
	Room	18.17 ± 2.3[a]	31.0 ± 2.0	67.38 ± 1.19
	Chill	4.32 ± 0.47[b]	27.47 ± 1.7	72.98 ± 0.2
	P - Value	***	*	*
Interaction				
	Breed*Age	NS	NS	NS
	Age * Pre-rigor temp	NS	NS	NS
	Breed *Pre-rigor temp	NS	NS	NS
	Breed*Age * Pre-rigor temp	NS	NS	NS

Mean values under the same category that bear different superscript letters are significantly different, ***= P<0.001, **= P<0.01, *= P<0.05, SE= standard error of mean, CV= coefficient of variation, HF-cross= Holstein Frisian cross breed, NS = not significant, TL = thawing loss, CL = cooking loss, WHC = water holding capacity, yrs =years

Correlation between Pre-Rigor Temperature, pH and WBSF value of *Semitendinosus* Muscle

Correlation between meat sample parameters and WBSF is presented in Table 8. The correlation in the present study indicated that carcass temperature significantly and highly influenced the WBSF value of *semitendinosus* muscle. As the temperature increased, the WBSF value increased. As the values of WBSF increase, the values for tenderness decreased, leading to toughness of the meat. The increase in temperature with simultaneous increase in the value of WBSF clearly indicates the negative influence of higher pre-rigor temperature, which is influencing the tenderness of the muscle. In general, the consequences of keeping muscle at pre-rigor room temperature was heat induced toughening. Moreover, the concentration of glucose, insulin and insulin resistance in the blood influenced the WBSF at lower level, moderate and higher level, respectively. The correlation further confirms on the importance of keeping muscle at chill temperature during pre-rigor development and resolution to produce tender beef for the consumers.

Table 8. Correlation between meat sample parameters

	Carcass Wt	Fat p8(mm)	Temp carcass	pH carcass	WBSF (N)	Glucose (mmolL)	Insulin (µuml)	IR
Carcass Wt (kg)	1							
Fatp8(mm)	-0.005	1						
Carcass Temp (°C)	0.134	-0.157	1					
Carcass pH	-0.033	0.085	-0.302	1				
WBSF(N)	0.180*	0.057	0.642***	-0.123	1			
Glucose (mmolL)	0.429	0.154	0.232	-0.272*	0.186**	1		
Insulin (µuml)	-0.118	0.110	0.387	0.110	0.371**	0.106	1	
IR	-0.045	0.127	0.442	0.012	0.430**	0.326	0.969	1

*** = P<0.001, ** = P<0.01, * = P<0.05, WBSF = Warner - Bratzler Shear Force, Temp = temperature, Wt- weight

Conclusion and Recommendations

Semitendinosus muscle held at pre-rigor room temperature exhibited higher-induced heat toughening leading to reduction in quality of the meat. Pre-rigor chilling temperature improved instrumental tenderness and water holding capacity of the muscle by reducing thawing and cooking loss. The correlation between pre-rigor temperature, pH, and the WBSF value of semitendinosus muscle further confirms the importance of chilling muscle during pre-rigor development and resolution. It is therefore recommended that awareness should be created among people working in public abattoirs and butchers about the importance of holding carcasses in a chilling condition for 6–12 hours post-slaughter to produce quality beef for the market. The use of heat tubes and the vascular infusion of a cold solution in the carcass to minimize heat load in the interior muscle need to be considered as an alternate means of reducing heat induced toughening in the future.

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Conflict of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Morphological characterization of indigenous sheep types in Anfillo and Sibu Sire Districts, Western Oromia, Ethiopia

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Abstract

This study was conducted with the objective of morphological characterization of indigenous sheep populations found in Anfillo and Sibu Sire districts of Oromia, Ethiopia. The study districts were selected purposively based on sheep population potential. Four peasant associations were selected from each district purposively based on sheep population. A total of 450 head of sheep (333 females and 117 male) from all age groups were involved in the study. Linear body measurements and field observations were used to capture data. Both quantitative and qualitative data were collected and analyzed. Plain brown coat color, smooth hair type, long-fat tails were the dominant features of sheep populations of the study areas. Location, sex, age and interaction of sex by age had significant effect (at least at $p<0.05$) on live body weight and linear body measurements considered in the current study. Highest positive correlations were observed between body weight and heart girth for both sexes. The analyzed structural indices revealed that sheep populations of the study areas had poor thoracic capacity and classified as meat type. Finally, a comprehensive phenotypic characterization study using more data from wider areas and covering all seasons is warranted.

Keywords: Anfillo; Indigenous sheep; phenotypic characterization; Sibu Sire

Introduction

Ethiopia has estimated sheep population of 42.9 million, out of which about 71% are females and 29% are males. Of the total sheep population, the country owns about 99.52% are indigenous types while only about 0.40% and 0.08% were crossbreds and exotic types, respectively (CSA, 2021). According to this same source, Oromia region possess about 23%. The country is rich in sheep population as well genetic diversity, which is developed by natural selection and potential genetic resources of sheep breeds (Gizaw *et al*. 2007). The existence of this genetic variation between and within breeds provides the raw materials for genetic improvement (Gizaw *et al.* 2010). Focus on this large numbers and diversity of sheep resources in the country might be a way of increasing the livelihood of the sheep producers.

Phenotypic characterization is the first step for identification of qualitative and quantitative traits of the livestock resources in general and indigenous sheep population in particular. The first phase of characterization is surveying to identify populations based on morphological, geographical distribution, uses and husbandry and production environments (Traore *et al*. 2008). Assessment of qualitative traits is subjective as opposed to the quantitative traits that are measured. Quantitative characters are influenced by environmental factors as opposed to the qualitative characters for which the influence of environment is absent or nil (FAO, 2012). Characterization of indigenous sheep breeds using morphological characters has significant importance for planning improvement and conservation strategies (Belay *et al*. 2021). In Ethiopia, there are high morphological variability (Gizaw *et al.* 2008) and variations on phenotypic performances and appearance (Weldeyesus, 2020) among the major sheep breeds/types. Measuring within population diversity is important since it is one of the major criterions to set improvement and conservation priorities (Gizaw *et al.* 2011).

Many sheep characterization studies were conducted in Ethiopia. However, such studies were limited only on few specific sheep types located at specific places. No characterization was done on indigenous sheep breeds/populations in Qellam Wallaga zone as a whole and Sibu Sire district of East Wallaga zone. Nevertheless, an accurate description of sheep population/breed kept under extensive management conditions would enable accurate comparisons of the breed/population with other sheep breeds in the country and elsewhere. In addition, characterization would enable devising improvement programs using information generated from the characterization works.

Materials and Methods

Study areas

The study was conducted at Anfillo district of Qellam Wallaga zone and Sibu Sire district of East Wallaga zone, Oromia. Anfillo district is located at about 694 km from Addis Ababa, capital city of the country, on the west direction. Anfillo district is situated at $8^0 29'$N latitude and $34^0 39'$ E longitude. The altitude of the district ranges from 500 to 3470 m.a.s.l. The mean maximum and minimum annual temperature of the district is 33^0 C and 14 ^{0}C, respectively. The district experiences a uni-modal type of rainfall with annual rainfall ranging from 1453 mm to 2074 mm. The major crops grown in Anfillo district is coffee (Anfillo district Agricultural office, 2023 unpublished data).

Sibu Sire is situated at about 278 km from Addis Ababa to the west direction on the main road to Nekemte. The district is located between altitudes ranging from 800 to 2750 m.a.s.l. Sibu Sire district is situated at $9^0 4'$N latitude and $36^0 49'$ E longitude. The mean annual maximum and minimum temperatures recorded for Sibu Sire were 26^0C and 20^0C, respectively. Sibu Sire district experiences a uni-modal type of rainfall ranging from 1000 mm to 1200 mm. The major crops grown in Sibu Sire district are cereal crops mainly maize and sorghum (Sibu Sire district Agricultural office, 2023, unpublished data). Some of the major livestock species produced in both districts are cattle, sheep, goats and equines.

Sampling techniques

Anfillo district of Qellam Wallaga zone and Sibu Sire district of East Wallaga zone, Oromia were purposively targeted for the current study. From each district four peasant associations (PAs) were identified for the study based on sheep population potential. A total of 450 head of sheep (333 females and 117 males) were randomly selected from the two districts and their corresponding PAs for linear body measurements and qualitative traits descriptions. Each sampled sheep was identified by district, sex and age to evaluate influences these categories may exert on body weight and linear body measurements. The qualitative variables recorded were: coat color type, coat color pattern, coat hair type, head profile, ear orientation, presence or absence of wattles, horn shape, horn orientation, presence or absence of horn, presence or absence of ruff, back profile, rump profile, tail type and tail shape. Quantitative traits measured included live body weight, body length, heart girth, wither height, rump height, pelvic width, ear length, tail length, rump width, head width, head length, rump length, tail width and horn length. In addition, scrotum circumference and scrotum length were measured for males. Scrotal circumference is measured by pulling down the testicles and measuring across the widest part of the scrotum. The sampled sheep were classified into five age groups: no pair of permanent incisor (0PPI), one pair of permanent incisor (1PPI), two pairs of permanent incisor (2PPI), three pairs of permanent incisor (3PPI) and four pairs of permanent incisor (4PPI) based on dentition. The average estimated age of the sampled sheep were taken according to Wilson and Durkin (1984) for African sheep breed. According to the authors, age of sheep with zero permanent incisors (0PPI) ranges from 6 to 12 months, those with one pair of permanent incisors (1PPI) are about 15.5 months old, those with two pairs of permanent incisors (2PPI) are about 22.5 months old, those with three pairs of permanent incisors (3PPI) are about 28 months old and those with four pairs of permanent incisors (4PPI) are about 39 months old and above. In the current study due to fewer number of animals above 2PPI, age groups used were 0PPI, 1PPI and ≥ 2PPI.

Data collection methods

Both the linear body measurements and body weight were recorded on 450 head of sheep (333 females and 117 males) maintained under on-farm conditions by smallholder sheep producers. All linear body measurements were taken by ensuring that each animal was in a standing position and weight of an animal was proportionally on all four feet. Physical restraint was sometimes applied, particularly for those which had wild behavior, to limit their movement. Pregnant females were excluded from sampling to remove the effect of pregnancy on some of body parameters. Similarly, castrates were excluded from the sampling. Fourteen qualitative traits were observed and recorded on the breed morphological characteristics descriptor list of FAO (2012). The linear body measurements were measured using measuring tape whereas live body weight was taken by using a hanging spring scale having 50 kg capacity with 200 g (0.2 kg) precision. Vertical measurements such as wither height and rump height were measured by using wooden meter.

Data analysis

Districts, sex, age and sex by age interaction were fitted as fixed effects while live body weight and other linear body measurements were considered as dependent variables. The General Linear Model (GLM) Procedure of the Statistical Analysis System (SAS, release 9.4, 2012) was employed to analyze quantitative variables to determine effects of class variables. The Statistical Package for Social Sciences (SPSS) was employed to analyze qualitative variables; where a chi-square (X^2) was fitted test significance. Pearson correlation was carried out to evaluate the relationship among live body weight the different linear measurements for each sex. This is to know whether the attributes are positively or negatively associated and to know the magnitude of their associations. Stepwise multiple linear regression analysis was carried out to obtain the best fit model to predict body weight of both sexes from the linear body measurements.

The following model was fitted to analyze the linear body measurements and live body weight, except scrotal circumstances and scrotal length:

$$Y_{ijkl} = \mu + A_i + S_j + D_k + (AS)_{ij} + e_{ijkl}$$

Where:

Y_{ijkl} = the observed mean live body weight or linear body measurements in the i^{th} age group, j^{th}sex and k^{th} district**,**

μ= overall mean,

A_i= the i^{th} effect of age group (0PPI, 1PPI and ≥ 2PPI),

S_j= the j^{th} effect of sex (1=male, 2= female),

D_k= the k^{th} effect of district (1 =Anfillo district, 2= Sibu Sire district),

$(AS)_{ij}$= the interaction effect of i^{th} age group and j^{th} sex, and

e_{ijkl}= random residual error

The model fitted to analyze the scrotal circumference (SC) and scrotal length (SL) was:

$$Y_{ikl} = \mu + A_i + D_k + e_{ikl}$$

Where:

Y_{ikl} = the observed or measured mean scrotal circumference (SC) or scrotal length (SL) in the i^{th} age group and k^{th} district,
μ= overall mean,
A_i= the i^{th} effect of age group (0PPI, 1PPI and ≥ 2PPI),
D_k= the k^{th} effect of district (1 =Anfillo district, 2= Sibu Sire district),
e_{ikl}= random residual error

The statistical models used for the analysis of multiple linear regressions are indicated for females and males as indicated below.

1) For females:

$$Yj = β0 + β1X1 + β2X2 + β3X3 + β4X4 + β5X5 + β6 X6 + β7X7 + Ej$$

Where, Yj= the dependent variable live body weight, β0 = the intercept, X1, X2, X3, X4, X5, X6 and X7 are the independent variables; heart girths, body length, wither height, rump height, tail length, rump width, pelvic width, respectively, β1, β2, β3, β4, β5, β6 and β7are the regression coefficients of the variables X1, X2, X3, X4, X5, X6 and X7 respectively, Ej = the residual random error

2) For males:

$$Yj = β0 + β1X1 + β2X2 + β3X3 + β4X4 + β5X5 + β6 X6 + β7X7 + Ej$$

Where: Yj= the dependent variable body weight, β0= the intercept, Ej = the residual random error,
X1, X2, X3, X4, X5, X6 and X7 are the independent variables; heart girths, body length, wither height, rump height, scrotal circumstances, scrotal length and tail length respectively, β1, β2, β3, β4, β5, β6, and β7 are the regression coefficients of the variables X1, X2, X3, X4, X5, X6 and X7, respectively.

Eleven structural indices (Body index (BI), Body frame index (BFI), Pelvic index (PI), Area index (AI), Body ratio index (BRI), Compact index (CI), Height slope index (HIS), Proportionality index (PrI), Thoracic development index (TdI), Conformational index (ConI) and Cephalic index (Cel)) were calculated from the morphometric measurements of traits based on Salako (2006), Banerjee. (2015) and Chiemela *et al*. (2016) to assess the types and functions of the indigenous sheep types in the study areas.

Results and Discussions

Characterization of qualitative traits

Detailed qualitative characters of the studied sheep population are presented in Tables 1 and 2. The overall major dominant coat color patterns observed were plain (79.10%) followed by patchy (20.90%) in both districts. Plain coat color pattern was more dominant at Sibu Sire than it was at Anfillo district. About 90.2% and 68% head of sheep observed had plain coat color at Sibu Sire and Anfillo districts, respectively. Patchy coat color pattern (32%) was observed at

Anfillo district which was 9.8% at Sibu Sire district. The likely explanation for the coat color variation at Anfillo district may indicate the absence of selection intervention compared to sheep flocks at Sibu Sire district. Smallholder sheep producers at Sibu Sire district may have better exposure to agricultural extension services due to the presence of Bako Agricultural Research Center nearby/at its vicinity.

Majority of the studied sheep population (70.2%) were characterized by having short and smooth coat hair type in both districts, which might be one of the indictors for evaluating the adaptability of the sheep population in these particular study areas. About 68.4% and 72% of sheep observed in the current study had short and smooth hair type, respectively. With regard to head profile, about 93.1% of the sheep (about 94.7% at Sibu Sire district and 91.6% at Anfillo district) had straight head profile. The result is paralleled with the report of Birhanu and Oli (2020). All of the sampled sheep in both districts were polled. Duguma *et al.* (2011) also characterized Horro sheep as polled and a breed having a long fat tail. About 94.6% and 64.5% of sheep flocks had either semi-pendulous or pendulous ear orientation at Sibu Sire and Anfillo districts, respectively. The qualitative characteristics obtained in the current study are in general agreement with the report of Edea *et al*. (2009) for Horro sheep. The observed tail shape was similar with the result of Edea (2008) and Hizkel (2017) for Horro sheep breed and Bonga sheep breed (indigenous sheep types in southern Ethiopia), respectively. In the present study, the frequently observed back profile was straight (65.8%) followed by slopes up towards the rump (27.1%) and slopes down from withers (5.3%). The majority of rump profile recorded was sloppy (52.7%) followed by flat type of ramp (26.2%). Sheep flocks at both districts had neither ruff nor wattles. All sheep flocks monitored had long straight fatty tail which is slightly twisted at its tip below the hock. The qualitative characters reported in the current study are in general agreement with literature reports (Galal, 1983; Edea, 2008; Duguma et al., 2011).

Table 1: Summary of coat color types of sheep population of the study areas

Traits	Descriptors	Districts													
		Anfillo						Sibu Sire						Overall	
		Male		Female		Total		Male		Female		Total			
		№	%	№	%	№	%	№	%	№	%	№	%	№	%
Coat color pattern	Plain	51	76.1	102	64.5	153	68	47	94	156	89.1	203	90.2	356	79.1
	Patchy	16	23.9	56	35.4	72	32	3	6	19	10.9	22	9.8	94	20.9
	Total	67	100	158	100	225	100	50	100	175	100	225	100	450	100
	X^2 between population	33.7**													
Coat color type	White	10	14.9	9	5.7	19	8.4	1	2.0	19	10.9	20	8.9	39	8.7
	Red	4	5.97	13	8.2	17	7.6	3	6.0	17	9.7	20	8.9	37	8.2
	Black	3	4.50	8	5.1	11	4.9	2	4.0	24	13.7	26	11.5	37	8.2
	Brown	31	46.3	67	42.4	98	43.6	23	46.0	62	35.4	85	37.8	183	40.6
	Light brown	3	4.5	5	3.2	8	3.6	18	36	34	21.1	52	23.1	60	13.3
	Red and White with red dominant	1	1.5	13	8.2	14	6.2			3	1.7	3	1.3	17	3.80
	Black + White with black dominant	4	6.0	11	7.0	15	6.7							15	3.3
	White + black with white dominant	3	4.5	8	5.1	11	5.9							11	2.4
	Brown & white with brown dominant	6	9.0	18	11.4	24	10.7	2	4.0	9	5.1	11	4.9	35	7.8
	White + brown with white dominant	1	1.5	4	2.5	5	2.2			5	2.9	5	2.2	10	2.2
	Brown & black with brown dominant	1	1.5	2	1.3	3	1.3	1	2.0	2	1.1	3	1.3	6	1.3
	Total	67	100	158	100	225	100	50	100	175	100	225	100	450	100
	X^2 between population	77.5**													
Coat hair type	Short and smooth	45	67.2	117	74.1	162	72	31	62	123	70.3	154	68.40	316	70.2
	Short and course	22	32.8	41	25.9	63	28	19	38	52	29.7	71	31.60	134	29.8
	Total	67	100	158	100	225	100	50	100	175	100	225	100	450	100
	X^2 between population	10.7**													

Table 2. Summary of some of qualitative traits of sheep population of the study areas

Head profile	Straight	57	85.10	149	94.3	206	91.6	38	76	175	100	213	94.67	419	93.1
	Slightly concave			3	1.9	3	1.3							3	0.7
	Slightly convex	10	14.9	6	3.8	16	7.1	12	24			12	5.33	28	6.2
	Total	67	100	158	100	225	100	50	100	175	100	225	100	450	100
	X² between population	3.7NS													
Horn	Absent	67	100	158	100	225	100	50	100	175	100	225	100	450	100
Ear orientation	Pendulous	23	34.3	57	36.1	80	35.6	4	8	46	26.3	50	22.2	130	28.9
	Semi-pendulous	34	49.3	67	42.4	101	44.9	41	82	122	69.7	163	72.4	264	58.9
	Horizontal	10	14.9	34	21.5	44	19.6	5	10	7	4	12	5.3	56	12.4
	Total	67	100	158	100	225	100	50	100	175	100	225	100	450	100
	X² between population	39.8**													
Back profile	Straight	43	64.20	104	65.80	147	65.3	37	74	112	64	149	66.20	296	65.8
	Slopes up towards the rump	15	22.40	34	21.50	49	21.8	13	26	60	34.30	73	32.40	122	27.1
	Slopes down from withers	9	13.40	12	7.60	21	9.3			3	1.70	3	1.3	24	5.3
	Curved			8	5.10	8	3.6							8	1.80
	Total	67	100	158	100	225	100	50	100	175	100	225	100	450	100
	X² between population	26.3**													
Rump profile	Flat	28	41.80	52	32.90	80	35.6	13	26	25	14.30	38	16.90	118	26.2
	Sloppy	36	53.7	95	60.1	131	58.2	30	60	76	43.4	106	47.1	237	52.7
	Roofy	3	4.5	11	7.0	14	6.2	7	14	74	42.3	81	36	95	21.1
	Total	67	100	158	100	225	100	50	100	175	100	225	100	450	100
	X² between values 64.8**														
Wattles	Absent	59	88.1	142	89.9	201	89.3	48	96	166	94.9	214	95.1	415	92.2
	Present	8	11.9	16	10.1	24	10.7	2	4	9	5.1	11	4.9	35	7.8
	Total	67	100	158	100	225	100	50	100	175	100	225	100	450	100
	X² between population 5.2*														
Ruff	Absent	54	80.6	154	97.5	208	92.4	10	20	174	99.4	184	81.8	392	87.1
	Present	13	19.4	4	2.50	17	7.6	40	80	1	0.60	41	18.2	58	12.9
	Total	67	100	158	100	225	100	50	100	175	100	225	100	450	100
	X² between population 11.4**														
Tail type	Long fat tailed	67	100	158	100	225	100	50	100	175	100	225	100	450	100
Tail shape	Straight tip	36	53.7	109	68.9	145	64.4	21	42	87	49.7	108	48	253	56.2
	Twisted up at the tip	31	46.3	49	31	80	35.6	29	58	88	50.3	117	52	197	43.8
	Total	67	100	158	100	225	100	50	100	175	100	225	100	450	100
	X² between population 12.4**														

Live Body Weight and Linear body measurements

The least squares means (±SE) for the effect of district, sex, age and the interaction of sex and age on live body weight and linear body measurements of sheep population in the study areas are presented in Table 3. District had significant effect ($p<0.01$) on live body weight and most of the linear body measurements, except rump height (RH), wither height (WH), head width (HW) and head length (HL). Sheep flocks at Sibu Sire district had significantly heavier body weight and higher body length (BL) and heart girth (HG) than sheep flocks at Anfillo district. On the other hand, sheep flocks at Anfillo district had higher rump length (RL), rump width (RW), wider pelvic width (PW), tail length (TL), tail width (TW) and ear length. Intact males from Sibu Sire had significantly ($p<0.05$) larger scrotum circumference (SC) than those at Anfillo district. They had, however, shorter scrotal length (SL) than males at Anfillo district. The likely explanation for the higher body weight and larger scrotum circumference may be due to the fact that testicular development in rams is positively associated with body weight (Motos and Thomas, 1992). The difference in body weight may be due to agro-ecology difference and differences in production environments. Wagari *et al.* (2020) also reported that location/agro-ecology had significant effect on live body weight and most of the linear body measurements. Contrary to the present result, Michael *et al* (2016) reported that location had no effect ($p>0.05$) on live body weight of sheep in Northern Ethiopia.

Sex had significant ($p<0.01$) effect on mean live body weight and most of the linear body measurements, except ear length (EL), head width (HW) and head length (HL) (Table 2). Higher values were recorded for male sheep for both live body weight and all linear body measurements including ear length (EL), head width (HW) and head length (HL) those traits for which both sexes did not vary significantly. The least squares mean live body weight of rams and ewes obtained in the current study were 26.2±0.50 kg and 23.1±0.60 kg, respectively. On average, males were heavier than females by about 3.1 kg. The higher performance of males compared to their female counterparts reported in the current study is in close agreement with results reported in the literatures (Kassahun, 2000; Tibbo *et al.* 2004; Hizkel *et al*. 2017; Wagari *et al.* 2020). According to Sowande and Sobola (2007), female sheep have slower growth rate and reach maturity at smaller size compared to males due to the effect of estrogen that restricts the growth of the long bones of the body. Therefore, it might be due to this effect that male sheep were heavier than female sheep in most variables considered, except ear length, head width and head length.

Age had significant (at least at $p<0.05$) on live body weight and the linear body measurements evaluated in the current study (Table 2). Both live body weight and linear body measurements have showed significant ($p<0.01$) increasing trend with advance in age. The live body weight of the sampled sheep increased by 4.6kg and

6.08kg as sheep age advances from milk tooth (0PPI) to 1PPI dentition class and from 1PPI to ≥ 2PPI dentition class, respectively. The age effect obtained in the current study is in general agreement with the findings reported in the literatures (Edea *et al*. 2009; Weldeyesus and Yayneshet, 2016; Nurlign *et al*. 2017; Zemenu, 2020).

Sex by age interaction effect significantly ($p<0.01$) influenced both the live body weight and most of the linear body measurements, except ear length (EL), head width (HW) and head length (HL) (Table 2**.** Males with 0PPI, 1PPI and ≥ 2PPI age groups weighed 22.0±0.20 kg, 25.7±1.00 kg and 30.9±0.40 kg, respectively. The corresponding female age groups weighed 18.2±0.90kg, 23.2±0.90 kg and 28.1±0.70 kg, respectively. The differences of about 3.8 kg, 2.5 kg and 2.8 kg were observed among the different male and female age groups in live body weight. Similar trends were also obtained for the linear body measurements in both sexes of different age groups. In line with the current study, Kerga (2021) reported that male sheep are larger than female sheep with quantitative traits in Gurage zone of Southern Ethiopia.

Table 3. Least square means and standard error (LSM ± SE) of live body weight and least square means of sampled sheep

Effect	N	BW(Kg)	BL(cm)	HG(cm)	RL(cm)	RH(cm)	RW(cm)	PW(cm)	SC(cm)
Overall	450	24.7±0.65	58.1±0.39	65.2±0.53	17.4±1.70	61.1±0.40	15.9±1.70	14.5±1.50	26.0±2.65
CV	450	12.7	6.4	5.3	9.9	4.7	10.5	10.2	12.3
R^2	450	0.71	0.62	0.60	0.5	0.6	0.50	0.50	0.60
Districts		**	*	**	*	**NS**	**	**	*
Anfillo	225	23.4±0.80^{b}	57.1±0.40^{b}	63.6±0.75^{b}	17.8±1.90^{a}	60.9±0.20^{b}	16.6±1.70^{a}	15.3±1.60^{a}	25.5±3.60^{b}
Sibu Sire	225	25.9±0.30^{a}	59.2±0.35^{a}	66.7±0.31^{a}	17.0±1.40^{b}	61.2±0.60^{b}	15.2±1.65^{b}	13.7±1.40^{b}	26.5±1.70^{a}
Sex		**	**	**	**	**	**	**	
Male	117	26.2±0.50^{a}	59.4±0.38^{a}	66.5±0.80^{a}	18.0±1.50^{a}	62.3±0.10^{a}	16.6±1.60^{a}	15.3±1.40^{a}	25.9±3.20
Female	333	23.1±0.73^{b}	56.8±0.40^{b}	63.8±0.33^{b}	16.8±1.80^{b}	60.0±0.72^{b}	15.2±1.70^{b}	13.8±1.50^{b}	
Age		**	**	**	**	**	**	**	**
0PPI	160	19.1±0.40^{c}	53.5±0.51^{c}	61.7±0.31^{c}	15.8±1.40^{c}	57.5±0.30^{c}	14.4±1.40^{c}	13.1±1.60^{c}	22.4±4.00^{c}
1PPI	92	23.7±0.60^{b}	57.8±0.26^{b}	64.9±0.72^{b}	17.5±1.80^{b}	60.8±0.65^{b}	15.6±1.40^{b}	14.5±1.20^{b}	25.7±1.70^{b}
≥2PPI	198	29.8±0.80^{a}	62.9±0.40^{a}	68.8±0.52^{a}	18.9±2.00^{a}	65.0±0.34^{a}	17.8±2.10^{a}	16.1±1.80^{a}	29.9±2.70^{a}
Sex by age		**	**	**	**	**	**	*	
0Female	113	18.2±0.90^{e}	52.1±0.35^{f}	59.7±0.33^{e}	15.6±1.40^{cd}	56.3±0.90^{f}	14.0±1.40^{d}	12.6±1.30^{e}	
1Female	71	23.2±0.90^{d}	56.7±0.37^{d}	64.3±0.29^{c}	16.5±1.80^{c}	59.8±0.90^{d}	15.0±1.40^{c}	13.5±1.20^{d}	
≥2Female	149	28.1±0.70^{b}	61.6±0.43^{b}	68.2±0.40^{b}	18.5±2.00^{b}	64.0±0.32^{b}	16.6±2.50^{b}	15.2±1.80^{b}	
0Male	47	22.0±0.20^{d}	54.9±0.48^{e}	63.2±0.64^{d}	16.0±1.40^{dc}	58.7±0.05^{e}	14.9±1.20^{c}	13.6±1.10^{d}	22.4±4.00^{c}
1Male	21	25.7±0.10^{c}	58.5±0.24^{c}	65.5±0.80^{c}	18.0±1.70^{b}	61.5±0.08^{c}	16.6±1.50^{b}	15.0±1.40^{c}	25.7±1.70^{b}
≥2Male	49	30.9±0.40^{a}	64.9±0.40^{a}	70.3±0.97^{a}	19.9±1.50^{a}	66.8±0.27^{a}	18.5±1.90^{a}	17.0±1.70^{a}	29.9±2.70^{a}

Means with different superscripts within the same column and class are statistically different (at least $P<0.05$). NS = non-significant; NA = not applicable. * Significant at 0.05 **significant at 0.01 0PPI = 0Pair of permanent incisor, 1PPI = 1Pairs of permanent incisors and ≥2PPI=2 or more pairs of permanent incisors=number, CV=coefficient of variation, R^2 =coefficient of determination, BW=body weight, BL=body length, HG=heart girth, RL=rump length, RH=rump height, RW=rump width, PW=Pelvic width, SC=scrotal circumstances,

Table 3. Continued

Effect	N	SL(cm)	TL(cm)	TW(cm)	EL(cm)	WH(cm)	HW(cm)	HL(cm)
Overall	450	11.8±1.20	28.0±0.50	12.2±1.50	9.8±0.80	60.2±0.93	9.6±0.90	16.2±1.73
CV	450	10.5	12.4	12.9	9.3	5	9.30	10.7
R^2	450	0.50	0.30	0.50	0.20	0.60	0.30	0.24
Districts		**	**	**	**	**NS**	**NS**	**NS**
Anfillo	225	12.6±1.30[a]	29.6±0.40[a]	13.1±1.50[a]	10.4±0.80[a]	59.8±0.89	9.6±0.90	16.0±2.30
Sibu Sire	225	11.0±1.00[b]	26.3±0.60[b]	11.4±1.30[b]	9.1±0.80[b]	60.5±0.96	9.5±0.76	16.3±0.63
Sex			**	**	**NS**	**	**NS**	**NS**
Male	117	11.9±1.30	29.0±0.40[a]	13.3±1.40[a]	9.9±0.80	61.10±.84[a]	9.6±0.80	16.40±1.60
Female	333		26.9±0.50[b]	11.2±1.60[b]	9.7±0.90	59.20±.93[b]	9.5±0.90	15.90±1.80
Age		**	**	**	*	**	**	**
0PPI	160	10.4±1.30[c]	25.6±0.55[c]	10.2±1.50[c]	8.5±0.80[c]	56.0±0.88[c]	8.2±0.80[c]	14.5±1.70[c]
1PPI	92	11.9±1.20[b]	27.5±0.35[b]	12.1±1.30[b]	9.7±0.80[b]	60.3±0.85[b]	9.4±1.00[b]	15.9±1.30[b]
≥2PPI	198	13.2±1.20[a]	30.8±0.64[a]	13.9±1.80[a]	10.6±0.90[a]	63.9±1.00[a]	10.6±0.90[a]	17.3±2.00[a]
Sex by age		*	**	*	**NS**	*	**NS**	**NS**
0Female	113		24.8±0.34[d]	10.4±1.00[d]	9.8±0.90	55.5±0.98[e]	8.8±0.80	15.5±1.80
1Female	71		26.7±0.45[c]	10.7±1.30[d]	9.9±0.80	58.8±0.90[d]	9.4±1.10	15.9±1.40
≥2Female	149		29.2±0.70[b]	12.5±1.90[c]	10.2±0.90	62.8±0.95[b]	10±0.90	16.3±2.00
0Male	47	10.4±1.30[c]	26.5±0.38[c]	11.7±1.60[c]	9.9±0.80	57.1±0.80e	9±0.80	16.0±1.50
1Male	21	11.9±1.20[b]	28.3±0.26[b]	13.4±1.40[b]	9.9±0.90	60.5±0.69[c]	9.3±1.00	16.3±1.00
≥2Male	49	13.2±1.20[a]	32.2±0.60[a]	15.0±1.20[a]	10.3±1.10	65.9±0.95[a]	10.3±0.80	16.7±1.90

Means with different superscripts within the same column and class are statistically different (at least $P<0.05$). NS = non-significant; NA = not applicable. * Significant at 0.05 **significant at 0.01, 0PPI = 0Pair of permanent incisor, 1PPI = 1Pairs of permanent incisors and ≥2PPI=2 or more pairs of permanent incisors, CV=Coefficient variation, R^2 =Coefficient of determination, SL=Scrotal length, TL=tail length, TW=tail width, EL=ear length, WH=withers height, HW=head width, HL=head length

Correlation between live body weight and linear body measurements

The Pearson's correlation coefficients (r) between the live body weight and linear body measurements are presented in Tables 4 and 5 for sheep flocks of Anfillo and Sibu Sire districts, respectively. Live body weight was significantly ($p<0.01$) correlated with all linear body measurements considered in the present study, except ear length in both districts. Ear length was positively and significantly (at least at $p<0.05$) associated with linear body measurements, except body weight at Anfillo district for both male and female sheep. It was however, only significantly ($p<0.01$) and positively associated with head width (HW) and head length (HL) for female sheep at Sibu Sire district. In the current study, the highest correlation coefficient values of 0.94 and 0.91 were obtained between heart girth (HG) and body weight (BW) for male and female sheep at Sibu Sire district, respectively (Table 5). The corresponding correlation coefficient values for male and female sheep of Anfillo district were 0.91 and 0.89, respectively. Similar trends were reported by Karga (2021). Highest correlation coefficient value of 0.91 was recorded between heart girth (HG) and body weight (BW) and between body length (BL) and rump height (RH) for males at Anfillo district (Table 4). Among the linear body measurements evaluated, heart girth had the highest positive association with live body weight for both sexes at Sibu Sire district. The current finding is in general agreement with findings reported in the literatures (Bosenu *et al*. 2014; Mohammed *et al*. 2015**;** Abbaya and Dauda, 2018; Guadie, 2021; Sintayehu, 2021). The current findings confirmed that heart girth is the best variable for the prediction of live body weight than other measurements. This is particularly important in rural settings where weighing balance is not available.

Multiple linear regression analysis

The multiple linear regression analysis of live body weight on different body measurements for Anfillo and Sibu Sire district is presented in Tables 6 and 7, respectively. Seven linear body measurements were included for both sexes to estimate live body weight from them. Stepwise regression analysis was employed for each district for each sex by entering all the seven linear body measurements at a time. The R^2 (coefficient of determination) was the criterion used to select the model that best predict the live body weight of sheep. That means, the higher the R^2 value indicates that the statistical model well predicts an outcome. The result of the stepwise multiple regression analyses in the present study showed that adding of other linear body measurement's to heart girth did not result in a significant improvements in accuracy of live body weight prediction. Hence, the present study suggested that live weight estimation using sole heart girth would be preferable under field conditions. Similar trends were also reported by Asefa *et al*. (2017), Hizkel (2017), Abebe and Korato (2020). Heart girth consists of bones, muscles and viscera that share larger contribution to the body weight

(Thiruvenkadan, 2005). Based on the current study findings the following regression equations are suggested for the flocks of the two districts for each sex group.

I. Anfillo district:
   a. Male sheep: $Y= -38.787+0.980X$
   b. Female sheep: $Y= -38.062+ 0.971X$

II. Sibu Sire district:
   a. Male sheep: $Y = -40.900+ 0.997X$
   b. Female sheep: $Y=-56.154+1.217X$

where: Y and X are live body weight) BW) and heart girth (HG), respectively.

Table 4. The coefficient of correlation between body weight and linear body measurements of sheep population in Anfillo district (above diagonal for males and below diagonal for females N= 67 males and N=158 females)

Traits	BW	BL	HG	RL	RH	RW	PW	SC	SL	TL	TW	EL	WH	HW	HL
BW	**1**	.87**	.91**	.75**	.86**	.77**	.71**	.65**	.62**	.63**	.74**	.55ns	.86**	.52**	.51**
BL	.86**	**1**	.88**	.69**	.91**	.73**	.68**	.63**	.69**	.64**	.73**	.57**	.89**	.60**	.45**
HG	.89**	.87**	**1**	.71**	.90**	.79**	.68**	.62**	.59**	.61**	.67**	.54**	.87**	.50**	.40**
RL	.75**	.73**	.77**	**1**	.74**	.88**	.72**	.56**	.50**	.52**	.60**	.47**	.75**	.37**	.60**
RH	.86**	.87**	.92**	.77**	**1**	.80**	.74**	.68**	.67**	.67**	.76**	.60**	.96**	.60**	.49**
RW	.72**	.69**	.70**	.84**	.73**	**1**	.84**	.64**	.61**	.60**	.64**	.52**	.77**	.48**	.58**
PW	.65**	.63**	.61**	.72**	65**	.87**	**1**	.63**	.69**	.62**	.66**	.62**	.74**	.58**	.59**
SC								**1**	.69**	.60**	.63**	.66**	.65**	.55**	.35**
SL									**1**	.66**	.69**	.63**	.66**	.76**	.32**
TL	.64**	.55**	.52**	.41**	.58**	.46**	.53**			**1**	.60**	.52**	.69**	.55**	.26*
TW	.69**	.70**	.61**	.61**	.67**	.64**	.62**			.51**	**1**	.68**	.75**	.63**	.53**
EL	.51ns	.50**	.38**	.39**	.48**	.48**	.51**			.49**	.48**	**1**	.60**	.61**	.44**
WH	.85**	.85**	.88**	.72**	.94**	.72**	.66**			.57**	.68**	.50**	**1**	.62**	.47**
HW	.54**	.54**	.45**	.32**	.51**	.41**	.43**			.55**	.48**	.53**	.53**	**1**	34**
HL	.49**	.51**	.55**	.56**	.51**	.46**	.39**			.20*	.40**	.19*	.46**	.25**	**1**

BW=body weight, BL=body length, HG=heart girth, RL=rump length, RH=rump height, RW=rump width, PW=pelvic width, SC=scrotal circumstances, SL=scrotal length, TL=tail length, TW=tail width, EL=ear length, WH=withers height, HW=head width, HL=head length, NA=not applicable, ns=non-significances=non significance, * significant at 0.05, **significant at 0.01

Table 5. The coefficient of correlations between body weight and linear body measurements of sheep population in Sibu Sire district (above diagonal for males and below diagonal for females) (N= 50 males and N=175 females)

Traits	BW	BL	HG	RL	RH	RW	PW	SC	SL	TL	TW	EL	WH	HW	HL
BW	**1**	.89**	.94**	.83**	.89**	.80**	.77**	.87**	.80**	.67**	.71**	0.05ns	.91**	.58**	.67**
BL	.87**	**1**	.89**	.85**	.89**	.84**	.83**	.84**	.72**	.62**	.69**	0.03ns	.88**	.63**	.58**
HG	.91**	.85**	**1**	.74**	.91**	.76**	.76**	.79**	.76**	.59**	.65**	0.10ns	.88**	.55**	.59**
RL	.64**	.65**	.47**	**1**	.80**	.81**	.78**	.76**	.66**	.65**	.62**	-0.13ns	.83**	.63**	.45**
RH	.87**	.87**	.84**	.68**	**1**	.79**	.77**	.80**	.81**	.65**	.72**	0.01ns	.97**	.54**	.60**
RW	.74**	.72**	.64**	.69**	.74**	**1**	.90**	.72**	.67**	.64**	.61**	0.04ns	.81**	.73**	.49**
PW	.73**	.67**	.71**	.51**	.72**	.80**	**1**	.69**	.65**	.66**	.69**	0.12ns	.75**	.72**	.57**
SC								**1**	.85**	.60**	.63**	0.06ns	.79**	.59**	.59**
SL									**1**	.58**	.59**	0.04ns	.81**	.43**	.50**
TL	.60**	.54**	.45**	.62**	.60**	.65**	.58**			**1**	.68**	0.01ns	.64**	.49**	.45**
TW	.44**	.41**	.34**	.64**	.52**	.48**	.41**			.55**	**1**	0.14ns	.70**	.47**	.54**
EL	.31ns	.27**	.40**	-.17*	.17*	.22**	.37**			0.06ns	-.25**	**1**	0.03ns	0.22ns	.37**
WH	.62**	.63**	.47**	.59**	.68**	.61**	.55**			.69**	.48**	0.04ns	**1**	.54**	.58**
HW	.43**	.39**	.47**	.22**	.40**	.40**	.43**			0.11ns	0.12ns	.27**	0.09ns	**1**	.43**
HL	.75**	.63**	.70**	.36**	.63**	.60**	.63**			.60**	.24**	.45**	.49**	.35**	**1**

Acronym as indicated under Table 3

Table 6. Multiple regression analysis of live body weight on different linear body measurements for sheep population at Anfillo district of all age group

Sex	Model	Intercept	β_1	β_2	β_3	β_4	β_5	B_6	B_7	R^2	Adj.R^2	MSE
Female (N=158)	HG	-38.062	0.971							0.77	0.74	8.59
	HG+BL	-36.143	0.530	0.455						0.80	0.80	7.74
	HG+BL+WH	-39.488	0.351	0.354	0.346					0.81	0.81	7.18
	HG+BL+WH+RH	-39.238	0.370	0.359	0.38	-0.062				0.81	0.81	7.22
	HG+BL+WH+RH+ TL	-38.852	0.419	0.311	0.347	-0.174	0.274			0.84	0.83	6.26
	HG+BL+WH+RH+ TL+RW	-36.812	0.403	0.293	0.312	-0.207	0.267	0.259		0.85	0.84	6.06
	HG+BL+WH+RH+ TL+RW+PW	-36.680	0.393	0.297	0.322	-0.213	0.280	0.370	-0.145	0.86	0.84	6.07
Male (N=67)	HG	-38.787	0.980							0.80	0.78	8.67
	HG+BL	-34.840	0.575	0.375						0.83	0.82	7.22
	HG+BL+WH	-36.805	0.495	0.275	0.215					0.83	0.82	7.07
	HG+BL+WH+RH	-36.163	0.517	0.285	0.285	-0.112				0.83	0.82	7.16
	HG+BL+WH+RH+SC	-33.810	0.520	0.275	0.302	-0.203	0.109			0.84	0.83	7.02
	HG+BL+WH+RH+SC+SL	-33.740	0.517	0.278	0.302	-0.201	0.112	-0.026		0.85	0.82	7.14
	HG+BL+WH+RH+SC+SL+TL	-33.941	0.514	0.282	0.273	-0.191	0.105	-0.072	0.065	0.86	0.84	7.23

HG=Heart girth, BL=Body length, WH=Wither height, RH=Rump height, TL=Tail length, RW=Rump width, PW=Pelvic width, MSE=Mean square error, R^2 =coefficient of determination

Table 7: Multiple regression analysis of live weight on different linear body measurements for sheep population in Sibu Sire district

Sex	Model	Intercept	β_1	β_2	β_3	β_4	β_5	B_6	B_7	R^2	Adj.R^2	MSE
Female(N=175)	HG	-40.900	0.997							0.83	0.82	4.09
	HG+BL	-37.909	0.655	0.336						0.86	0.86	3.21
	HG+BL+WH	-41.782	0.700	0.202	0.146					0.88	0.88	2.80
	HG+BL+WH+RH	-42.865	0.642	0.161	0.119	0.145				0.88	0.88	2.76
	HG+BL+WH+RH+ TL	-42.568	0.643	0.164	0.057	0.101	0.225			0.89	0.89	2.54
	HG+BL+WH+RH+ TL+RW	-43.414	0.639	0.114	0.055	0.740	0.182	0.351		0.90	0.89	2.49
	HG+BL+WH+RH+ TL+RW+PW	-43.263	0.651	0.138	0.056	0.075	0.185	0.405	-0.122	0.91	0.89	2.50
Male(N=50)	HG	-56.154	1.217							0.87	0.84	4.72
	HG+BL	-45.317	0.586	0.535						0.90	0.90	3.08
	HG+BL+WH	-45.306	0.407	0.390	0.335					0.92	0.91	2.62
	HG+BL+WH+RH	-45.632	0.465	0.402	0.488	-0.218				0.92	0.91	2.62
	HG+BL+WH+RH+SC	-42.611	0.455	0.257	0.477	-0.284	0.418			0.94	0.93	2.08
	HG+BL+WH+RH+SC+SL	-42.982	0.464	0.238	0.491	-0.275	0.459	-0.139		0.94	0.93	2.12
	HG+BL+WH+RH+SC+SL+TL	-43.050	0.472	0.230	0.483	-0.307	0.435	0.154	0.123	0.96	0.94	2.04

HG=Heart girth, BL=Body length, WH=Wither height, RH=Rump height, TL=Tail length, RW=Rump width, PW=Pelvic width, MSE=Mean square error, R^2= coefficient of determination

Structural indices of sheep population of the study areas

Indices calculated from body measurements are presented in Table 8. The overall mean body index value of 89 was obtained in the current study. The mean body index value (90) obtained from sheep flocks at Anfillo district was significantly different ($p<0.05$) from the mean body index value (88.6) obtained from sheep flocks of Sibu Sire district. The overall mean value obtained in the present study areas are higher than the 78.6 and 88.4 body index values reported for the local and crossbred sheep, respectively (Mohammed *et al*., 2018). According to Dauda (2018) and Silva-Jarquin *et al.* (2019), when index of proportionality or body index value is ≥ 0.90 the animals have longiline profile, body index value between 0.86-0.89 indicate that animals have medigline profile and body index value ≤ 0.85 indicate that animals have brevigline profile. Thus, sheep population at Anfillo district has longiline profile while those sheep population at Sibu Sire district has medigline profile. In the current study, there were significant differences ($p<0.05$) between sheep populations at Anfillo and Sibu Sire districts pelvic index, area index, height slope index, conformational index and cephalic index values (Table 7). However, significant differences ($p>0.05$) were not observed between the two sheep population in body frame index, body ratio index, compact index, proportionality index and thoracic development index values computed.

The area index values obtained from sheep population at Sibu Sire district was significantly ($p<0.05$) higher than the area index value recorded for sheep population at Anfillo district (Table 8). This indicates that Sibu Sire sheep have larger body surface than those of Anfillo district. According to Dereje *et al*. (2019), animals with larger body surface area relative to their body mass have a better ability to tolerate heat stress effectively by dissipating the excess heat load from their body surface by means of sensible and insensible heat dissipation mechanisms. The difference between the two sheep populations in area index value may be due to agro-ecological differences. For instance, the minimum altitude for Sibu Sire district is as low as 1300m.a.s.l. and that of Anfillo district is 1845 m.s.a.l. Conformational index value of sheep population at Sibu sire district was also significantly higher ($p<0.05$) than the value of conformational value obtained for sheep population of Anfillo district. Conformational index indicates the overall body shapes of an animal and the greater the conformational index is the more vigorous the sheep population is (Dereje *et al*. 2019). The overall conformational index value obtained in the current study was 70.50, which is lower than the 119.40 reported for Nigerian sheep (Olaniyi *et al*., 2018). Accordingly, Nigerian sheep are expected to be much vigorous with healthier physical appearance than sheep population in the present study area. Compact index shows how compact the animal is. Meat type animals have values above 3.15 and value close to 2.75 or 3.14 to 2.75 indicates that the animals are dual purpose and those with compact index values closer to 2.60 and below shows that the animals are more suitable for milk purpose (Dauda, 2018). The overall mean compact index value of sheep populations in the study areas was 4.05. Therefore, sheep populations considered in the current study can be classified as meat type animals. Similarly, Mohammed *et al*. (2018) classified pure Dorper and crossbred sheep in Ethiopia as meat type animals.

Table 8: Calculated structural and functional indices from morphometric traits of sheep types

Indices	Districts			CV	SEM
	Anfillo	Sibu Sire	Overall		
Body index (BI)	90.00[a]	88.60[b]	89.00	5.20	4.60
Body frame index (BFI)	0.97	0.97	0.97	5.10	0.05
Pelvic index (PI)	111.20[a]	108.60[b]	109.90	6.90	7.70
Area index (AI)	3459[b]	3610[a]	3534.50	17.90	630.70
Body ratio index (BRI)	0.98	0.98	0.98	2.40	0.02
Compact index (CI)	3.90	4.20	4.05	16.70	0.60
Height slope index (HIS)	1.30[a]	1.10[b]	1.20	13.03	1.40
Proportionality index (PrI)	98.8	98.8	98.8	5.10	5.30
Thoracic development index (TdI)	1.06	1.10	1.08	4.23	0.04
Conformational index (ConI)	68[b]	73[a]	70.50	9.50	6.70
Cephalic index (CeI)	65[a]	58[b]	60.15	17.50	10.50

a, b means different superscripts along the same row are significantly different($p<0.05$). SEM-Standard Error of Mean

Thoracic development is another essential indicator of good fitness and good respiratory system particularly for animal breeds that adapt to the higher altitudes (Khargharia *et al*. 2015; Dereje *et al*. 2019). Animals with thoracic development index values above 1.2 indicate animals that adapt to the higher altitudes (Dauda, 2018; Guadie, 2021). However, the overall mean thoracic development index value obtained in the current study was 1.08, which fall short of the 1.2. The mean thoracic value (1.08) obtained in the present study implies that indigenous sheep in the study districts had poor thoracic capacity and may not be efficiently survived in the highland areas. This is general agreement with the detailed genetic diversity study results reported by Edea *et al*. (2017). According to the authors, Horro sheep breed is best suited to areas with altitude ranges of 1400 to 2000 m.a.s.l.

Conclusions and Recommendations

In the current study, 450 sheep of different age groups were used for qualitative trait observation and quantities variables measurements. Phonotypic variations were observed within and among sampling districts. Plain coat color pattern was the most dominant qualitative trait observed with brown coat color type. District, sex, age and interaction of sex with age had significant effects (at least at $p<0.05$) on linear body measurements and live body weight of sheep. Based on the live body weight, the linear body measurements and other qualitative traits observed, sheep populations of both districts are classified under same breed. In addition, when one look at the dominant plain brown coat color, smooth hair type, the long-fat tails and the uniform polled population reported in the current study, the sheep population used in the current study are categorized under Horro sheep breed. That means, the current study confirmed characterization conducted four decades back by Galal (1983). Heart girth was the most important trait identified for the prediction of body weight. The structural indices revealed that sheep population considered in current study are medigline with poor thoracic capacity and they are categorized as meat type. The findings of the current study serves as baseline for sheep breed improvement program in the study areas. For further characterization and identification, genetic characterization of sheep types in the study areas is necessary.

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Contribution of Authors

- This article is extracted from the MSc thesis of the major author, Dinka Hora.
- Hasan Yusuf, Ayantu Mekonnen and Diriba Diba have contributed in the analysis and interpretation of data in the preparation of the article.
- The Senior Author, Gemeda Duguma is the advisor of the MSc thesis work and involved in the conception, design, analysis and interpretation of data

Conflicts of Interest

- We declare that there is no conflict of interest.

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Investigating Soil Types, Crops and Use of Inorganic and Organic Fertilizer in Mixed Farming System of Ethiopia: A Baseline Survey

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Abstract

Due to high mineral fertilizer prices, use of available alternative organic fertilizers has got focuses now-a-days. Objectives of the current work were to investigate major soil types and means of soil fertility analysis by farmers, inventory crops grown, usage of improved seeds and yields of major crops, and reveal usage of inorganic and organic fertilizers in selected districts of East Shewa and West Shewa zones of Oromia regional states of Ethiopia. The study districts of the zones represented mid altitude and highland agro-ecologies of the country. The dominant soil type in East Shewa zone was Vertisols while that of West Shewa was Nitisols. In both zones, observations of soil texture and crops growth performance were used to judge soil fertility by farmers. Teff, barely, wheat and faba bean were the major crops grown where the productivity was the lowest for Teff (951 kg ha^{-1}) and the highest (2337 kg ha^{-1}) for wheat. Chemical fertilizer usage was lower for faba bean compared to the cereals. Usage of sewage, bio-slurry, green manure, cover crops and mulching were not common. About 62% of respondents reported that livestock manure was not sufficient to fertilize own crop fields still could be used in combination with chemical fertilizers. Future research should focus on characterizing crop productivity under different levels of agricultural inputs under farmers' management.

Keywords: Bio-slurry; chemical fertilizer; green manure; mulching; Nitisol; organic fertilizer;Vertisols

Introduction

Agriculture in Ethiopia is not only the backbone of the country's economy but also determines the growth of all other sectors. However, the agricultural production is overwhelmingly subsistence (Getu and Almaz, 2022). Smallholder farmers who practice rain-fed mixed farming dominate the sector. The small-scale farmers that make about 90% of the total agricultural product till about 95% of the total area under agriculture using animal power (Hanjira *et al.* 2009) which indicate that crop production is highly dependent on livestock production. The livestock manures are also potential organic fertilizers for crop fields. However, the proportion of crop fields treated with organic fertilizer has showed a decreasing trend in the last decade (Desta *et al.* 2023).

In relative term, use of chemical or inorganic fertilizer increased from 12 kg ha^{-1} in 1996 to 36 kg ha^{-1} in 2018 in Ethiopia, and consequently, the main cereals' production also increased from 1.65 t ha^{-1} in 2009 to 2.394 t ha^{-1} in 2018 (Tilahun *et al*. 2022). However, both use of chemical fertilizers and crop yield are quiet low relative to other developing countries. According to same source, soil fertility reduction in Ethiopia is evolving as a serious contest causing low crop yields. At the country level, nutrient balance indicated a depletion rate of 122 kg N $ha^{-1}year^{-1}$, 13 kg P $ha^{-1}year^{-1}$, and 82 kg K $ha^{-1}year^{-1}$ which could be the major cause for yield reduction (Haileslassie *et al*. 2005). Unless these soil nutrients are replaced, the agricultural productivity even will go down. Due to high mineral fertilizer prices, use of available alternative organic fertilizers is vital. Nitrogen fixing legumes, livestock manure and compost are organic fertilizers, which could partially or fully replace the chemical fertilizers in general. Exhaustive list of atmospheric nitrogen fixing legume plants are available for Ethiopian farmers. Different legume plants could be screened based on their potential of soil fertility improvement. Knowledge of soil names and types is essential in making crop production decisions. Knowledge of soil types could be used to reduce the negative impacts of unpredictable rain on smallholder farming (Rankoana, 2023). Through soil analysis, farmers can make informed decisions about the crops to be produced, determine the quantity and types of fertilizers to be used, and strategize their soil management practices to optimize their crop production. Understanding the nutrient composition of the soil enables farmers to prevent insufficient or excessive application of any fertilizer to their crop fields. In general, success of soil management depends on understanding of how soils respond to agricultural land use practices over time (Elias, 2017). However, the major soil types which could determine the management to be made to different crops are not well known in East Shewa and West Shewa zones. It is also not clear whether farmers could conduct soil fertility analysis of their crop land. Usage of inorganic and organic fertilizer types including livestock manure of soil fertility improvement means in East Shewa and West Shewa zone also requires documentation. As per the plan of Korea Africa Food and Agriculture Cooperation Initiative-Crop-Livestock Agriculture (KAFACI-CLA) project which was implemented in 16 African countries including Ethiopia, investigating use of other fertilizers alternative to chemical fertilizers across the 16 project implementing countries was required. These alternative fertilizers included sewage, bio-slurry, green manure, cover crops, mulching, and livestock manure. Therefore, the objectives of the current work were (1) to investigate major soil types and means of judging soil fertility by farmers, (2) to inventory crops grown, usage of improved seeds and yields of major crops and (3) to reveal usage of chemical and other types of fertilizers in East Shewa and West Shewa zones of Oromia regional states of Ethiopia.

Materials and Methods

The study areas

The survey was conducted in two administrative zones of Oromia Regional State of Ethiopia namely East Shewa and West Shewa that represent mid altitude and highland agro-ecologies, in respective order. East Shewa is found on the eastern direction and West Shewa is found on the western direction. The capital town of East Shewa zone, Adama, is found at about 100 km from Addis Ababa and that of West Shewa, Ambo, is found at about 115 km from Addis Ababa. The geographical map of the surveyed districts and kebeles from both East Shewa (Figure 1) and West Shewa (Figure 2) are indicated hereunder. Adea and Lomme districts from East Shewa and Ejere and Welmera districts from West Shewa were considered in the present study. Different colors are used to demarcate study districts while the surveyed kebeles are filled by unique colors. The districts or regions/sub-cities bordering the study districts are indicated in Table 1.

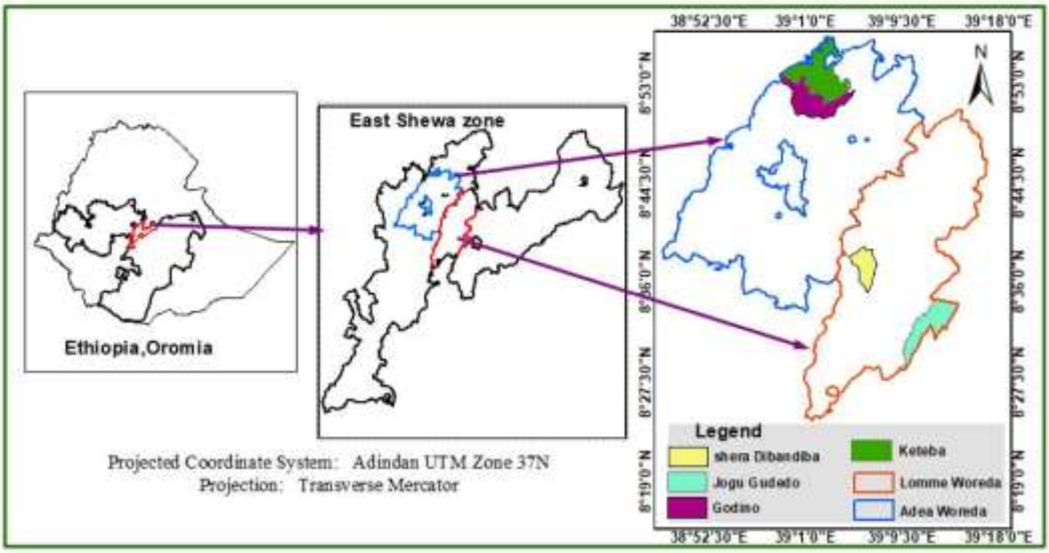

Figure 1. Map of districts and kebeles where the survey was conducted in East Shewa zone of Oromia region, Ethiopia.

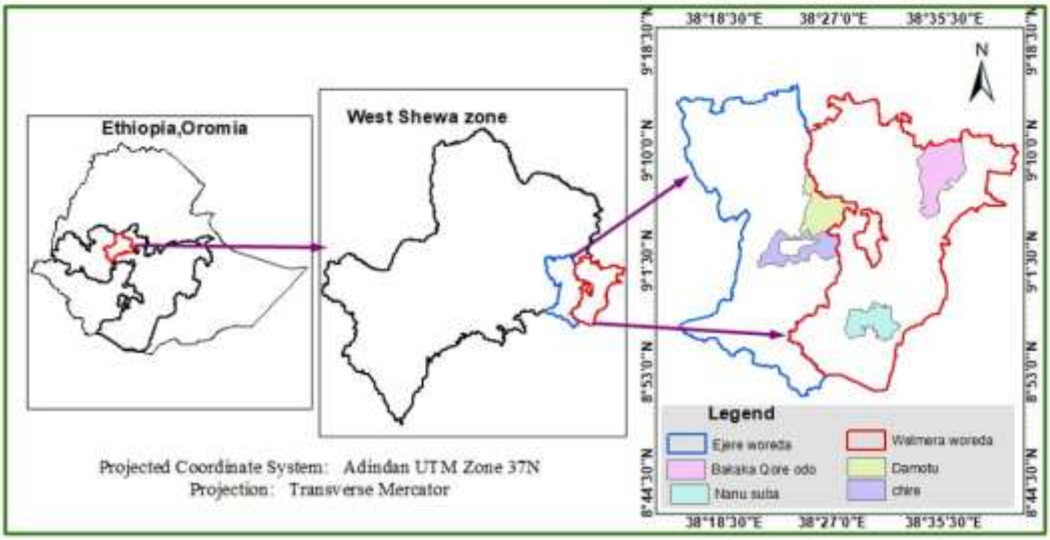

Figure 2. Maps of districts and kebeles where the survey was conducted in West Shewa zone of Oromia region, Ethiopia.

Table 1. Administrative zones, districts or sub cities bordering surveyed districts from different directions

District	North	West	South	East
Welmera	Mulo district	Ejere district	Sebeta Hawas	Sheger city
Ejere	Meta Robi district	Ejersa lafo	Southwest Shewa Zone	Welmera district
Ada'a	Akaki and Gimbichu districts	West Shewa zone	Dugda Bora district	Lome district
Lomme	Amhara Region	Ada'a district	Koka Reservoir	Adama city

The respondents' selection strategy was multistage. There was a mobility and logistics limitations at the time of conducting the survey to reach various zones and districts in the country; hence, the research team of KAFACI-CLA project in Ethiopia agreed to conduct the current survey in East Shewa and West Shewa Zones of Oromia, Ethiopia. The project team were composed of researchers from livestock, pulse crops, socio-economics, soil chemistry and livestock feeds. The districts were almost selected purposively. Higher officials at regional and respective zonal level were requested to suggest districts that practice crop-livestock production systems most and easily accessible as well. District level officials and livestock experts were given free chance to suggest any Kebele from their districts. In the same way, Kebele level development agents and Kebele managers identified farmers; they were, however, informed to focus on farmers that rear livestock and produce crops simultaneously in addition to considering female headed households. Experts and officials at district level played great role in mobilizing respective kebele development agents and other kebele administrative personnel. The kebele development agents and kebele administrators, in turn, facilitated the interview of the questionnaire through randomly selecting and appointing respondent farmers and communicating the enumerators for ease time management. Finally, 203 respondent farmers were interviewed from the two zones during September 18 to November 27, 2023. Out of the 203 respondent farmers, however, two interviews were discarded because of failing to fulfil the minimum requirement; the data analysis was based on the interview of 201 (94 from East Shewa and 107 from West Shewa) respondents. Detail of districts in which the survey was conducted is given in Table 2. The formula used for selecting the sample of the respondents is indicated herewith:

Formula developed by Cochran (1977) using pre-survey preliminary field assessments:

$$n = \frac{Z^2pq}{e^2}$$

Where, n is the sample size, Z the standard normal distribution variable represented by the normal curve that cuts off an area α at the tails ($1 - \alpha$ equals to the desired confidence level, e.g., 95%), e is the desired level of precision, P is the estimated proportion of cooperative members in the population, and q is $1 - P$ representing the proportion of non-member farmers in the population. The value for Z is found in statistical tables which contain the area under the normal curve. It is recommended to assume maximum variability (P=0.5) with a 95% confidence level and ±5% precision level to produce a more conservative sample size (Israel, 2013). A desired level of precision of 0.0693 (~ 0.07) or less is well enough to have a representative sample. In this study, we set a desired level of precision at 0.07 and obtained a sample size of 201 as follows:

$$n = \frac{(1.96)^2(0.5)(0.5)}{(0.07)^2} = 201$$

Table 2. Summary of information where the KAFACI-CLA project main survey was conducted in Ethiopia

№	Kebele	District	Zone	Number of participants
1	Bakaka Kore Odo	Welmera	West Shewa	32
2	Chirri	Ejere	West Shewa	29
3	Damotu	Ejere	West Shewa	23
4	Godino	Adea	East Shewa	26
5	Jobo Gudedo	Lume	East Shewa	22
6	Kataba	Adea	East Shewa	23
7	Nano Suba	Welmera	West Shewa	23
8	Shara Dibandiba	Lume	East Shewa	23
Total	8	4	2	201

Questionnaire and Data collection: A semi-structured questionnaire was uploaded to a free open-source tool, called Kobo Toolbox (https://www.kobotoolbox.org/) that was used for the collection of the data. This tool is similar to the Open Data Kit (ODK) and others open-source mobile data collection means. The Kobo Toolbox helps to collect, transfer, and process the data collected using Android phones and tablets with or without internet connectivity.

Data collection and analysis: Rainfall pattern and cropping seasons, household characteristics, farming experiences, soil types and analysis of cropping fields, major crops grown, adoption of agricultural inputs including chemical fertilizers, usage of other fertilizers than chemical fertilizers including livestock manure and yields of major crops were collected. The use of chemical fertilizer (Urea and NPS) for major crops was judged by calculating the proportion of plots sown without any fertilizer, plots on which less than 100 $kgha^{-1}$ fertilizer was applied, plots on which 100 $kgha^{-1}$ fertilizer was applied and plots on which greater than 100 $kgha^{-1}$ fertilizer was applied. In the case of understanding the respondents crop land soil types, enumerators got explanation of the characteristics of respective soils and categorized to one of the soil types presented as alternative in the current survey work. These soil types were Andosols, Cambisols, Nitisols and Vertisols. Consensus on the characteristics of these soil types was reached on before starting the survey. In analyzing percent and yields of crops grown in the two zones, relatively smaller number of observations were used. This was due to the fact that yields from considerably smaller plots were ignored in analyzing crop yields where these were used to calculate the percentage of crops grown. Descriptive statistics, general linear model and logistic regression methods were used to analyze the data.

Results and Discussion

Cropping season

Out of 201 respondents in the surveyed area, 95.52% mentioned that the rainfall pattern was uni-modal which means that crops were produced once per year (Figure 3). In the context of this study, the cropping season refers to the number of months in a year during which sowing begins for major crops and harvesting is completed for those same crops. The cropping season was reported to be during different ranges of months where the majority of the respondents indicated that it was during June to December. Considerable number of respondents also indicated that it was during June to January.

Risks associated with rainfall variability are one of the most visible concerns of rainfed agricultural production in developing countries. The opportunity of producing crops twice in a year is exploited when the rainfall pattern of an area is bimodal which was not the case for the current study locations. Rainfall variability was linked to risks such as late onset, early cessation, short and prolonged dry periods, and drought with a high frequency and moderate-to-severe intensity.

Where there is a moderate to strong intensity of drought, planned interventions such as climate advisory service, water conservation practices, supplemental and deficit irrigation, using drought tolerant and early maturing crops, and using multiple cropping and livelihood diversification have to be introduced to the area to cope with the effect of risks associated with rainfall variability in addition to farmers' own adaptive strategies (Habte *et al*. 2023). However, in the current study area, none of such rainfall risks were reported where the rainfall in North Shewa, an adjacent zone to both study zones, was reported to be highly variable both in space and time (Wagaye and Anteneh, 2020).

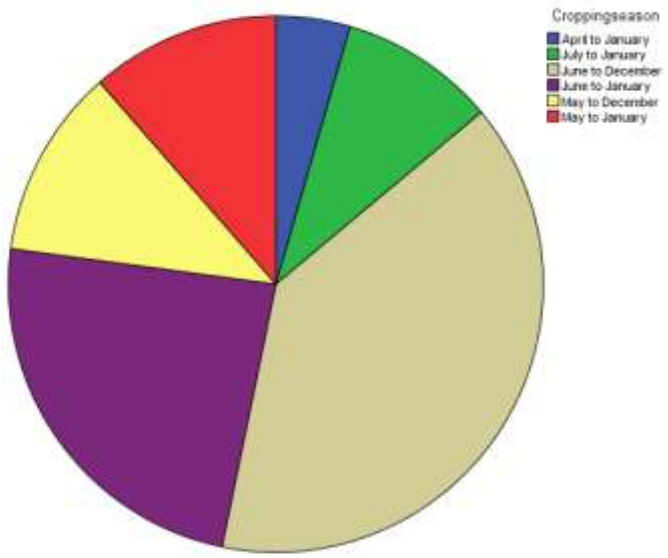

Figure 3. Cropping seasons in East Shewa and West Shewa zones, Ethiopia.

Demographic characteristics of the respondents

The age, family size and farming experiences of the heads of the households of the respondents during the survey is given in Table 3. The age of the respondents ranged from 22 to 75 years where there was no significant difference between the zones. The overall least squares mean age of respondents was 46.72±11.364 years. Age is a significant factor influencing survey responses, affecting participation rates and the quality of data collected. An increasing age of respondents and cognitive impairment are usual suspects for increasing difficulties in survey interviews and a decreasing data quality (Danuta and Marta, 2021; Schanze, 2023) where engagement of younger age respondents could increase the likelihood of incomplete survey responses. The average age of respondents in the current study could show that information was collected from middle age respondents justifying the reliability of the information.

The overall least squares mean of family size of the respondents' house hold was 5.14±1.800 where the range was from 2 to 10. The family size showed significant difference by the two zones where relatively higher number of family size was reported in West Shewa zone compared to the east Shewa zone. The average family size in Ethiopia was estimated to be about five (CSA, 2016; CSA and World Bank, 2020; ILO, 2021). The family size of the respondent in the current study is in agreement with the existing evidences. The implication of family size could be for minimum wage setting and adjustment at national or regional level (ILO, 2021), evaluation and improvement of existing government programs or initiatives (CSA, 2016) and to estimate the dependency ratio within the household (CSA, 2016; World Bank, 2020).

The average experience of respondents in agricultural farming was 24±12 years where the range was from 2 to 55 years. In general, the age of respondents and experiences of the respondents could indicate whether the information gathered from these respondents was reliable. Studies indicated that farming experiences can contribute to the entrepreneurial decision of urban resident's relative to those without experience in agricultural farming (Zhou and Li, 2022). Farming experience was found to be useful in early stages of adoption of a given agricultural technology (Ainembabazi and Mugisha, 2014) as well.

Table 3. Age and family size of the respondents for the crop livestock related questionnaire in Ethiopia

Parameter	Overall mean		East Shewa		West Shewa		Ranges
	N	LSMeans	N	LSMeans	N	LSMeans	
Age of HH (year)	201	46.72±11.364	94	46.43±1.18	107	46.97±1.09	22 – 75
Family size per HH (number)	201	5.14±1.800	94	4.46±0.18	107	5.72±0.173	2 – 10
Farming experiences (year)	201	24.24±11.667	94	24.09±1.21	107	24.37±1.12	2 – 55

LSMean=Least Squares Means; HH=Household head; N=Number of respondents

Primary and secondary activities of farmers

Agricultural activity was the sole primary activity for all the farmers in the present studied areas. Majority of the respondents (about 86%) did not have additional secondary activity than agriculture which indicated that the agricultural activity was the mainstay of the farmers but few of them were employee (6%), art workers (1%) and traders (7%) (Figure 4). The fact that majority of the respondents did not have secondary activity to agriculture did not show significant differences by the study sites. Other studies, however, indicated that non-agricultural participation ranges from 17 to 37% in Amhara and the then SNNPR regions, respectively (Mosa *et al*. 2019). The same source also indicated that the rate of non-agricultural activity participation varies across the different economic sectors such as trade (52%), manufacturing (36%) and service provisions (12%). The presence of secondary activity may help the rural farmers in diversifying their income and livelihoods. Rural households could also engage in non-agricultural activities when they do not have agricultural land, and have low earnings. According to Mosa *et al.* (2019), the major constraints limit the participation of farmers on non-agricultural or secondary activities are poor access to road, credit facility, market opportunities and lack of education/training.

Figure 4. Percentage of Respondents with different activities in East and West Shewa zones, Ethiopia

Soil types in cropping fields in East Shewa and West Shewa zones

According to the data gathered from the respondents in the surveyed districts of East Shewa zone of Ethiopia, the majority of soil types in the surveyed areas were Vertisols while other soil types including Nitisols were also reported (Table 4). On the other hand, Cambisols and Andosols were known to be not common soil types in current surveyed districts of East Shewa zone. Vertisols are among the most extensive soil types in the Ethiopian highlands, occurring in a wide range of agro-ecological zones where complex crop-livestock farming systems are practiced (Elias *et al*. 2022). According to Santra *et al.* (2017), understanding the interplay between land use systems and soil properties is key to find avenues to sustainable agricultural production. Vertisols generally show a large spacial difference in soil properties, even over relatively short distances. As a result, these soil types remain the most difficult resource systems in the world to manage successfully (Somasundaram *et al.* 2018; Kovda, 2022). On the other hand, vertisols are generally hard when dry and sticky when wet with a very low infiltration rate when the surface is sealed (Debele & Deressa, 2016).

The majority of soil types in surveyed districts of West Shewa zone were found to be Nitisols where considerable proportion of respondents indicated that portion of their crop fields were vertisols in this zone (Table 4). Nitisols are among the most extensive agricultural soils in the Ethiopian highlands but soil degradation threatens productive capacity of these soil types (Elias, 2017). The crops grown in

East and West Shewa zones include, but not limited to, teff (*Eragrostis tef*), wheat (*Triticum spp.*), barley (*Hordeum vulgare*) faba bean (*Vicia faba*), field pea (*Pisum sativum*), grass pea/rough pea (*Lathyrus sativus*), chickpea (*Cicer arietinum*), lentils (*Lens culinaris*), linseed (*Linum usitatissimum*), noug (*Guizotia abysssinica*) and fenugreek (*Trigonella foenum-graecum*) (ESS, 2023). Sustainable agricultural production on Nitisols depends on the replenishment of organic matter and application of fertilizers in proper balance and right amounts (Elias & Agegnehu, 2020).

Table 4. Number of farmers that indicated their cropping field soil types in East Shewa and West Shewa zones of Ethiopia

Zone	Plot with soil type (%)	0%	(0-25%]	(25-50%]	(50-75%]	(75-100%]
East Shewa	Nitisol	72.0	11.8	9.7	3.2	3.2
	Vertisol	20.4	9.7	15.1	19.4	35.5
	Cambisol	92.5	2.2	3.2	0.0	2.2
	Andosol	78.5	7.5	4.3	6.5	3.2
	Others	90.3	0.0	1.1	0.0	8.6
West Shewa	Nitisol	1.9	6.5	10.2	9.3	72.2
	Vertisol	64.8	16.7	13.0	3.7	1.9
	Cambisol	100	0.0	0.0	0.0	0.0
	Andosol	100	0.0	0.0	0.0	0.0
	Others	100	0.0	0.0	0.0	0.0

Soil fertility analysis in the study area

Means of judging soil fertility includes soil test at laboratory, plant tissue analysis, soil texture observation and crop growth observation. These methods were investigated in the current study area (Table 5). In in the surveyed districts of both zones, respondents revealed that they use neither plant analysis nor soil test to know their soil fertility status by themselves. Soil test was reported to be done by other organizations like agricultural researches, agricultural offices or other non-governmental organizations and the analysis was focusing on knowing soil acidity. The organizations collect soil sample from farmers' crop field and conduct soil analysis at Holeta Agricultural Research Center laboratories, for instance according to reports from Welmera and Ejere districts of West Shewa zone. Instead, long-term fertility history and crops growth observation were used to judge the fertility of the crop field soils by farmers.

Laboratory based soil test results are pH level in the soil which helps to judge whether application of lime is needed, plant available phosphorus and potassium levels to know if these levels are sufficient or if fertilizer is needed, magnesium and calcium levels in the soil, the percentage of organic matter in the soil and amounts of nitrogen, phosphorus, and potassium (USDA, 2022). A soil sample should be tested at least once every three years, or when there is a change in crop to be produced. A soil sample should also be taken if problems occur during the growing season. More details about soil testing frequency are explained in Staben *et al*. (2003). Studies indicated that the frequency of testing crop field soils depend on the farmers experiences. Beginning or young farmers may be the most frequent soil testers (Successful farming, https://www.agriculture.com/about-us-7487846). In the surveyed districts of the two zones, soil texture and crops grown observations were practical which are supposed to be the indirect indicators of soil nutrients.

Table 5. Means of soil fertility analysis in East and West Shewa districts of Ethiopia

Zones	N	Soil analysis		Plant analysis		Soil observation		Crop observation	
	201	Yes	No	Yes	No	Yes	No	Yes	No
East Shewa	93	0	93	0	93	90	3	88	5
West Shewa	108	25	83	0	108	76	32	103	5

Major crops grown in the study area

List of crops grown in the study districts of East and West Shewa zones of Oromia Regional States of Ethiopia are given in Table 6. The dominant crops grown were wheat, teff, faba bean, in respective order. Teff was dominantly produced in East Shewa where wheat, barley and faba bean were dominantly grown in West Shewa zone of Ethiopia. On the other hand, some like onion, avocado, sugarcane, and tomato that grow in East Shewa are not grown in Welmera and Ejere districts of West Shewa. Similarly, sorghum and chat are not grown in Adea and Lomme districts of East Shewa zone. However, this is limited to the information obtained from the respondents and might not be generalized for the entire districts or zones. Exhaustive crops grown in East and West Shewa zones were found in CSA (2022). According to this source, the crops grown in both East Shewa and West Shewa zone were the same and included cereals (teff, barley, wheat, maize, sorghum, finger millet, oats (‘Aja’) and rice), pulses (faba bean, field pea, beans, chick peas, soya bean, lentils, grass pea, fenugreek, mung bean and lupine), oil seeds (neug, linseed , groundnut, safflower, sesame and rape seed), vegetables (lettuce, head cabbage, kale, tomato, green pepper, red pepper and Swiss chard), root crops (beat root, carrot, onion, potato, yam, garlic, taro and sweet potato), fruit crops (avocados, bananas, guavas, lemon, mangos, oranges, papayas and pineapples), ‘chat’, coffee, hops and sugarcane. The list of crops identified during the present survey study was in agreement with the list of crops grown in the zones. On the other hand, few or none of the respondents were engaged in the production of field pea, maize, onion, beans, lentil, sorghum, ‘chat’, linseed, avocado, sugarcane and tomato in the surveyed areas. In agreement with our results, the production of these crops nationally is very low (CSA, 2022). Although maize production is high in the two zones, the interviewed respondent did not report maize as their major crop. This could be due the fact that, regardless of the random selection, kebeles considered in the current survey were not maize growing ones.

Table 6. Percentage of crops grown by the two zones in Ethiopian as indicated during the survey

Crop types	Zone				Total	
	West Shewa		East Shewa			
	N	%	N	%	N	%
Barley	52	15.3	14	5.1	66	10.7
Tef	98	28.8	82	29.6	180	29.2
Wheat	101	29.7	80	28.9	181	29.3
Faba bean	47	13.8	34	12.3	81	13.1
Chick peas	10	2.9	14	5.1	24	3.9
Field peas	1	0.3	22	7.9	23	3.7
Grass peas	8	2.4	1	0.4	9	1.5
Maize	2	0.6	10	3.6	12	1.9
Oats	11	3.2	2	0.7	13	2.1
Others*	10	3.0	18	6.2	28	4.5
Total	340	100.0	277	100	617	100

*Onion, potatoes, haricot beans, Lentil, Sorghum, Chat, Linseed, Avocado, Sugarcane, Tomatoes

Yield of major crops in the study areas

According to the survey result of the current study, the productivity of major crops was generally low in ranging from 951 kg ha^{-1} teff in West Shewa to 2337 kg ha^{-1} wheat in East Shewa. In relative terms, the yield of crops from East Shewa were higher than that of West Shewa (Table 7). The reported productivity of the major crops was lower than the report of CSA (2022). In CSA (2022), it was reported that the yield of cereals, pulses and oil crops was reported to be 2900.1 kg ha^{-1}, 1900.0 kg ha^{-1}and 1040.0 kg ha^{-1}, respectively, which was considerably higher than that of our findings from the surveyed districts of East Shewa and West Shewa zones. The reason for being low to this extent could be low adoption and use of improved varieties, low application of inputs, continual usage of un-optimized crop management practices, and uncontrolled biotic and abiotic stresses (Belachew *et al.* 2022; CSA, 2022).

Table 7. Yield (kg ha^{-1}) of major crops in East Shewa and West Shewa zones

	Zone	N	Mean	Std. Error	T-value
Barley	West Shewa	44	1662.70	282.272	0.17
	East Shewa	12	1761.67	374.663	
Tef	West Shewa	85	951.43	121.565	4.8***
	East Shewa	81	1301.07	50.686	
Wheat	West Shewa	88	1193.32	98.289	5.9***
	East Shewa	78	2337.30	173.624	
Faba bean	West Shewa	39	1407.41	178.734	2.3**
	East Shewa	32	2072.71	224.360	
Chick peas	West Shewa	10	1275.80	240.044	2.2**
	East Shewa	14	2168.13	289.754	

Area cultivated and improved seed usage

The area cultivated and proportion of improved seeds used during 2021/2022 cropping season per household for major crops produced in East Shewa and West Shewa zones is given in Table 8. Among these major crops known to be grown in the two zones, farmers used relatively largest farm size for teff (0.25 – 6.00 ha) and smallest for Faba bean and barely (0.065 – 1.500 ha). The farm size used for barley and wheat ranged between these values. Among the major crops identified, the percentage of area covered by seed was the highest for wheat (79.8%) and lowest for faba bean (49%). In the case of teff and barely, the percentage of improved seed was about 74.1% and 68.2%, respectively. The area coverage of crops reported in the current report is in agreement with reports of CSA (2022)

Table 8. Total area cultivated and proportion of improved seeds used during 2021/2022 cropping season for major crops produced in the surveyed districts of East and West Shewa zones of Oromia regional states, Ethiopia

Major crops	Number of plots	Range of area of plots (ha)	Total area covered (ha)	% of area covered by improved seeds
Teff	181	0.25 – 6.00	304.6	74.1
Barely	66	0.0625 – 1.500	36.49	68.2
Wheat	186	0.075 – 4.00	162.71	79.8
Faba bean	78	0.0625 – 1.500	24.78	49.0

Usage of Urea and NPS fertilizers

Usage (%) of Urea and NPS on major crops cultivated during 2021/2022 cropping season per household in the study area is given in Table 9. Among the major crops cultivated in the surveyed areas, the majority of faba bean plots were sown without urea (86%) or NPS (54%). Besides, about 24% of faba bean plot received NPS below the recommended 100 $kgha^{-1}$. It could be inferred that the pulse crops are grown almost without or with sub-optimal application of chemical fertilizer. Daemo (2024) recommended application of 125 kg NPSB per ha fertilizer rate for high yield and profitability of faba bean production. However, farmers are not applying the recommended amount when it comes to pulses. In fact, faba bean offers ecosystem services such as renewable inputs of nitrogen into crops and soil via biological N2 fixation, and a diversification of cropping systems. Several studies have demonstrated substantial savings (up to 100–200 kg N per ha) in the amount of N fertilizer required to maximize the yield of crops grown after faba bean (Jensen *et al.* 2010). Regarding the major cereal crops identified, about a third of the plots of barley and wheat received 100 kg ha^{-1} NPS and 100 kg ha^{-1} urea, respectively (Table 9). Considerable number of respondents (about 46%) used more than 100 kg NPS for teff and wheat (about 51%).

Table 9. Use of Urea and NPS on major crops cultivated during 2021/2022 cropping season per household in surveyed districts of East and West Shewa zone of Oromia regional states, Ethiopia

Major crop name	Number of plots	Not used (%)		Less than 100 kg ha^{-1} (%)		100 kg ha^{-1} (%)		Greater than 100 kg ha^{-1} (%)	
		Urea	NPS	Urea	NPS	Urea	NPS	Urea	NPS
Teff	181	9.94	12.15	40.88	17.12	27.07	24.31	22.11	46.42
Barely	66	21.21	15.55	34.85	25.36	28.79	31.82	15.15	27.27
Wheat	186	11.29	13.97	30.65	13.44	31.72	22.04	26.34	50.55
Faba bean	78	85.89	53.85	8.01	24.36	3.84	12.82	2.26	8.97

Usage of Sewage and Bio-slurry for soil fertility improvement

The number of farmers that used sewage (waste matter such as water or human urine or solid waste) and bio-slurry as means of soil fertility improvement was negligible; only three out of 201 respondents for each sewage and bio-slurry. This could be due to luck of availability of these organic fertilizers in the area or unfamiliarity of the farmers with these types of alternative fertilizer sources. However, studies indicated that usage of sewage for fertilizing crop fields are feasible options particularly those originating from municipalities (Zhang *et al.* 2023). The benefits of applying sewage to agricultural land include increased supply of major plant nutrients (in particular N and P), provision of some of the essential micronutrients (e.g. Zn, Cu, Mo, and Mn), and improvement in the soil physical properties, i.e., better soil structure, increased soil water capacity, and improved soil water transmission characteristics (Korentajer, 1991). The same source also indicated that the benefits of sewage application may be limited by its potential health hazards where measures that could minimize these health hazards are also indicated. Warnars and Hivos (2014) indicated that biogas produced from cattle, pig, and buffalo dung (and/or human excreta and kitchen waste), together with the by-product bio-slurry, can offer a solution to poor access to modern energy services and help mitigate poverty, climate change and soil fertility problems. Bio-slurry from biogas can be an excellent fertilizer and use of 10 to 20 tons/ha in irrigated areas and 5 tons/ha in dry farming could increase crop revenues by 25 percent on average (Warnars and Hivos, 2014). Other study also indicated that the combined bio-slurry and chemical fertilizer application at the dose of 25% bio-slurry and 75% chemical fertilizer gave the highest plant height (251.3 cm), grain yield (7.09 t ha^{-1}), biomass yield (24.4 t ha^{-1}) and stover yield (11.5 t ha^{-1}) (Kebede *et al.* 2023). The usage of sewage was almost not common in the surveyed areas whereas the usage of bio-slurry depended on the availability of biogas plants at the farmers' levels. Respondents that mentioned the usage of bio-slurry were those who participated on another separate project that helped them construct biogas infrastructure.

Usage of green manure, cover crop and mulching as soil fertility improvement methods

Green manuring is a practice of plowing or turning the grown green plants into the soil for the purpose of improving fertility status, physical and biological condition of the soil. It is a form of sustainable agriculture that focuses on the use of organic matter to improve soil fertility and crop yields.

Out of the total respondents interviewed about the use of green manure, cover crop and mulching as soil improvement method, only one, three and three respondents, respectively, said that they use the methods. In general, the most majority of them do not use the methods as soil improvement method. Some respondents indicated that they did not use these methods because the methods were time consuming, labor intensive and there are sometimes difficulties in identifying specific crops for such purposes. Utilization of green manuring might be difficult for smallholder farmers in Ethiopia where the area for croplands is quite small and the crop production is rainfed based. Dengia *et al.* (2024) evaluated seven green manure plant species including sunn-hemp, lablab, cowpea, soybean, mung bean, dhaincha, and sugarcane trash and recommended utilization of these green manure plant. However, green manuring could be considered in state farms where mono cropping is practiced year after year.

Green manuring and sustainable agriculture go hand in hand in order to maintain long-term productivity and environmental health (Patra *et al.* 2023). Studies showed that the usage of some green manure has an added advantage to soil fertility improvement. For instance, Sintayehu *et al*. (2014) indicated that green manure amendments of rapeseed and Ethiopian mustard significantly reduced disease incidence by 21% and 30% and disease severity by 23% and 29%, respectively. These results indicated that Ethiopian mustard and rapeseed crops have potential as green manure for the management of FBR disease of shallot crop.

Similar to green manuring, cover cropping is a helpful practice in improving the physical, chemical, and biological soil properties, optimizing nutrient use efficiency and reducing the dependency of crops on external supplies of nutrients. Since the interactions between cover crops and the nutritional status of soil and plants are complex and dynamic, understanding the complexity and dynamism could be useful to set up an appropriate and site-specific management of fertilization (Scavo *et al.* 2022). Mulching could also be used for the environmental modification of forests, agriculture lands, and urban landscapes. The advantage of mulches could include buffering soil temperature, prevent soil water loss by evaporation, inhibit weed germination, and suppress weed growth. Further, mulches can protect soils from wind, water, and traffic-induced erosion and compaction (Ni *et al.* 2016). Same source indicated that mulching can improve crop production by enhancing soil quality by conserving soil moisture, enhancing soil biological activities, and improving the chemical and physical properties of soil.

Sufficiency of farm gate produced livestock manure to fertilize the crop fields

The chi-square, probability of chi-square and point estimate of odds ratio for sufficiency of farm gate produced livestock manure in East Shewa and West Shewa zones is given in Table 10. The likelihood ratio chi-square of 15.71 with a p-value of <0.0001 indicated that the model as a whole fitted significantly better than an empty model in analyzing the sufficiency of livestock manure to fertilize the crop fields. The point estimate odds ratio value indicated that the sufficiency of farm gate produced livestock manure in the surveyed districts of East Shewa compared to that of West Shewa increased by 3.258 times. This means, a greater number of respondents from surveyed districts of East Shewa zone reported that farm gate produced manure is sufficient to fertilize crop fields compared to respondents from surveyed districts of Westh Shewa zone. In general, about two third (61.81%) of the respondents indicated that farm gate livestock manure was not sufficient for fertilizing crop fields. The proportion of respondents reporting that livestock manure is sufficient to fertilize their crop field was higher in East Shewa zone (24.62%) compared to West Shewa zone (13.57%) (Table 11). In agreement with our finding, in many parts of Ethiopia (Mekonnen and Köhlin, 2008) and in other Sub-Saharan African countries (Haffmann *et al.* 2001; Powell *et al.* 2004), it is widely acknowledged that quantities of manure available to farmers are limited because of low numbers of livestock per household, thus constraining crop production. Other studies (Jagisso *et al.* 2019), however, indicated that enormous amount of manure with substantial fertilizer value and economic benefit had been accumulated over the years at farm level. The same study also showed that a considerable scope exists for increasing the yields of marginal lands by using manure. Ketema & Bauer (2011) showed that where the prices of chemical fertilizers are very high, manure is labor-intensive in its application. According to these authors it was implied that the ability to afford high fertilizer prices decreases the probability to apply manure; and endowment with adequate labor input decreases the probability to opt for chemical fertilizer.

Table 10. Chi-square, probability of chi-square and odds ratio point estimate of odds ratio for sufficiency of farm gate produced livestock manure in East Shewa and West Shewa zones

Parameters	**Values**
Chi-square	15.71
Probability of chi-square	<0.0001
Point estimate Odds ratio of East Shewa versus West Shewa	3.258

Table 11. Percentage of respondent that reported farm gate produced livestock manure sufficiency to fertilize crop fields in East Shewa and West Shewa zones (total number of respondents was 199).

Zone	**Sufficient**	**Not sufficient**
East Shewa	24.62	22.11
West Shewa	13.57	39.70
Total	**38.19**	**61.81**

The respondent farmers were asked to which crops they give priority when farm gate livestock manure was not sufficient to fertilize all of their crop fields. The crops were latter categorized in to fruits and vegetables, cereals and pulses. The overall survey result revealed that fields of cereals (48.78%) followed by that of fruits and vegetables (19.51%) were given priority to receive livestock manure when there was shortage to apply to all of their crop fields. When the priority was seen zone wise, priority differences were observed where cereals fields were given priority in the case of the two zones (16.26% in East Shewa zone and 32.52% in West Shewa zone). Followed to fields of cereal crops, however, fields of pulse crops (13.82%) were the second to receive livestock manure followed by fields of fruits and vegetables (13.82%) in the case of West Shewa zone. On the other hand, fields of fruits and vegetables were given the second priority (11.38%) in East Shewa zone followed by fields of pulse crops (4.88%). According to (Tafes Desta *et al.* 2023), significant proportion of crop fields of different categories were treated with organic fertilizers which was in agreement with the current report. The same source, however, indicated that the proportion of crop field treated with organic fertilizer showed a decreasing trend over the past decade. Livestock manure could be applied to crop fields in sole form or in combination with chemical fertilizer. The combined efficacy of NPS blended fertilizer and cattle manure significantly affected the days to flowering, days to physiological maturity, plant height, panicle length, number of panicles per plant, weight of thousand-grain, above-ground biomass yield, and grain yield of Amaranth in Southern Ethiopia (Mekonnen, 2022). On the other hand, manure could be used as a whole or partial substitute for commercial fertilizers, whose prices rose sharply in recent years. According to Mekonnen (2022), the highest price 22,759 ETB ha^{-1} was received from combined application of 60 $kg \cdot ha^{-1}$ NPS fertilizer and 12 $t \cdot ha^{-1}$ cattle manure.

Table 12. Percentage of respondents considering different crop types when farm gate manure was not sufficient to fertilize crop fields (total number =123)

Crop type	East Shewa	West Shewa	Total
All crops	3.25	9.76	13.01
Fruits and vegetables	11.38	8.13	19.51
Cereals	16.26	32.52	48.78
Pulses	4.88	13.82	18.70

Conclusion

Majority of the respondents indicated the cropping was during months of June to December. The average experience of respondents in agricultural farming was 24±12 years. Agricultural activity was the sole primary activity for all the farmers in the present studied areas and majority of the respondents (about 86%) did not have additional secondary activity. The majority of soil types in the surveyed areas of East Shewa zone were Vertisols while that of West Shewa zone were Nitisols. Long-term fertility history and crops growth observation were used to judge the fertility of the crop field soils by farmers. The dominant crops grown in the surveyed areas were wheat, teff, barely and faba bean, in respective order where the productivity was the lowest for Teff (951 $kgha^{-1}$) and the highest (2337 $kgha^{-1}$) for wheat. Relatively largest farm size for teff (0.25 – 6.00 ha) and smallest for Faba bean (0.0625 – 1.500 ha). The percentage of area covered by seed was the highest for wheat (79.8%) and lowest for faba bean (49%). Chemical fertilizer usage was lower for faba bean compared to the cereals. Usage of sewage, bio-slurry, green manure, cover crops and mulching were not common in the current surveyed districts. About 62% of respondents reported that livestock manure was not sufficient to fertilize own crop fields, which still could be used in combination with chemical fertilizers. Future research should focus on characterizing crop productivity under different levels of agricultural inputs under farmers' management.

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Urban Agricultural Practices, Challenges, and Opportunities: The Case of Ambo and Waliso Towns, Oromia Region, Ethiopia

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Abstract

The study was conducted in the towns of Ambo and Waliso with the main objective of assessing the types, technology use practices, contributions of urban agriculture to agriculture household livelihoods, and challenges faced by urban agriculture producers. It focused on all types of urban agricultural practices and related activities carried out in cities. The study used descriptive methods with qualitative survey data. Agricultural production is heavily reliant on improved agricultural technology use by agriculture households, and the gap is influenced in part by the level and types of appropriate technology used. Improved agricultural technologies entail the use of various breeds, varieties, and practices that necessitate knowledge and skill in application and management practices. Producers in urban agriculture have adopted and used various agricultural technologies to some extent, but the adoption of these technologies has not been completely optimal. Introducing new dairy and poultry technologies should be supported by continues training or technical assistance on how to manage and use the technology. Producers' deviation from using improved agricultural technologies was found to be partly due to low awareness, a lack of proper agriculture technologies, and agriculture households lack of financial capacity to use improved agricultural technologies in accordance with recommendations. The study result revealed that urban agriculture has played a significant role in improving the livelihoods of urban agriculture households. It has provided households with additional income, a fresh food source, and employment opportunities for youth and women. Lack of feed supply, problems with appropriate dairy cows and poultry chickens, high prices of agriculture inputs, insufficient modern agriculture facilities and tools, absence of training and experience sharing visits with proper technology use, unavailability of credit services, poor technical support from agricultural offices and respective organizations, problems with selling places and linkages were the major challenges to urban agriculture in Ambo and Waliso towns. The study findings would help in addressing the need for genuine urban agricultural development interventions, appropriate technology generation, and cost-effective methods to boost urban agricultural productivity and contribute to household livelihood improvement.

Keywords: Urban Agriculture, Agricultural technology, Opportunities, Challenges

Introduction

Background

Urbanization is accelerating in many countries. Over half of the world's population now lives in cities and towns, and expected to rise to 60% by 2030 (Bisaga *et al*., 2019). As the world becomes more urbanized, the food supply and urban environment are put under pressure, especially in rapidly developing cities, resulting in complex socioeconomic and demographic characteristics (Ranagalage *et al*., 2021). So, it has been recognized that governments can create jobs through urban agriculture, especially for women and young people (Mahteme and Akalewold, 2020). Residents of cities are involved in urban agriculture, either directly or indirectly. The rural-urban population flow is growing, primarily in search of better job opportunities and a better life (Terfa *et al*., 2019; Busho *et al*., 2021).

However, most urban areas are unable to accommodate all of the skilled and unskilled labor that congregates around. As a result, governments and urban administrations are having difficulty creating jobs and providing adequate food for urban dwellers. In response to these challenges, governments are implementing a number of initiatives to strengthen urban agriculture as an alternative source of food and income. Agricultural planners misunderstand people's desire to grow food in cities (Deelstra and Girardet, 2004). To improve household income and livelihood, cities and towns may need to consider agricultural production in their respective urban areas or on the urban fringes. Urban agriculture has been identified as one of the government's options for creating job opportunities, particularly for youths and women.

Urban agriculture is a traditional practice in Ethiopia, and urban dwellers are used to raising cattle, sheep, and chickens or growing rain-fed crops, fruits, and vegetables on plots adjacent to their homes (Gittleman, 2009). Dairy, fattening, fruits and vegetables, poultry, and other sectors have been identified as potential contributors to urban agriculture. It is commonly practiced as an informal economic sector in many cities and towns across the country. Urban agriculture is a viable activity for supplementing food supplies from rural areas to towns and cities, it is also a source of income for many urban poor, and its importance has been overlooked (Manga *et al*., 2021; FAO, 2022). Despite urban agriculture has been practiced along Ethiopia's riverine landscape, information on agriculture labor skills, technology use practices, market linkages, value-added practices and challenges of urban agriculture is limited. A few studies have been done on urban agriculture, and they have been outdated and focused on particular commodities (Tewodros, 2007; Girma, 2010; Agajie and Bart, 2018). The focus of this study was to provide adequate information on urban agriculture carried out in Ambo and Waliso towns for targeted research, development, and urban agricultural extension services.

The study covered a wide range of urban farming practices. The study has produced information that would be useful to agricultural researchers and extensionists, development partners, policymakers, municipal governments, and other development actors. This study was undertaken in selected towns with objectives identifying types urban agriculture, and technology use practices, prioritize major challenges and opportunities in urban agriculture practices, as well as generate information that required interventions to improve urban agriculture productivity.

Research Methodology

The Study area

The study was conducted in the towns of Ambo and Waliso, the capital cities of the West Shewa and South West Shewa zones, respectively. These towns were chosen for urban agricultural practice studies because of their potential for urban agriculture, and they are also the target areas of large towns in the urban agriculture. The two towns have a large number of urban agricultural practices in various sectors as well as the potential to produce urban agriculture.

Sampling procedure

To select sample respondents, a two-stage sampling technique was used. In the first stage, two towns were selected from each study zone. The towns (Ambo and Waliso) were purposively chosen based on their representativeness of the two zones. In the second stage, respondents from urban agriculture were chosen randomly from the targeted participants. The sampling frame consisted of urban agriculture producers, consumers, agriculture input suppliers, collectors, artificial insemination technician, and agricultural experts. Individual urban agriculture producers for personal and key informant interviews (KII) were chosen from the sample frame. Actors in the urban agriculture were selected in consultation with each town's administrative agricultural office. Therefore, 30 respondents from Ambo town and 42 respondents from Waliso town were randomly selected from urban agriculture participants (Table 1). Finally, a total of 72 sample respondents were selected for this study considering different categories of farming practices and activities related to urban agriculture.

Table 1. Sampling distribution of households by urban agriculture practices and actors

S. No	Types of urban agriculture practiced	Ambo	Waliso	Overall
1	Dairy	11	17	28
2	Poultry	5	4	9
3	Dairy & Poultry	3	2	5
4	Dairy & other agriculture	1	9	10
5	Poultry & other agriculture	0	1	1
6	Animal fattening	2	0	2
7	Fattening & other agriculture	2	1	3
8	Nursey seedlings	0	1	1
9	Seedlings & other agriculture	0	1	1
10	Beekeeping & other agriculture	2	0	2
11	Crop production/vegetables	0	1	1
12	Collectors/milk collectors	0	3	3
13	Input supplier (factory, ATI, traders)	2	1	3
14	Agricultural experts & AI technician	2	1	3
	Total households	**30**	**42**	**72**

Source: Survey results, 2021

Note: AI-Artificial insemination; ATI-Agricultural transformation institute/one stop shops selling inputs

Data collection

The study collected both primary and secondary data sources. The data was gathered using a mix of formal and informal survey techniques, including key informant and individual urban agriculture producer interviews. Individual interviews were used to collect qualitative and quantitative primary data from selected urban agricultural actors using checklists. Information gathered from urban agricultural actors such as individual agriculture businesses, agriculture input suppliers, consumers, and urban agriculture enablers. The key informants were selected based on their involvement in urban agriculture. The key informant interviewees were drawn from urban agriculture offices (agricultural experts, artificial insemination technicians), input suppliers (traders and factories), and urban agriculture consumers and collectors.

Data analysis

Using the proper instruments, the data management were undertaken and made ready for analysis. The data collected from the field survey was analyzed using descriptive techniques. The socioeconomic and urban agriculture-specific features of the respondents were described using descriptive statistics including frequency distribution/ percentage, mean, and graphs. We also used maximum and minimum to describe urban agricultural practices in the study towns. The chi-square test and the t-test were used to assess the relationship between the selected towns' urban agriculture practices and characteristics.

Results and Discussions

General socioeconomic characteristics of urban agriculture households

Household and agriculture characteristics

Socioeconomic characteristics, such as educational level, gender of the household head, and age were used to describe demographic characteristics of urban agriculture. According to study results, 74% of sample respondents in the study towns were male-headed. The results also revealed that 60% and 93% of respondents in Ambo and Waliso towns were male-headed households, respectively. The educational level of the agriculture household head can have an influence on how agriculture owners view urban agriculture, the use of new technologies, and business practices. Household educational levels in the study towns range from illiteracy to graduated levels. According to the survey results, the majority of the sample respondents (90%) received formal education in the study towns The proportion of illiterate urban agriculture producers was 17% and 5% in Ambo and Waliso towns, respectively. In Ambo and Waliso towns, the sample participants who attended secondary school were 30% and 50%, respectively. About 23% and 5% attended BSc and higher educational levels in Ambo and Waliso, respectively. The descriptive analysis of Pearson’s chi-square proportion difference test between the two towns shows that there is a significant difference in terms of sex and educational status of respondents at 5% and 10% levels of significance, respectively (Table 2).

Table 2. Sex and educational status of sample respondents

Sex and Educational status	Ambo		Waliso		Overall		χ2 (chi2)	P _value
	n	%	n	%	n	%		
Male	18	60	35	83	53	74	4.905	0.027**
Female	12	40	7	17	19	26		
Educational status								
Illiterate	5	17	2	5	7	10	9.802	0.081*
Primary school (1-4 grade)	2	7	4	9	6	8		
Primary school (5-8 grade)	4	13	6	14	10	14		
High school (9-12 grade)	9	30	21	50	30	42		
Certificate/Diploma	3	10	7	17	10	14		
BSc graduate or above	7	23	2	5	9	12		

Source: Survey results, 2021

Age is important in any business, particularly in agriculture, where family labor is widely used. As a result, the respondent's maximum and minimum age was 25 and 76 years, with a mean age of 46 years in Ambo town, respectively. In Waliso town, the age range is 18 to 72 years, with an average age of 44 years (Table 3). This indicates that the majority of urban agriculture households belonged to the vibrant age group.

Table 3. Age of sample respondents

Town	n	Mean	Minimum	Maximum	SD	t-test
Ambo	30	46	25	76	13.767	0.6190
Waliso	42	44	18	72	15.757	
Overall	72	44	5	76	16.202	

Source: Survey results, 2021

Dairy agricultures (milk), poultry agricultures (chicks and eggs), seedling nursery raising, fattening (sheep, oxen, and bulls), crop production (fruits and vegetables), and a combination of different agriculture were practiced in the Ambo and Waliso towns. The practice of urban agriculture and related activities were carried out in cities to meet the diverse needs of city dwellers. The majority of urban agriculture practices in Ambo town were dairy (42%), poultry (19%), combination of dairy and poultry production (12%). While, dairy (46%), dairy and other agricultures (24%), and poultry (11%) were the most common urban agriculture practices in Waliso town (Table 4). Private individuals operated the majority of urban agricultural practices (79%), with about 65% taking place in their primary residence compounds in the study towns. Dairy, poultry, animal fattening, beekeeping, fruits and vegetable production, and mixed agriculture are mostly concentrated in Ambo and Waliso town cores and periphery areas. Nursery seedling raising was primarily concentrated in areas along the river.

Table 4. Types of urban agriculture practiced in Ambo and Waliso towns, 2021

Descriptions	Ambo		Waliso		Overall	
	N	%	N	%	N	%
Types of agriculture practiced						
Dairy agricultures	11	42	17	46	28	44
Poultry agricultures	5	19	4	11	9	14
Dairy & poultry agricultures	3	12	2	5	5	8
Dairy & other agricultures	1	4	9	24	10	16
Poultry & other agricultures	0	0	1	3	1	2
Crop prod/vegetables.	2	8	0	0	2	3
Nursery seedlings raising	2	8	1	3	3	5
Nursery seedlings & other agricultures	0	0	1	3	1	2
Fattening	0	0	1	3	1	2
Fattening & other agricultures	2	8	0	0	2	3
Beekeeping & other agricultures	0	0	1	3	1	2
Types of agriculture business						
Private individual	26	100	27	73	53	84
Enterprise and groups/jobless	0	0	10	27	10	16
Where the agriculture business established						
In the compound	21	81	24	65	45	71
Away from home	5	19	13	35	18	29

Source: Survey results, 2021

Land, labor and capital availability

Urban agriculture producers obtained land from family, city administrators, and private individuals. The group of enterprises (unemployed youth and women) obtained land by leasing from governments. A few urban agricultural activities were also carried out by rented or shared land from other city dwellers. Town administrations provided lands for agriculture operations to some urban agriculture business owners.

The labour sources used in the urban agriculture practices was both family and hired labour forces. Mainly, urban agriculture used family labors (61%) and about 25% engaged both family and hired labour forces in Ambo and Waliso towns (Table 5). The labour sources used for urban agriculture were unskilled (79%) and few individual agriculture entrepreneurs engaged professionally as business owners. Therefore, the types of labour sources involved in urban agriculture practices were both family and hire labors with unskilled labor forces for operating agricultural activities.

Different financial sources were used for operators engaged in urban agriculture. Urban agriculture operators primarily funded their operations with personal funds. In the study towns, 79% of the urban agriculture producers carried out their operations with funding from their own sources. Donations (8%) and credit services (13%) were additional financial sources that some of them utilized for urban agriculture practices. Agriculture owners used credit services from microfinance and other sources for urban agriculture practices. Thus, the urban agriculture owners start businesses with their own money, using credit services and donations from certain institutions in Ambo and Waliso towns (Table 5). The initial capital required for urban agriculture practices was insufficient for operating agriculture practices. Borrowing capital from financial institutions for urban agriculture are difficult in the study towns.

Table 5. Sources of labour used in the urban agriculture (Ambo and Waliso towns, 2021)

Sources and types of labour used	Ambo		Waliso		Overall		χ^2	P _value
	n	%	n	%	n	%		
Family	17	61	24	62	41	61		
Hired labour	3	11	6	15	9	14	0.460	0.794
Both	8	28	9	23	17	25		
Types of labour used								
Skilled	2	7	0	0	2	3		
Unskilled	20	72	24	86	44	79	2.764	0.251
Both	6	21	4	14	10	18		
Sources of capital								
Own	22	79	31	79	53	79		
Credit	2	7	7	18	9	13	4.419	0.110
Donation	4	14	1	3	5	8		

Source: Survey results, 2021

Agriculture inputs acquisition

Processed feed, such as integrated poultry feed, was obtained from traders and factories for dairy and poultry production. Animal feeds were supplied by beverage and agro-processing factories, which mixed them with various grains for dairy and poultry feeding. Dairy farmers used dry grass and hay obtained from farmers and feed producers. Grain crops and other industrial byproducts were used as feed in dairy and poultry production. In Ambo and Waliso, traders provided balanced (concentrated feeds) and other feeds required for animal fattening, dairy, and poultry production. Some farmers used forages which multiplied in their small plots. They also used local beverage byproducts (*atela*) and breviary byproducts in dairy production. Grain crops and concentrated feeds were the most popular poultry feed sources in the study towns. Traders, food plants, and beverage factories provided concentrated feed types. Thus, agricultural entrepreneurs used purchased (87%) and both supplemented with their own feed sources (13%) available (Table 6). Feed types such as grass were mainly purchased from local farmers, whereas *fagulo*, *furishkilo*, and *furishka* were purchased from food factories (wheat milling and oil factories) as factory byproducts. Some inputs used in urban agriculture practices were supplied by individual business owners. However, providing the necessary quantity and quality of inputs for urban agriculture may be challenging. Urban agriculture inputs (feeds) were not available in the study towns at the required time or in a variety of feeds at an affordable price.

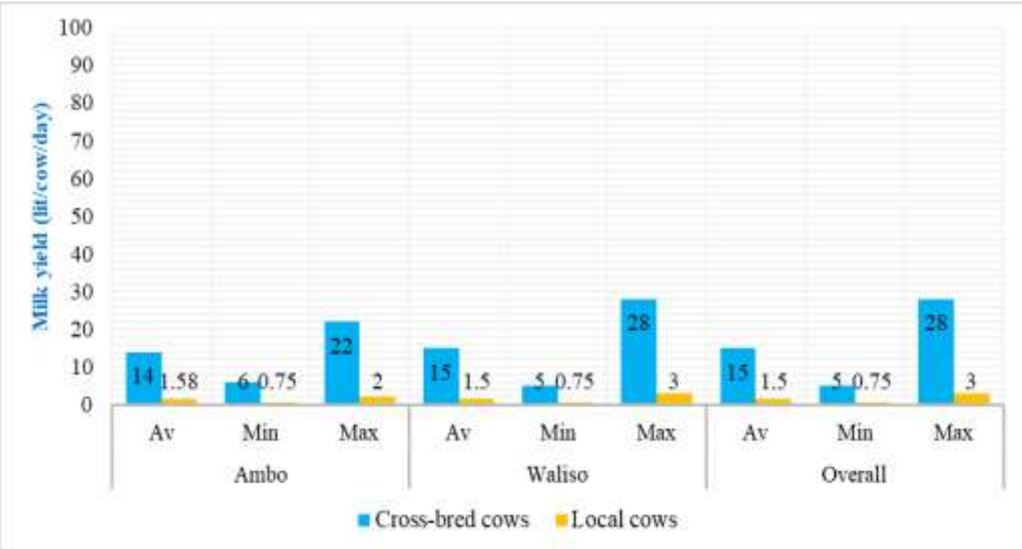
Table 6. Sources of inputs used in the urban agriculture

Sources of inputs	Ambo		Waliso		Overall	
	n	%	n	%	n	%
Only own	0	0	0	0	0	0
Purchased	21	81	34	92	55	87
Both purchased and own	5	19	3	8	8	13

Source: Survey results, 2021

Production and productivity of urban agriculture

Feed availability (concentrated feed, variety of feeds provided to cows), proper dairy barn handling, a favorable environment, and dairy cow breed types all contributed to dairy production productivity. Milk production from improved or cross-bred dairy cows in Ambo and Waliso towns averages about 15 liters per cow per day, with a minimum of 5 liters and a maximum of 28 liters. It was higher than the local one, which produced only 1.5 liters per day per cow in the towns. Local dairy cows produced 0.75 to 3 liters of milk per day in the study towns (Figure 1). To increase the productivity of urban dairy production, producers need to provide better feed and maintain improved management. Urban agriculture producers enhanced agricultural productivity by implementing better agricultural management practices and following up properly.



Source: Survey results, 2021

Figure 1. Productivity of milk from improved breed and local cows (lit/cow/day)

Capacity development and extension services

The formal extension system of government agricultural experts and veterinarians provides urban agriculture with advisory services and technical support for breeding services (AI), improved crop varieties, and improved agriculture management. Town administrative agricultural experts provide limited agricultural extension services on urban agriculture practices using new technologies and technical backstops for the urban agriculture producers. They provided advisory and AI services, vaccinations (medication services), and support with new agricultural technology practices. About 84% of urban agriculture producers received extension advice services from town agricultural offices. Experience sharing and exposure to visits were important for learning new agricultural technologies and improved agricultural management practices. Few urban agriculture producers received experiences sharing (31%) in the study towns. The exchange of improved agriculture visits was extremely beneficial to urban agriculture operations, assisting in the implementation of improved management practices in their agricultural activities. Urban agriculture producers received training in a variety of agricultural practices from various organizations. Only a few urban agriculture producers received and were exposed to capacity development training from various sources. About 43% of producers received training in a variety of topics in the study towns. In the absence of agricultural experts, there was limited access to reading production manuals (40%) related to urban agriculture production for guidance. There is no statistically significance differences in exposure to capacity development and agricultural extension services among the two towns (Table 7). Urban agriculture entrepreneurs require additional training and experience-sharing visits about modern agricultural practices. They require training, field visits, and manuals to help them develop their urban agriculture capacity.

Table 7. Capacity development and extension services

Descriptions	Ambo		Waliso		Overall		χ2	P _value
	n	%	n	%	n	%		
Get extension services	21	78	35	88	56	84	1.110	0.292
Exposed to experience sharing	11	41	10	25	21	31	1.856	0.173
Received training	14	52	15	38	29	43	1.353	0.245
Read production manuals on agriculture	13	48	14	35	27	40	1.158	0.282

Source: Survey results, 2021

Technology utilization and marketing

Agriculture technologies such as milk churning and processing machines, feed mixers, incubators, and improved dairy cow and poultry breeds (chickens) are crucial for enhancing urban agriculture production and productivity. The majority of urban agriculture practiced in Ambo and Waliso towns used combination of traditional and improved production technologies. In the study towns, urban agriculture operators and entrepreneurs made use of improved technologies such as AI (artificial insemination services), medicines, and improved agriculture tools. They used improved dairy cow breeds, chickens, waterers, feeders, and improved crop varieties, as well as vaccines and seedlings. A large number of producers used mixed agricultural technologies, accounting for 89% of urban agriculture entrepreneurs in the study towns. They used combination of improved agricultural technologies with traditional agriculture facilities. The majority of urban agriculture producers lacked the skilled labor required to operate modern agricultural technologies, but they hope to improve more through training and experience sharing. About 22% of urban agriculture producers used skilled labor to operate agricultural technology (Table 8). The skilled labor required to operate improved agricultural technologies differed between Ambo and Waliso towns, which was statistically significant at the 5% probability level.

Table 8. Types of agriculture technologies practiced in Ambo and Waliso urban agriculture, 2021

Descriptions	Ambo		Waliso		Overall		χ2	P _value
	n	%	n	%	n	%		
Types of facility/agriculture technology the agriculture using								
Traditional	3	12	3	8	6	10		
Improved	1	3	0	0	1	2	1.703	0.427
Mixed	22	85	34	92	56	89		
Skilled labor to operate the technology	9	35	5	14	14	22	3.934	0.047**

Source: Survey results, 2021

Agriculture producers in Ambo and Waliso towns sold urban agriculture products to customers at farm gates (32%), houses (27%), shops (17%) and market centers (16%). Thus, the products of urban agriculture are sold to buyers at various points throughout the towns. Fattened animals, vegetables, and seedlings were sold to market centers. Contract sales were the primary way to market milk in towns. They sold milk to institutions and individuals directly. The eggs were sold to residents, restaurants, hotels, and retailers in the study towns. In Ambo and Waliso towns, consumers (62%) were the primary buyers of urban agriculture products, followed by traders (21%), and retailers (17%). Urban agriculture producers sold products to both regular and irregular customers. Customers who purchased urban agriculture products were both regular and irregular (Table 9). The price of urban agriculture products is determined by producers (60%) based on feed costs and other agricultural expenses. In the study area, the market (demand and supply) determined by 38% of urban agriculture products. To promote their products, urban agriculture producers used noticeboards with phone numbers, paper distribution, and individual communications. They were creating demand for their products through promotion and one-on-one information sharing. Some urban agricultural producers generated demand for their products through regular customers and market centers.

Table 9. Marketing of urban agricultural products

Marketing of urban agricultural products	Ambo		Waliso		Overall		χ^2	P _value
	n	%	n	%	n	%		
Market places								
Agriculture gate	8	31	12	32	20	32		
Home	6	23	11	30	17	27		
Market center	6	23	3	8	9	14	4.238	0.375
Hotels/restaurants and institutions	1	4	5	14	6	10		
Shops	5	19	6	16	11	17		
Buyers								
Consumers/users	16	62	24	65	40	63		
Traders	6	23	6	16	12	19	0.513	0.774
Retailers	4	15	7	19	11	18		
Customers								
Regular	15	58	26	70	41	65	1.063	0.303
Not regular	11	42	11	30	22	35		
Price determinations								
Producer itself using markup price	15	58	23	62	38	60		
Consumers/buyers	0	0	1	3	1	2	0.959	0.619
Market itself (demand and supply)	11	42	13	35	24	38		

Source: Survey results, 2021

Processing and consumption practices

For urban agriculture outputs, there is a very limited processing mechanism. Households processed urban agriculture outputs (milk) primarily at home during the festive seasons. Only 10% of the sample producers processed their urban agricultural products at home in the study towns (Table 10). The lack of agricultural processing technologies and a lack of skill were some of the major issues associated with the processing and value addition of urban agricultural products in the Ambo and Waliso towns. Family members consumed urban agriculture products at home. However, some urban agriculture producers did not consume their agricultural outputs because they preferred money over use at home, and others may have done so due to product limitations with contract agreements for supplying their customers. Agriculture households consumed around 75% of urban agriculture products at home (Table 10). Consumption is determined by the size of the family (household members living with agriculture producers) and the type of agriculture products. As a result, consumption trends of agricultural producers' products are increasing, except during the year's fasting period. Agricultural products were consumed as usual or regular food items by the producers in the study towns.

Table 10. Processing and Consumption of urban products in Ambo and Waliso towns, 2021

Descriptions	Ambo		Waliso		Overall		χ2	P _value
	n	%	N	%	n	%		
Value addition/processing	5	19	1	3	6	10	4.841	0.028**
Consumption of urban agriculture products	21	81	27	71	48	75	0.777	0.378

Source: Survey results, 2021

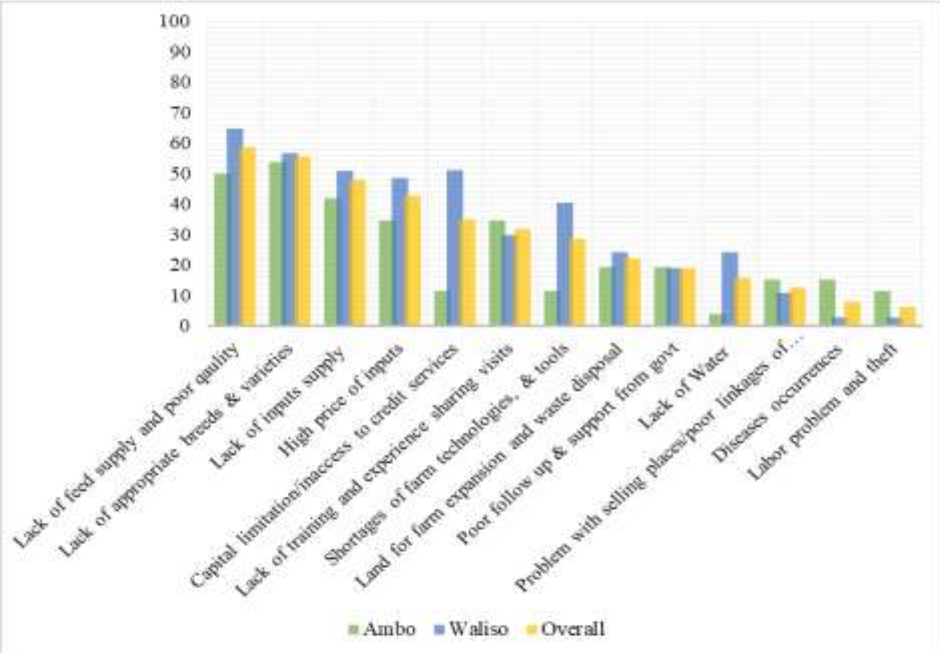
Partnerships and policy support

Advisory services, visiting, technical assistance, vaccination, and veterinary services were mostly provided to urban agriculture producers in Ambo and Waliso towns by various organizations. The primary organizations that supported urban agriculture were agricultural offices by providing artificial insemination technical services and agricultural extension services. Some non-governmental organizations (NGOs) provided training, financial support, and material assistance for urban agriculture producers. Organizations such as Ambo University, Ambo Agricultural Research, and urban administrative agricultural offices were given assistance for improving the urban agriculture.

Challenges and Opportunities of urban agriculture

Challenges of urban agriculture

Urban agriculture is a relatively new development target comes up with both opportunities and challenges. The main problems identified in the Ambo and Waliso towns were inadequate feed supply and poor quality, a lack of appropriate agricultural technologies (poultry and dairy breeds, seeds, seedlings, forages), too much high price of agriculture inputs, capital sources (inaccessibility to capital and credit services), a lack of training and experience sharing visits to bridge skill gaps, and shortages of improved agricultural technologies and farm tools. There were also shortages of inputs (polythene bags, medicines, vaccines, AI services), poor follow-up and support from respective government organizations, inadequate water supply poor linkages between actors and selling places for urban products, disease occurrences (death of calves and cows), labor problems, and theft in the study towns.



Source: Survey results, 2021

Figure 2. Major constraints of urban agriculture in Ambo and Waliso towns (%)

Opportunities available

Urban agriculture has different best opportunities for the existed and newly interested to establish the agriculture activities in the towns. Availability of users and better market for urban products (milk and eggs) are some of the opportunities for urban agriculture producers. Thus, high users/consumers of products (market demand for urban agriculture products and interest for the sectors), more profitability of sectors with low investments, and high demand for practicing agricultural technologies (dairy and chicken) were attracting agriculture businesses. Opportunities in urban agriculture were summarized as:

Urban agriculture provides various best opportunities for existing and newly interested farmers to establish agriculture activities in towns. Some opportunities for urban agriculture producers include the availability of users and a better market for urban products (milk and eggs). Thus, high users and consumers of products (market demand for urban agriculture products and interest in the sectors), higher profitability of sectors with low investments, and high demand for practicing agricultural technologies (dairy and chicken) were attracting agriculture businesses. The following are some of the opportunities in urban agriculture:

- A better market for products (milk, chicken and eggs) with close users in towns.
- It provides employment opportunities for jobless youths and women in the towns.
- Generates additional income for urban agricultural producers.
- The Ethiopian government has recently emphasized and supported urban agriculture.
- Good weather conditions (favorable environment for urban agriculture) in Ambo and Waliso towns.

To capitalize on the opportunities identified, the actors and enablers involved in urban agriculture should focus on providing improved technologies to meet domestic agricultural products demand. Facilitate credit services for agricultural production, as well as technical assistance from experts and institutions through training, and improved management practices.

Conclusions and Implications

This study was aimed to evaluate the different types of urban agriculture, technology use practices, their role in improving the livelihood of producers, and challenges related to urban agriculture. Various agricultural technologies have been introduced to boost production and productivity in urban agriculture, but only a few improved technologies have been adopted by producers. This could be due to incompatibility of developed agricultural technologies and their inaccessibility to urban agriculture producers with affordable means. Many factors limit the use of technology and the expansion of urban agriculture in Ambo and Waliso towns. The study identified major challenges such as animal feed supply shortages, a lack of agriculture technologies and facilities, a lack of agriculture inputs, a lack of credit, limited institutional support for urban agriculture, a lack of training and experience sharing, limited AI and veterinary services, and the prevalence of disease that affect the practice of urban agriculture. Furthermore, producers in urban agriculture do not widely adopt improved agricultural technologies due to unavailability of appropriate agricultural technologies, a lack of awareness, and inadequate extension services. The study also revealed that urban agriculture improves producers' financial and social capital. Urban agriculture enabled producers to supplement their family's income while also serving households as a good source of food derived directly from urban agriculture. It contributes to the creation of job opportunities for unemployed household members (both men and women). To address the challenges and expand urban agriculture in the study towns, urban agricultural offices should be provided training and supplied appropriate agricultural technologies. Thus, respective stakeholders play their roles by promoting technologies to support urban agriculture, providing training and technical assistance, supplying input such as feed and animal medicines, and making financial institutions available to credit service urban agriculture. Concerned stakeholders should get involved in developing and implementing appropriate agricultural technologies for urban agriculture producers. Promoting the adoption of improved agricultural technologies that increase the production and productivity of urban agriculture is critical. With the right combination of infrastructure, agriculture facilities, training, extension services, and credit services, appropriate technology use leads to better improvements in the livelihoods of urban agriculture households As a result, it is suggested that developing appropriate agricultural technologies, increasing access to improved agricultural technology, raising awareness of technology use, and closing skill gaps are better ways of integrating technology in urban agriculture for widespread adoption of improved technologies. The study's findings led to the following recommendations:

- Research institutions should play a vital role in generating appropriate agricultural technologies best suited to urban agriculture conditions.
- Access to credit services for urban agriculture households should be prioritized along with creating awareness about agricultural productivity-boosting technologies. As a result, improved dairy and poultry technology dissemination should be provided to urban producers in credit for those who cannot afford the price.
- Women and youths play a significant role in urban dairy and poultry agricultural practices, and the agricultural technologies should be targeted to these groups.

- Feed inadequacy has remained the most significant constraint to dairy and poultry production in urban agriculture. The provision of improved forage technologies and feed supply is critical to ensuring production and productivity in the sectors.
- To encourage the use of improved agricultural technologies, agricultural tools, vaccines, and medications should be supplied at affordable price for urban producers. It is important to provide various agricultural technologies at reasonable prices and make them available to urban agricultural households.
- It is critical to organize training, field visits, and experience sharing to increase urban agriculture producers' awareness and knowledge of improved agriculture technologies. Furthermore, training with practical demonstrations on improved technologies practices and production packages should be organized to increase awareness among urban agriculture producers.
- Attention should be given to artificial insemination services in order to increase dairy technology adoption for cows breeding practices.

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Performance Evaluation of Sasso Chickens that Fed on Rations formulated from Locally Available Feed Ingredients around Nekemte Area, Western Ethiopia

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Abstract

The present experiment was conducted to evaluate feed intake, growth performance, carcass characteristics and profitability of rearing Sasso chickens that fed rations made from locally available feed ingredients around Nekemte area, western Ethiopia. The experiment was conducted with a total of 120 male Sasso T44 chickens at the age of 42 days. The chicks were randomly assigned to the four dietary treatments of T_1 (diet formulated from maize, non-toasted soybean, lupine, noug seed cake, limestone, salt (MSL));T_2 (diet formulated from wheat, non-toasted ground soybean, non-toasted ground lupine, noug seed cake, limestone, salt and premix (WSL)); T_3 (diet formulated from maize, wheat, non-toasted ground soybean, non-toasted ground lupine, noug seed cake, limestone, salt and premix (MWS)] and T_4 [Commercial ration (CR), positive control]. The dietary treatments for growers and finishers were formulated from same feed sources nearly an isocaloric (3600 and 3500 kcal/kg DM and ME, respectively) and iso-nitrogenous (19 and 18% CP, respectively). The treatments were replicated three times with 30 chickens per treatment. The General Linear Model (GLM) Procedures of the Statistical Analysis System (SAS, 2008) was used to analyze the data. Average daily feed intake and all growth parameters were significantly affected ($p < 0.05$) by the dietary treatments. The highest feed intake was recorded in chickens that fed CR (151.7 g/day) while the least was for those fed on MSL (135.4 g/day). Similarly, chickens fed on CR and MWS attained the highest final body weight (BW) of 4048.3 g and 3928.1 g, respectively. The highest eviscerated carcass yields were recorded for those chickens fed on CR (2874.7 g) and MWS (2827.0 g) while those fed on MSL (2138.3 g) and WSL (2197.3 g) attained the least. The highest dressing percentages were obtained from those fed on CR (72.7%) and MWS (72.0%) whereas those fed on MSL (64.0%), and WSL (64.0%) showed the least. From the results of the current study, it can be concluded that MWS can be used as an alternative feed source in Sasso chicken for meat purpose without any adverse effects on feed intake and growth, and for better profitability of Sasso chickens according to this experiment.

Keywords: Carcass Yield; Feed Intake; Growth Performance; Homemade Ration; Sasso Chickens

Introduction

Poultry production has important economic, social and cultural benefits and plays a significant role in the provision of animal protein and family income in the developing countries (Mebratu *et al.,* 2020). They provide animal protein of high biological value in terms of eggs and meat (Desalew *et al*., 2013). Chicken constitutes a high-quality food source, densely packed with essential macro and micronutrients particularly, important for infants and young children, pregnant and lactating women and elders (De Bruyn *et al*., 2015). The rapid growth of human population in the world has led to a relatively high demand for quality protein, where Ethiopia is not exceptional.

In Ethiopia, chicken production is an important and integral part of most activities of households in rural, urban and peri-urban areas like other developing countries, enabling farmers to harvest the benefits of high-quality protein in the form of eggs and meat (Habte *et al*., 2017). Ethiopia's chicken population is estimated at 57 million (CSA, 2021). According to Sahpiro *et al.* (2015), successful poultry intervention would contribute to considerably to reducing poverty and malnutrition among rural and urban poor, as well as increasing national income. However, most of the chicken populations of the country (78.9%) are indigenous chicken which stay on scavenging where their nutritional status, particularly in rural areas found to be below the requirements of improved growers and finishers for optimum performance. Based on crop content analysis of confined hens, Minh (2005) reported that the crude protein (CP) and metabolizable energy (ME) intake of the hens were about 30%. Feeds consumed by scavenging chicken contain on average low nutrient concentration of protein (100 g/kg DM), energy (11.2 MJ/kg DM) and minerals such as Ca (11.7 g/kg DM) and P (5 g/kg DM) (Goromela *et al*., 2006).

Even though, the chicken population of Ethiopia is large in number , the annual meat and egg outputs are only about 50,000 and 54,395 metric tons, respectively (FAO, 2019). The average annual per capita chicken product consumption is less than 1 kg, which is one of the lowest in the world (FAS, 2017), indicating a huge gap between demand and supply of poultry product in the country. To alleviate the problems regarding the lowest annual per capita chicken products, Ethiopia planned in its National Livestock Road Map (NLRM) to increase the total chicken meat and egg production to 64,000 and 3,889 million tons, respectively (Shapiro *et al*., 2015). In the contrary, indigenous chickens kept under village management systems contributed about 94.31% of the total national poultry products (eggs and meat) while the remaining 2.49% is obtained from exotic breed of chickens kept under intensive management system and 3.21% is obtained from crossbreds in Ethiopia (CSA, 2017).

In the intensive commercial system, the profit from poultry production can be attained by minimizing feed cost which accounts for more than half of the total cost of production. According to Wilson and Beyer (2000), feed cost accounts 60-70% of the total cost of poultry production. Any attempt to improve commercial poultry production and increase its efficiency, therefore, needs to focus on better utilization of available feed resources (DZARC, 1997 as cited by Etalem, *et al*., 2009). In the current study area, availability, quality and cost of feed are the major constraints to poultry production despite of its immense potential for different cereal grain production. Broilers/pullets (commercial layers) have been distributed by extension workers to smallholder farmers of this region for the objective of increased income. Though the impact was not evaluated yet, farmers complained that the distributed broilers/pullets are not profitable due to absence of poultry compound feed in the area. Procurement of poultry ration either from Addis Ababa or Bishoftu is a major challenge for smallholder chicken producers and even beyond their reach. Unless problems related to feed cost are addressed through formulating rations from locally available feed resources, the high feed cost will discourage chicken producers and may even jeopardize the future expansion and development of chicken production in the country. It is, therefore, very important to formulate rations from locally available feed sources with affordable costs, without negatively affecting the nutritional values, to improve egg laying performances of chickens in the area. The current study, therefore, was conducted to determine the effect of rations from locally available ingredients on feed intake, growth performance, meat yield and profitability of Sasso chicken.

Materials and Methods

Description of the study area

The present study was conducted in Wallaga University (Figure 1) poultry farm which is located $9^{0}5'$ North latitude and $36^{0}33'$ East longitude and an elevation of 2,088 meters above sea level. It is at a distance of 328 km from Addis Ababa, the capital city, Ethiopia. The mean annual rainfall of the area is about 1998 mm and the minimum and maximum temperatures are 8 ^{o}C and 30 ^{o}C, respectively, and the mean was 19 ^{0}C (Nekemte Metrology Agency, 2020, unpublished report).

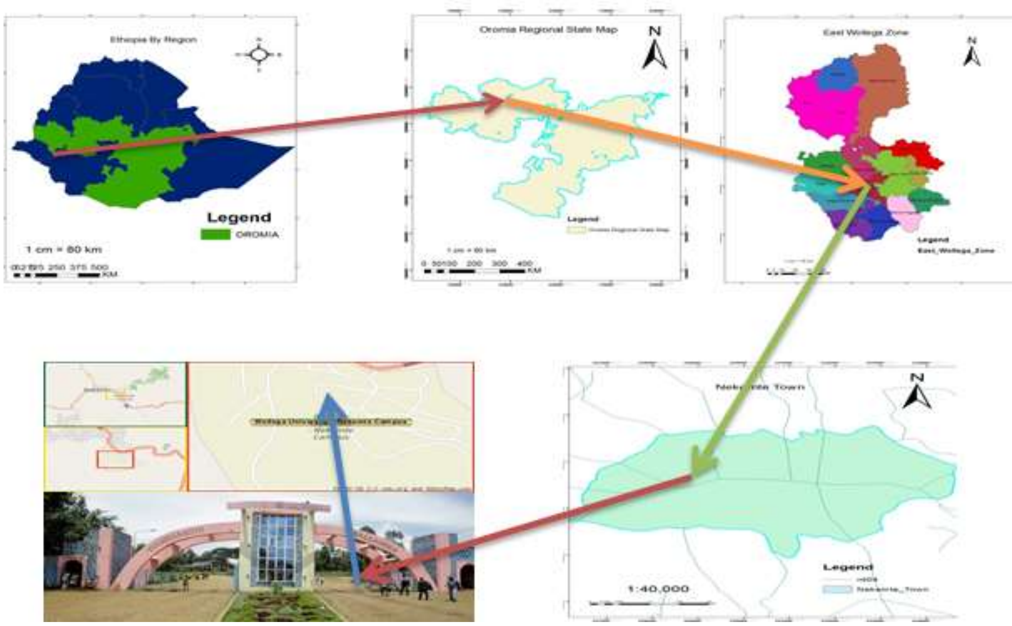

Figure 1. Map of study area

Housing and equipment

Properly constructed house with concrete floor was partitioned into equal pens depending on an individual chicken floor space requirement (0.96 m^2/ chicken) (Galobart and Moran, 2005) and covered with saw dust at a depth of 5 cm. The house was roofed with corrugated iron sheet, concrete wall, half wall covered with a wire mesh and curtain. The house was partitioned in to 12 pens and in each pen, 11 watts bulbs were suspended at 45 cm over the floor to offer heat and light during the night. The rooms were then properly cleaned and disinfected with 37% formalin solution disinfectant based on veterinary professional's guide before chickens were introduced. Different equipment and materials including feeder, waterer, digital weighing balance, record book, and permanent ink marker used to write on their shank for identification of chickens, etc. were bought and used to measure and record data.

Experimental feed preparation and chemical analysis

Preparation of feed ingredients: The rations were prepared from locally available feed ingredients such as maize, wheat, soybean, lupins (*L. albus*), noug seed cake and mineral and vitamin sources such as premix, limestone and common salt similar to the nutrient contents of the commercial ration (CR). The CR was purchased from Ethio-Chicken PLC, Addis Ababa to use as positive control. The local feed ingredients were purchased from open markets in and around Nekemte town.

Chemical analysis of feed ingredients and experimental rations: Samples of feeds were collected from each feed ingredient used in the experiment and taken to the National Veterinary Institute (NVI) at Bishoftu, Ethiopia for chemical analysis before formulating the actual dietary treatments. The chemical composition of feed ingredients used in the current study are shown in Table 1.

Table 1. Chemical composition of feed ingredients used to formulate experimental rations.

Feed Ingredients	Parameters (gm/kg)						
	DM	CP	CF	EE	Ash (MM)	Ca	ME* (Kcal/Kg)
Maize	884	88	33.9	48.9	14	66.3	3858.90
Wheat	898	135	46.7	44.7	31.2	27.8	3652.50
Soybean	906.3	380	46.3	146.3	40.8	18.6	4169.30
Lupin	924	322	128.8	70.8	41.1	12.6	3025.90
NSC	940	374.6	181.2	92.6	89.7	8.9	2481.30
Limestone	999	-	-	-	969.3	10.5	-

Note: DM=Dry Matter, CP=Crude Protein, CF=Crude Fat, EE=Ether Extract, MM=Mineral Matter, Ca = Calcium, ME*=Metabolizable Energy.

In the same way, samples were taken from each treatment ration at each mixing time and from refusals every day during the experimental period and kept in paper bags until analyzed. All samples were analyzed for dry matter (DM), ether extract (EE), crude fiber (CF) and ash contents (A.O.A.C., 1990). Nitrogen was determined by Kjeldhal procedure and crude protein (CP) was calculated through multiplying N content by 6.25. The Ca content was determined by atomic absorption spectrometer after dry ashing. The ME value was determined according to Wiseman (1987).

$$\text{ME (kcal/kg DM)} = 3951 + 54.4\ \text{EE} - 88.7\ \text{CF} - 40.8\ \text{Ash}$$

Experimental ration formulation:

Locally sourced ingredients (maize, soybean grain and wheat) were milled at a 5 mm mesh to produce their meal ready for formulation. Based on chemical analysis results of sampled feed ingredients, growers (six to eleven weeks of age) and finishers (eleven to twenty weeks of age) rations were formulated at 3000 kcal/kg DM of ME and 19% CP for growers and 3200 kcal/kg DM of ME and 18% CP for finishers. The experimental rations (MSL, WSL and MWS) were formulated using feed win software. Proportion of the experimental feed ingredients and their respective calculated composition (%) used in experimental rations are detailed in Table 2.

Table 2. Proportion of ingredients and calculated composition (%) used in experimental rations

Ingredients (%)	Grower Rations				Finisher Rations			
	MSL	WSL	MWS	CR	MSL	WSL	MWS	CR
Maize	60	-	20	Commercial Ration	60	-	35	Commercial Ration
Wheat	-	70	50		-	70	35	
Toasted Soybean	24	10	23		6	1.5	10	
Lupin	6	10	-		24	24.5	-	
Noug seed cake	8	8	5		7.5	1.5	17.5	
Limestone	1.25	1.25	1.25		1.65	1.65	1.65	
Salt	0.25	0.25	0.25		0.35	0.35	0.35	
Vitamin premix	0.5	0.5	0.5		0.5	0.5	0.5	
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Chemical composition (%)								
Dry Matter	89.34	90.17	89.61	90	89.68	90.25	90.25	90
Crude Protein	19.33	19.47	19.12	19	18.10	18.47	18.16	18
EE (C-Fat)	7.61	6.04	7.04	9	6.20	5.22	5.22	8
Crude Fiber (CF)	5.37	6.47	4.99	5.5	6.76	6.77	6.77	5.5
Ash	4.00	4.93	4.44	6.17	4.34	4.97	5.17	6.168
Calcium	4.60	2.36	3.21	0.25	4.49	2.33	2.33	0.65
ME (kcal/kg DM)	3725	3505	3710	3701	3512	3432	3424	3647

Note: MSL=Maize, Soybean, Lupin, Noug seed cake, Limestone, Common salt and premix; WSL= Wheat, Soybean, Lupin, Noug seed cake, Limestone, Common salt and premix; MWS= Maize, Wheat, Soybean, Noug seed cake, Limestone, Common salt and premix; CR=Commercial Ration. Vitamin premix=25kg Broiler premix contains, Vitamin A 1000 000IU, Vitamin D3 200 000 IU. Vitamin E 1000 mg, Vitamin K3 225 mg, Vitamin B1 125 mg, Vitamin B2 500 mg, Vitamin B3 1375 mg, Vitamin B6 125 mg, Vitamin B12 2mg, Vitamin PP (niacin) 4, 000 mg, Folic Acid, 100 mg, choline chloride 37,500 mg, Calcium 29.7%, Iron 0.4%, Copper 0.05%, Manganese 0.6%, Zinc 0.7%, Iodine 0.01%, Selenium 0.004 %

Experimental animal management

A total of 120 (Sasso T44) dual purpose chickens with an average initial live weight of 552.0±1.20 gm was bought from '*Ethio-Chicken'*PLC and grown for five months in Wallaga University, Nekemte Campus. The chickens were allowed to adapt to the rations and environment for one week prior to the commencement of the actual data collection. They were 42 days old and they were vaccinated against Mareks, Gumboro, Fowl pox, Fowl typhoid and Newcastle diseases with Marek's, Gumboro, Fowl pox, Fowl thyphoid, HB1 and Lasota vaccines. Other health precautions and disease control measures were taken throughout the study period.

Experimental design and treatments

The experiment was conducted using a Completely Randomized Design (CRD), with four feeding treatments each with three replications. The chickens were weighed individually to determine initial BW before commencement of the trial. One hundred twenty chickens were grouped into four treatments of 30 chickens each and randomly assigned to the four different dietary treatments. Each treatment group was further sub-divided into three replicates of 10 chickens per replicate and kept in 3m x 3m wire mesh partitioned pens. The four experimental treatments were categorized separately as growers and finisher rations (Table 2). In the experimental ration formulation, efforts were done particularly to make the experimental rations iso-nitrogenous with the commercial ration.

The chicks were randomly assigned to the four dietary treatments of T_1 (diet formulated from maize, soybean, lupine, noug seed cake, limestone, salt (MSL)); T_2 (diet formulated from wheat , non-toasted ground soybean, non-toasted ground lupine, noug seed cake, limestone, salt and premix (WSL)); T_3 (diet formulated from maize, wheat, non-toasted ground soybean, non-toasted ground lupine, noug seed cake, limestone, salt and premix (MWS)] and T_4 [Commercial ration (CR) (positive control.

Feed intake:

Measured amount of feed was offered twice a day at 08:00 am and 05:00 pm hours on *ad-libitum* base throughout the experimental period. As age of chickens increased the amount feed offered also increased. Feed left over from each replicate was collected the next morning before the daily offer was given. The feed offered and left over was recorded for each replicate. The amount of feed consumed was determined as the difference between the feed offered and left over. The average daily feed intake (ADFI) was calculated by dividing the total amount of feed consumed by the group for the total number of experimental days (150 days) and for the total number of chickens in each replicate (10 Sasso chickens).

Measurements and observations

All measurements on BW, feed intake and carcass weight were recorded using a digital balance. Data on chemical analysis of rations was recorded based on the assay reports from the National Veterinary Institute.

Body weight measurements: The experimental chickens were weighed on the first day before being randomly assigned to respective replicate of the treatment group by digital balance and the weight per chick was calculated as the mean weights of chickens in the replicate and recorded to form the initial BW. Weekly BW was recorded every week by weighing chickens individually until the end of the experimental period. Final BW was taken at the end of the experiment and recorded. Body weight gain per pen and per chicken was determined as the difference between the final and initial BW. The average daily BW gain (ADG) was calculated by subtracting the initial BW from the final and then dividing by the total experimental days (150).

Feed conversion efficiency

Feed conversion ratio (FCR) was calculated through dividing the average daily feed intake by its corresponding average daily weight gain (gm) (g) per chicken.

Carcass yield

A total of 48 chickens, twelve chickens from each treatment, were randomly selected and slaughtered at the end of the feeding trial. The chickens were starved for twelve hours before slaughter to ensure empty crop. Then, each chicken was weighed, killed and bled for 180 seconds. The slaughtered chickens were immersed in a bucket of hot water (63°C) for approximately 120 seconds, and de-feathered by hand plucking. The carcass was then eviscerated (removing of head, heart, crop, pancreas, kidney, lungs, proventriculus, small intestine, large intestine, caeca, urogenital tracts and lower leg) and suspended over the evisceration line and allowed to drain for 15 minutes prior to weighing. The back, the two thighs, two drumsticks, two wings and breast were used to evaluate the commercial carcass yield. Dressing percentage was calculated as the proportion of carcass weight to slaughter weight multiplied by 100. Gizzard, skin and liver are edible in most places in Ethiopia and included in the edible component. The giblets which included the heart, gizzard and liver were weighed and recorded. The total edible offal (TEO) component which includes skin, gizzard and liver were weighted and recorded as TEO. Under Ethiopian context the total non-edible offal (TNEO) component includes blood, shank and claws, feather, head, crop, esophagus, proventriculus, spleen, pancreas, kidney, heart, lung, small intestine, large intestines and abdominal fat were weighed and recorded as TNEO (Melesse *et al*., 2013).

Partial Budget Analysis

The profitability of feeding the chickens with locally formulated rations was determined by employing partial budget analysis. Partial budgeting is a method of organizing experimental data and information about the cost and benefits from some change in the technologies being used on the farm. The aim is to estimate the change that will occur in farm profit or loss from some change in the farm plan (Yared, 2019).

The profitability of feeding locally formulated rations was determined based on costs of feed ingredients and transporting the ration, the purchasing price of commercial ration, and selling price of Sasso chicken. The costs incurred for purchasing of feed ingredients, transporting, processing locally formulated ration and purchasing price of commercial ration were the total variable costs and the selling price of chickens was the total return. Selling price of chickens was estimated by five experienced persons on marketing of chicken in the study area. The net income (NI) was calculated by subtracting the total variable cost from the total return (Upton, 1979):

NI = Total income – Total variable cost

The change in net income (ΔNI) was calculated as the difference between the change in total income and the change in total variable cost (Upton, 1979):

ΔNI = Change in total income – Change in total variable cost

The marginal rate of return (MRR) which measures the increase in net return associated with each additional unit of expenditure was computed using the equation developed by (Upton, 1979):

$$\text{MRR} = \frac{Chnage\ in\ net\ income\ (\Delta\text{NI})}{Change\ in\ total\ variable\ cost\ (\Delta\text{TVC})}\, x100$$

Statistical Analysis

The data on feed intake, BW change and carcass yield were analyzed using the General Linear Model (GLM) procedure of Statistical Analysis System, SAS (2008). Means differences were compared using the Tukey's honestly significant difference (HSD) at $\alpha = 0.05$. The following statistical model was fitted to analyze the data:

$$Yij = \mu + ti + eij$$

Where:

Yij = response variables (i.e. feed intake, body weight gain and carcass yield) taken under treatment i).

μ= the overall mean

ti= the i^{th} treatment effects (1=MSL, 2= WSL, 3= MWS, 4= CR)

eij = is a random error

Result and Discussion

Chemical composition of experimental rations

Chemical compositions of the four dietary treatments of grower and finisher rations are presented in Table 3. The rations were formulated from locally available feed ingredients comparing with the commercial ration (CR) purchased from Ethio-chicken PLC and to contain a minimum of similar amount of the nutrients contained in CR in the grower and finisher rations, respectively. The DM and CP contents of the experimental rations were similar for grower rations as well as for finisher rations. The similarity in CP content between locally formulated and commercial rations implies that the rations were formulated based on the CP requirements of broiler at grower and finisher stage which are 19% and 18%. The highest ash content was observed in CR for grower rations followed by WSL, MSL and MWS, respectively. However, ash content of CR was the least for finisher ration.

In the current study, the highest crude fiber (CF) contents were obtained from MSL and WSL for grower and finisher rations, respectively whereas the least % CF values were observed in CR for grower and finisher rations, respectively. ME was highest in CR and MWS for grower and finisher rations, respectively. This implies that the highest EE in CR and MWS for grower and finisher rations, respectively contributed to the highest values of ME observed in both rations. The highest fiber contents of MSL and WSL could be attributed by inclusion of lupins grain which contains high fiber content unlike that of MWS.

Table 3. Chemical composition of experimental rations (gm/Kg DM basis)

Chemical composition (g/kg)	Experimental Rations							
	Grower Rations				Finisher Rations			
	MSL	WSL	MWS	CR	MSL	WSL	MWS	CR
Dry Matter	925	924	912.7	923	930.3	925.3	919.7	924
Ash	72.4	77.6	62.5	103.7	69.9	76.7	76.5	62.1
Crude Fiber	46.5	22.7	32.9	4.3	37.6	39.9	28.3	20.6
Crude Protein	191.5	199.9	194.1	191.9	181.7	189.8	183.8	183
Crude Fat (Ether Extract)	41.3	9.5	32.2	45.5	103.2	21.2	118.1	37.9
Ca	30.6	25.3	21.9	28.9	26.9	27	21.8	25.3
ME*(kcal/kg)	3468	3485	3580	3737	3894	3398	4031	3722

MSL=Maize, Soybean, Lupin, Noug seed cake, Limestone, Common salt and premix; WSL= Wheat, Soybean, Lupin, Nou g seed cake, Limestone,
Common salt and premix; MWS=Maize, Wheat, Soybean, Noug seed cake, Limestone, Common salt and premix; CR=Co mmercial Ration. DM=

Feed intake, body weight change and feed conversion efficiency of Sasso chickens

The mean daily feed intake, body weight change and feed conversion efficiency of Sasso chickens during the entire experimental period is presented in Table 4. There were significant differences ($p<0.0001$) in average daily feed intake among chickens fed on the different experimental rations. Average daily feed intake of chickens fed on CR was significantly ($P<0.05$) higher than those kept on other experimental rations followed by those fed on MWS. There was no significant difference between chickens fed on MSL and WSL with regard to average daily feed intake during the experimental period.

Table 4. Feed intake, Body weight change and Feed Conversion Efficiency of Sasso Chickens fed experimental rations during the whole experimental period.

Parameters	Experimental rations				SEM	P-value
	MSL	WSL	MWS	CR		
ADFI (gm/day)	135.4^{c}	136.8^{bc}	140.5^{b}	151.7^{a}	0.783	<0.0001
IBW (gm)	553.9	553.7	553.6	553.5	0.246	0.7715
FBW (gm)	3346.6^{b}	3466.3^{b}	3928.1^{a}	4048.3^{a}	32.03	<0.0001
ADG (gm/day)	18.63^{b}	19.43^{b}	22.47^{a}	23.30^{a}	0.217	<0.0001
FCE (gain/intake)	0.14^{c}	0.14^{c}	0.16^{a}	0.15^{b}	0.002	0.0003

Note: abc Means with a different superscript in a row are significantly different (P<0.05): ADF = Average daily feed intake, IBW=Initial body weight, FBW=Final body weight, ADG=Average daily gain, FCE Feed Conversion efficiency; MSL=Maize, Soybean, Lupin, Noug seed cake, Limestone, Common salt and premix; WSL= Wheat, Soybean, Lupin, Noug seed cake, Limestone, Common Salt and premix; MWS= Maize, Wheat, Soybean, Noug seed cake, Limestone, Common salt and premix; CR=Commercial Ration; SEM= standard error of the mean

Average feed intake obtained for chickens fed on CR and MWS in the current study was within the report of Osei-Amponsai *et al.* (2015*)* who reported an average intake of 145 g/chicken/day for Sasso T44.

However, average feed intake values of chickens fed on WSL and MSL were below the average feed intake value reported by the previous same authors. Lower feed intake in MSL and WSL in the present study may be associated with high inclusion level of Lupins in the rations making it unsuitable for chicken feeding. Because, lupins contain relatively high levels of non-starch polysaccharides (NSP). The NSP reduces digestibility of nutrients as well as increased digesta viscosity (Anna and Maria, 2019). The main anti-nutritional factor of lupin grain is related to their specific carbohydrate composition, which is characterized by low levels of starch, high levels of NSP and high levels of raffinose oligosaccharides (Wolko *et al*., 2011). These properties affect the utilization of energy and contribute to the reduction of feed intake and digestibility, mainly in monogastric animals.

Significant differences (p<0.0001) were observed in final body weight among chickens fed on the different experimental rations. Chickens fed on CR recorded the heaviest final BW followed by those fed on MWS. However, no significant (p> 0.05) difference was observed between chickens fed on CR and MWS regarding the final BW recorded and average daily gains in 150 days. Significant difference was also not observed between chickens fed on WSL and MSL about final weight. The average final BW obtained in the current study was higher than 2.98 kg reported by Aman Getiso *et al*. (2017) for male Sasso T44 at age of sexual maturity. This might be due to management, location and nutritional differences. Additionally, the final BW obtained for chickens at 20 weeks in the present study was higher than the final BW reported by Mezgebu *et al.* (2020) who reported final BW in the range of 2755.98 g-3907.42 g for male Sasso T44 at 20 weeks of age in Nekemte. This might be due to nutritional differences among experimental rations.

The highest final BW attained by chickens fed on CR and MWS respectively. This might be due to absence of lupins in MWS, lower fiber content and higher energy content of both rations. In contrast to this, the lower final BW was obtained with MSL and WSL; although they contained similar CP values with the previous rations. This was probably due to higher fiber content as well as inclusion of lupin in both rations which may affect feed intake and proper utilization of nutrients in the rations.

Therefore, significantly lower BW recorded for chickens fed on MSL and WSL might be due to significantly lower feed intake of those chickens. Ferket and

Gernat (2006) confirmed in their report that feed intake was the major factor that influences the BW gain of broiler chicken.

In similar fashion to final BW, chickens fed on CR and MWS gained significantly ($p < 0.05$) more weight than those fed on WSL and MSL. Chickens fed both on MSL and WSL gained the least BW. The lower average daily gain attained by chickens fed on MSL and WSL might be due to the higher fiber content and the anti-nutritional content of lupin in MSL and WSL which might have depressed both feed intake and nutrient utilization by chickens. No significant difference ($p > 0.05$) was observed between chickens fed on WSL and MSL about average daily gain (ADG). Faster growth is usually associated with better feed utilization. Similar trends were observed between the final BW and ADG, which indicate that ADG is the direct translation of BW. It has also been reported that growth rate and feed efficiency are highly correlated (Scanes *et al*. 2004).

The ADGs observed in this study were higher than the ADG values of 16.6 g, 15.7 g, and 16.8 g according to the survey result reported by Etalem *et al*. (2013) for Sasso T44 chickens fed on maize diets substituted by 25%, 50% and 75% cassava root chips, respectively. Similarly, the result of ADGs in the present study were higher than the report of Mezgebu *et al*. (2020) who reported that ADGs range from 14.2 g/day to 21.9 g/day for male Sasso T44 at 20 weeks of age. These differences could be due to nutritional differences. Franco *et al*. (2012) reported lower ADG value of 5220 g/10 months (i.e. 17 g/day) for Mos rooster and Sasso T-44 which is lower than the ADGs reported in the current study. This might be due to nutritional differences as well as extended growth period in the former study.

There was significant difference ($P < 0.0003$) in feed conversion efficiency between group of chickens fed on the experimental rations and commercial ration. Chickens were most efficient in converting feed to BW from CR and MWS which is due to the higher growth rates obtained from chickens fed those diets. There was no significant ($P>0.05$) difference in feed conversion efficiency between chickens fed on MSL and WSL. The better feed conversion efficiency in MWS and CR could be due to differences in feed intake and weight gain among the treatment groups. The FCE values obtained in the current study were higher than the 0.10-0.12 FCE values reported by Mezgebu *et al*. (2020) for Sasso T44 chickens at 20 weeks of age. From this, one could easily observe that among the locally formulated rations; feeding of MWS had better feed utilization efficiency than CR. In general, chickens required more feed per unit of weight gain in WSL and MSL compared with MWS and CR.

Generally, the Saso chickens fed lupine-based diets showed markedly decreased feed intake and growth rate in the present study which is in line with the findings of Hong *et al.* (2022) who indicated that the lower performance of chickens could relate to the presence of anti-nutritional factors as lupine contains relatively high levels of non-starch polysaccharides (NSP). The NSP reduces digestibility of nutrients as well as increased digesta viscosity (Anna and Maria, 2019). This increase in gut viscosity reduced the mixing of digestive enzymes and substrates in the intestinal lumen. Also, the alkaloid content of bitter cultivars ranges from 5 to 40 g/kg (Erbas *et al.*, 2005). All of the above could eventually lead to a reduction in nutrient digestion and utilization.

Carcass characteristics of Sasso chickens fed the experimental rations

The carcass characteristics of Sasso chickens fed different experimental rations are presented in Table 5. The slaughter weight of chickens fed on the different dietary treatments ranged from 3360.3 g -3955.7 g. No significant (p>0.05) difference was observed between chickens fed on CR and MWS in all the parameters measured in the current study. In similar fashion, no significant (p> 0.05) difference was observed between chickens fed on MSL and WSL for all the carcass parameters investigated. Differences were observed among chickens fed on CR and MWS and those fed on WSL and MSL for all carcass characteristics considered during the current study, except for back and neck weights. There was no significant difference (p> 0.05) among chickens of the different treatment groups about back and neck weights.

In the current study, though there was no significant difference recorded between chickens fed on both MWS and CR in most of parameters evaluated (eg. Slaughter Weight, Breast, Back, Carcass Weight and Dressing Percentage), chickens fed on CR outperformed those fed on the other experimental rations in all carcass parameters investigated followed by those fed on MWS. On the other hand, those chickens fed on MSL (T_1) were inferior to the other two groups of chickens fed on WSL (T_2) and MWS (T_3). This could be due to the lower feed intake attributed by high fiber content and anti-nutritional factors of lupin included in MSL and WSL rations. Consumers prefer chickens with high yield of fine parts, such as breast, drumsticks, and thighs (Faria *et al*., 2010). Hence, the highest yields of commercial carcass components (breast, thigh, drumstick and wings) were attained by chickens fed on CR and MWS while the lowest yields of commercial carcass components were scored by those fed on MSL and WSL. This implies that carcass yield obtained from chickens fed on CR and MWS could produce more commercial carcass components as compared to others.

Table 5. Carcass characteristics of Sasso chickens fed on experimental rations

Parameters (g)	Experimental rations				SEM	P-value
	MSL	WSL	MWS	CR		
Slaughter Weight	3360.3[c]	3441.0[bc]	3934.0[ab]	3955.7[a]	10.4	0.0117
Breast (BT)	556.67[b]	571.00[b]	727.33[a]	756.67[a]	16.8	0.0003
Thigh (TH)	501.67[b]	510.33[b]	650.67[a]	680.33[a]	16.1	0.0004
Drumstick (DK)	363.33[b]	389.67[b]	522.33[a]	555.00[a]	10.6	<0.0001
Back (BK)	392.67	406.67	506.00	423.67	40.8	0.2963
Wings (WS)	205.33[b]	201.67[b]	289.33[a]	320.67[a]	11.7	0.0008
Neck (NK)	118.67	117.67	131.67	138.67	8.06	0.2831
Carcass weight	2138.3[b]	2197.3[b]	2827.0[a]	2874.7[a]	67.7	0.0004
Dressing (%)	64.0[b]	64.0[b]	72.0[a]	72.67[a]	0.29	<0.0001

Note: abcd Means with a different superscript in a row are significantly different (P<0.05); MSL=Maize, Soybean, Lupin, N oug seed cake, Limestone, Common salt and premix; WSL=Wheat, Soybean, Lupin, Noug seed cake, Limestone, Comm on salt and premix; MWS= Maize, Wheat, Soybean, Noug seed cake, Limestone, Common salt and premix; CR=Commer cial Ration; SEM=standard error of the mean

The dressing percentage (DP), as commonly observed in other parameters in Table 5, was highest for chickens raised on MWS and CR while those kept on MSL and WSL attained the least. The DP attained from CR and MWS agreed with the 71.20% reported by El said *et al.* (2016) for Sasso chickens. However, the DP obtained from MSL and WSL was lower than the reports of the same authors. Generally, the dressing percentage obtained during the current study was higher than the dressing percentage ranging from 53.7 – 56.7% reported by Melkamu (2017) for Sasso chickens slaughtered at 56 days of age. These differences could be due to age and nutritional differences.

It appeared that chickens fed on the MSL and WSL rations poorly utilized their feed as evidenced by lower slaughter weight, breast muscle, thigh, drumstick, carcass weights and dressed carcass. Low nutrient utilization which resulted in poor tissue growth and muscle deposition were suggested to be the cause for low carcass yield in broilers (Berhan and Wude, 2010). Additionally, Tegene and Asrat (2010) argued that high carcass yield suggests more nutrient bioavailability for anabolic process than other diets since the true muscle development is an accumulation of protein. Therefore, lower weights of carcasses from chickens fed on MSL and WSL may be due to less deposition of protein as well as lower nutrient utilization as result of anti-nutritional factors of lupin grain in both rations.

Giblet, total edible offal (TEO) and total non-edible offal (TNEO) yields of Sasso chickens

The giblets, total edible offal and total non-edible offal yields of Sasso chickens fed experimental rations are presented in Table 6. There was no significant difference (P>0.05) in giblet yield among chickens fed on the different experimental rations, except heart weight. Chickens fed on MWS recorded the highest heart weight followed by those fed on CR. During the current study, there were no significant differences among chickens fed on the different experimental rations both in yields of total-edible offal (skin, Liver and Gizzard) and the non-edible offal. The non-significant differences observed among the individual components of the giblet such as liver and gizzard in the present study were confirmed by the report of Melkamu (2016) who noted that the giblet weight and its components were not significantly (P>0.05) influenced by a diet containing dried blood-rumen content mixture.

Table 6.Giblet, Total edible offal (TEO) and Total nonedible offal (TNEO)

Parameters (gm)	Experimental rations				SEM	P-value
	MSL	WSL	MWS	CR		
Skin	218.67	209.67	228.00	232.67	10.3	0.46
Liver	51.00	50.00	52.00	49.33	1.72	0.72
Gizzard	54.00	54.00	57.00	58.00	1.40	0.19
Heart	19.33[b]	20.00[ab]	24.33[a]	21.67[ab]	0.96	0.04
Head	141.33	140.33	143.33	145.33	3.87	0.78
Shank	135.00	134.67	134.67	134.33	4.16	0.99
Feather	197.33	198.00	198.33	198.67	6.15	0.99
Giblet	124.67	124.00	128.67	131.00	3.95	0.58
Total edible offal	323.33	313.67	341.67	335.33	11.8	0.41
Total non-edible offal	448.33	493.33	501.00	500.33	24.6	0.44

Note: [ab] Maens with a different superscript in a row are significantly different (p<0.05); MSL=Maize, Soybean, Lupin, Noug seed cake, Limestone, Common salt and premix: WSL= wheat, Soybean, Lupin, Noug seed cake, Limestone, Common salt and premix; MWS=Maize, Wheat, Soyabean, Noug seed cake, Limestone, Common salt and Premix; CR=Commercial Ration; SEM=standard error of the mean

Total edible offal (TEO) under Ethiopian context includes gizzard, skin and liver (Asrat *et al*., 2008). The non-responsive of total edible offal (TEO) to the different experimental rations of the present study was in agreement with report by Melkamu (2016), where the TEO of chickens was not significantly influenced (P>0.05) by the dietary treatments.

In Ethiopia, the total non-edible offal components include blood, shank and claws, feather, head, crop, esophagus, proventriculus, spleen, pancreas, kidney, heart, lung, small intestine, large intestines and abdominal fat. In the current study, the TNEO weights obtained from chickens fed on the different dietary treatments were in close agreement with the TNEO weights ranging from 431.1g -525.8g reported by Melkamu (2016) which were also not significantly differed (P>0.05) among chickens fed on different dietary treatments.

Partial budget analysis

Output of the partial budget analysis of Sasso chickens fed on different experimental rations is presented in Table 7. The net income was determined based on ingredients' average costs of feed consumption in the treatment, transport, labor, and feed preparation costs and sales of chickens in the respective treatments. Price (ETB/kg) for MSL, WSL, MWS and CR were 9.27, 13.94, 11.48

and 15.38, respectively. Accordingly, the total costs (ETB) incurred to chickens fed on MSL, WSL, MWS and CR were 5273.86, 8006.99, 6773.83 and 9796.60, respectively. On the other hand, net incomes obtained in Ethiopian birr (ETB) were 4602.45, 2441.81, 5441.61 and 1251.27 from group of birds, fed on MSL, WSL, MWS and CR, respectively. This indicated that CR was the most expensive as compared to the other experimental rations.

Table 7. Partial budget analysis of Sasso chickens fed experimental rations.

Parameters	MSL	WSL	MWS	CR
Number of chickens	30	30	30	30
Total amount of feed consumed (kg)	568.68	574.56	590.11	637.14
Feed cost (ETB)	5273.86	8006.99	6773.83	9796.60
Transport cost (ETB)	203.00	214.31	120.84	1274.28
Labor and processing costs (ETB)	668.98	675.80	694.05	1401.71
Total variable costs (ETB)	6145.84	8897.11	7588.72	12472.58
Total income (ETB)	10748.29	11338.92	13033.33	13723.85
Net income (ETB)	4602.45	2441.81	5444.61	1251.27
∆TVC	-6326.74	- 3575.47	- 4883.86	-
∆TI	-2975.56	-2384.93	-690.52	-
∆NI	3351.18	1190.54	4193.34	-
MRR	52.97	33.30	85.86	-

Note: MSL=Maize, Soybean, Lupin, Noug seed cake, Limestone, Common salt and premix: WSL=wheat, Soybean, Lupin, Noug seed cake, Limestone, Common salt and premix; MWS=Maize, Wheat, Soyabean, Noug seed cake, Limestone, Common salt and Premix; CR=Commercial Ration; ETB= Ethiopian Birr ∆TVC=change in total variable cost, ∆TI=change in total income, ∆NI=change in net income, MRR= Marginal Rate of Return

Accordingly, the highest net income was generated from chickens fed on MWS followed by MSL, WSL and CR, respectively. Change in net income (∆NI) was highest for chickens fed on MWS, followed by those fed on MSL and then WSL. The differences in change of net income were due to the differences in feed cost, feed consumption efficiency and selling price of individual chickens in each treatment. The marginal rate of return (MRR) in the present study showed that a unit of ETB cost increment of ingredients per chicken, resulted in additional income (%) of 52.97, 33.30 and of 85.86 for MSL, WSL and MWS, respectively. Among experimental rations, MWS was the most profitable ration based on the consideration of net income (NI) and marginal rate of return (MRR).

Conclusion

Higher BW gain, better feed conversion efficiency, heavier carcass yield as well as the highest net income were obtained from feeding of Sasso chickens with MWS. Even if the CR had higher weight gains and heavier carcass yields, it is associated with highest cost (the most expensive one). Inversely, feeding of Sasso chickens on MSL and WSL had lower weight gains and carcass yields with lower total variable cost as compared to the CR. Thus, by considering weight gains and carcass yield parameters and feed costs, MWS was the most profitable ration with the desirable quantity of carcass from Sasso chickens. Therefore, MWS can be used as an alternative feed source in Saso chicken's ration, without any adverse effects on feed intake, for best growth performance, carcass yield and profitability of Sasso chickens, according to this experiment, instead of commercial ration which is expensive and not accessible.

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Contribution of Authors

- This article is extracted from the MSc thesis of the major author, Geremew Asfaw.
- Hasan Yusuf has contributed in the analysis and interpretation of data in the preparation of the article.
- Gemeda Duguma and Diriba Diba are advisors of the MSc thesis work and involved in the conception, design, analysis and interpretation of data

Conflicts of interest

- We declare that there is no conflict of interest.

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Registration of an Early-Maturing Orange-Fleshed Sweetpotato Variety Named "*Shafeta*" for Production in Ethiopia

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Abstract

Shafeta (13NC9350A-9-3) is an orange-fleshed Sweetpotato variety that was identified from a multi-location trial comprised of a total of 10 genotypes (9 selected and one standard check, Alamura, which is dominantly growing) evaluated across four different locations (Hawassa, Halaba, Koka, and Arba-Minch), in 2021 and 2022 under rain-fed conditions, with the objective to select best variety for high root yield and earliness. In all test environments, Shafeta outperformed the check (Alamura), with a yield advantage of 41.40%. Then, it was promoted to and conducted in a variety verification trial (VVT) along with two standard checks (Alamura and Kabode) at three locations (Hawassa, Halaba and Arbaminch) on one on-station and two on-farms for one more year in 2023. The results of VVT showed that Shafeta outperformed Alamura and Kabode, with yield advantages of 16.20 and 20.80 percentages, respectively. It consistently performed well and gave higher yields in all test environments. Its additional attributes are earliness, an appealing root shape and flowering profusely (for future crossbreeding). Accordingly, the National Variety Release Committee evaluated the performance of the proposed variety based on afro-mentioned traits and allowed its official release. Therefore, Shafeta variety is recommended for cultivation in mid-to-lowland sweetpotato-growing domains in Ethiopia.

Keywords: Food security; Nutrition; OFSP, Release, VVT

Introduction

Sweetpotato [*Ipomoea batatas* (L.)] is one of the most valuable root crops cultivated for various purposes in warm temperate, tropical, and sub-tropical regions of the world (FAO, 2021; Abebe *et al*., 2023). Its production in the tropics ranks fifth and seventh in world production after rice, wheat, maize, potato, barley, and cassava, with more than 119 million metric tons of yield in annual production, according to reports by FAOSTAT (2022). In Africa (excluding northern Africa) in 2021, 4.21 million hectares of land were covered with sweetpotato production, which yielded 29.11 million tons, according to the report by FAOSTAT (2022). Sweetpotato is considered an essential subsistence crop, particularly in East Africa, where it comes in fourth place (FAO, 2021). In Ethiopia, sweetpotato production covered 62,115 hectares during the 2021 Meher season, with a production of 1,598,838 tons (CSA, 2022).

The production of sweetpotato has remained mainly in the southern, southwestern, and eastern parts of Ethiopia (Gurmu and Mekonen, 2019), but it is being expanded to the northern parts of the country as the government of Ethiopia has recently given due attention to the potential of sweetpotato as a strategic crop for food security in an era of climate change (Gurmu *et al.*, 2017; Gobena *et al.*, 2022). According to the various reports (WHO, 2009; Makunde *et al.* ,2017; Ssali *et al.*, 2019; Laurie *et al.*, 2022; Jaing *et al.*, 2024) challenges currently we are facing such as recurrent drought due to climate-induced threats, vitamin A deficiency (VAD), a rapidly growing human population, the susceptibility of exiting sweetpotato varieties to sweetpotato virus disease, and expansions of urbanization, their ultimate causes call to action to develop climate resilient, nutrient dense, high yielding, and early maturing OFSP varieties that are bio-fortified with beta-carotene (BCC), i.e., an importance source of pro-vitamin A for sustainable production and consumption.

Developing, evaluating, and recommending OFSP varieties enriched with BCC along with other desirable traits such as earliness, high root yield, a good level of dry matter content, and tolerance to sweetpotato virus disease is thus crucial for achieving the contribution of OFSP varieties to meet the intended demands. Low *et al.* (2009) reported that just 125 grams of cooked OFSP root can meet a young child's daily vitamin A requirements. In general, an area of 500 m^2 planted with OFSP variety can provide enough Vitamin A to meet the annual needs of a family of five (Low *et al.*, 2017). Thus, it is critical to address all of the aforementioned issues in a systematic approach by generating best variety for sustainable production. Therefore, to contribute to the efforts of ensuring food and nutrient demands of consumers, the *Shafeta* variety was officially released and registered in 2023 as a new OFSP variety based on its outstanding performance.

Materials and Methods

Descriptions of experimental materials and management

Planting materials were initially introduced from Uganda in the form of botanical seeds that resulted from polycross hybridization. Prior to the establishment of the field trial, over 420 botanical seeds were characterized based on various traits (root yield and yield-related traits, SPVD reaction) following descriptors for sweetpotato (IBPGR, 1991). When the disease signs appeared at each evaluation step, genotypes exhibiting disease symptoms were discarded from each family. Finally, genotypes that demonstrated better performances for the traits of interest were advanced to a multi-environment trial to assess their performance across locations. Accordingly, 10 genotypes (nine selected genotypes along with one standard check) were tested in the national variety trial at three locations (*Hawassa*, *Arbaminch*, and *Koka*) over the course of two years (2021-2022). In 2023, genotype G3 (13NC9350A-9-3) later named *Shafeta* was promoted to test along with two standard checks that are grown in sweetpotato-growing areas in VVT.

Study locations, field design and trial management

The variety verification trial (VVT) was conducted on one main research station (on-station) and at two farmers' sites (onfarms), 5 km apart from one another onfarm across each location, namely *Hawassa*, *Halaba*, and *Arbaminch* in Central, Sidama, and Southern regions, respectively, under rain-fed conditions in 2023. The field experiment consisted of *Shafeta* variety (13NC9350A-9-3) and two released varieties, namely *Alamura* and *Kabode* that are currently grown across the country and were included as standard checks for comparison. A randomized block design was used, with farmer sites served as replications. A plot size of 10 m in width and 10 m in length with a total area of 100 m^2 that accommodated 555 vine cuttings per plot for each variety was used in the field experimental establishment. The spacing between rows and plants was 0.6 m and 0.3 m, respectively. Replanting was done after two weeks of planting to replace dead vines to maintain the uniformity of the plant population per plot. Cultural operations such as weeding, irrigation (a shower of irrigation during the plant establishment phase, i.e., within two months after planting), hoeing, and earthening-up were done following the technical manual for production of sweetpotato in Ethiopia (Hawassa ARC, 2015).

Table 1 . List of orange-fleshed sweetpotato genotypes used in the multi-location trials during 2021-2022

S/No	Code	Genotype name	Source of genotypes	Status	Root flesh color
1	G1	MUSG014052-51-5	CIP-Udanda	Advanced line	Orange
2	G2	MUSG014001-3-7	CIP-Udanda	Advanced line	Orange
3	G3	13NC9350A-9-3	CIP-Udanda	Advanced line	Orange
4	G4	CN1448-49-26-12	CIP-Udanda	Advanced line	Orange
5	G5	CN1448-49-28-9	CIP-Udanda	Advanced line	Orange
6	G6	107031-18-5	CIP-Udanda	Advanced line	Orange
7	G7	105413-5	CIP-Udanda	Advanced line	Orange
8	G8	105413-13	CIP-Udanda	Advanced line	Orange
9	G9	CORDNER-15-2	CIP-Udanda	Advanced line	Orange
10	G10	Alamura (Check)	Ethiopia	Released in 2019	Orange

Data collection

Data were recorded on sweetpotato virus disease incidence using a 1-9 scoring method, root yield (t ha^{-1}), number of roots per plant (count), root girth (cm), root length (cm), above-ground biomass (t ha^{-1}), root dry matter content (%), and beta-carotene content (mg100 g^{-1}) based on the standard protocol developed for sweetpotato to record each trait (Gruneberg *et al.*, 2019).

Data analysis

Data collected were subjected to analysis of variance (ANOVA) using SAS software version 9.3 (SAS Institute Inc. 2003). Mean comparison was employed using the least significant differences (LSD) technique, following the procedures suggested by Gomez and Gomez (1984).

The following statistical model was used for the analysis of variance for the data that resulted from the VVT trial.

$$X_{ij} = \mu + T_i + B_j + E_{ij}$$

Where, X_{ij} = the i^{th} treatment effect in j^{th} block, μ = the overall mean, T_i = i^{th} treatment effect (μ_i-μ), Bj is j^{th} block effect (μ_j-μ) and E_{ij} = the effect of i^{th} treatment in j^{th} block. j=1…r, i=1…t.

Results and Discussion

Agro-morphological characteristics of Shafeta and its implications for future use

Assessing the agro-morphological characteristics of a crop variety is an important step towards understanding and documenting the range of traits that are essential for its classification and potential cultivation benefits. It was assessed following the standard descriptors developed for sweetpotato by IBPGR (1991) for traits such as vine pigmentation, leaf shape, growth habit, flowering habit, predominant root skin and flesh colour, and root formation, in order to determine the distinctiveness of *Shafeta*. This approach significantly contributes to describe the variety when demanded.

Desirable agronomic characteristics of a newly released Shafeta variety

The variety *Shafeta* has the following positive features that make it preferable as compared to the currently grown OFSP varieties that were used as checks: Early maturity (ready to harvest in three months), higher root yield, 95% of plants in test environments had a profuse flowering habit that can make it used as a parent for future crossing/hybridization works, a root shape appeals to the market, adapts to low-moisture-stress areas, moderately tolerant to sweet potato virus diseases, has a suitable level of dry matter content; comparable beta-carotene (pro-vitamin A) content with the best-check variety (Table 2).

Table 2. Agronomic and morphological characteristics of *Shafeta* (3NC9350A-9-3)

Adaptation areas	Mid-low land areas of Sidama, Southern, Oromia and other regions with similar agro-ecologies
Altitude (m.a.s.l)	1000-1800
Soil texture	Loam and sandy loam
Seed rate (cuttings/ha)	55,555
Spacing (cm)	
Between rows	60
Between plants	30
Planting date	Rain-fed production: from mid June to Mid August Irrigation: can be planted at any time (if frost free)
Fertilizer (kg/ha)	None
Days to maturity	96-110
Petiole length (cm)	15-24
Petiole pigmentation	Most petioles green, some purple
Growth habit	Non-twining and semi-erect
Leaf color at maturity	Green with purple edge
Shape of central leaf-lode	Eliptic
General outline of the leaf	Lobed
Leaf lobe number	5 to 6
Flowering habit	Flowering Profusely enough, mostly flowering under test environments
Axial leaf pigmentation	Mostly green
Predominant root skin color	Red
Predominant root flesh color	Deep orange
Root shape	Round eliptic
Root diameter (cm)	6 to 7.5
Root length (cm)	14 to 16
Individual root weight (kg)	0.4 to 1.1
Root dry matter content (%)	30
Beta-carotene content (Rich in pro vitamin A)	7.4 $mg100g^{-1}$
Texture of cooked roots	Dry and powdery mouth feeling
Color of cooked roots	Deep orange, appealing to all ages
Taste	Sweet
Overall appearance	Excellent
Crop reaction to sweetpotato virus diseases	Moderately resistant/tolerant
Crop reaction to sweetpotato weevil	Moderately tolerant
Root yield (qt/ha,) Research field	300-360
Year of release	2024
Breeder/maintainer	Hawassa Agricultural Research Center

Root yield performance of Shafeta evaluated under variety verification in 2023

The analysis variance revealed the presence of a significant difference ($p<0.001$) in root yield between the three test environments and among the three varieties evaluated. The *Shafeta* (13NC9350A-9-3) variety had a mean root yield of 36.2 t/ha, outperformed the *Alamura* and *Kabode* varieties (standard checks), which yielded 16.2 and 20.8 t/ha, respectively, (Table 3). The *Shafeta* variety performed consistently across test locations and produced higher yields in all locations, indicating that it is a suitable variety for production in wider areas with moisture shortages.

Table 3. Total root yield (t/ha) performance of Shafeta vs checks Alamura and Kabode tested across three locations (one onstation and two onfarms in each location) in VVT in 2023

Variety	Locations									Mean	
	Hawassa			Halaba			Arba Minch				
	On station	Farmer1	Farmer2	On station	Farmer 1	Farmer 2	On station	Farm er1	Farmer2	Onstation	Onfarm
Shafeta	30.6	29.6	24.7	30.4	28.5	24.6	47.2	34.3	22.2	**36.2**	**27.3**
Alamura	22.7	22.0	17.3	18.6	16.0	17.3	7.4	9.3	12.0	**16.2**	**15.7**
Kabode	18.2	21.1	15.4	16.5	13.5	15.5	27.7	32.4	11.1	**20.8**	**18.1**
Mean	23.8	24.2	19.1	21.8	19.3	19.1	27.4	25.3	15.1		

Performance of the genotypes for resistance to SPVD, number of roots per plant, root girth and root length, root dry matter content, beta–carotene content, days to maturity and flowering ability

Table 4 presents the mean sweetpotato virus disease (SPVD) reaction scores, days to maturity, dry matter content, and flesh color of the varieties. The mean SPVD score of the varieties in VVT ranged from 1.16 (no visible symptom) for varieties *Shafeta* (13NC9350A-9-3) and *Kabode* to 2.60 (some leaves showed virus-like symptoms) for *Alamura* variety. This shows that *Shafeta* showed a high level of tolerance/resistance to SPVD reaction under test environment (Abebe et al., 2023). The root girth trait varied from 5 cm for Kabode to 6.38 cm for *Shafeta*. In addition, a maximum root length of 14.60 cm was recorded for *Shafeta* whereas a minimum of 14.24 cm was observed for Kabode (Table 4). When selecting sweetpotato genotypes, it is important to consider root traits like length and girth. Suitable genotypes include those with early bulking and roots of appropriate size, i.e., root length no longer than 15 cm, smallest no less than 10 cm, and root-girth/ diameter at least greater than 4 cm; this is practically what most consumers stated as their ideal root sizes, and it is now incorporated in the target product traits profile (Targeted traits profile document, unpublished).

The root dry matter content (DMC) of the variety is the main factor influencing the adoption of OFSP varieties, especially among consumers in East African countries, including Ethiopia. In order to meet consumer preferences in the humid tropics, Mwanga et al. (2016) and Tumwegamire et al. (2016) state that an OFSP dry matter level defined as medium in the range of 24% -28% and a high dry matter content >28% are required.

In this study, DMC trait ranged from 28.2% for the *Kabode* to 31.0% for the *Alamura* variety, and *Shafeta* variety has 30.0%. A DMC content of more than 25% is acceptable in orange-fleshed sweetpotatoes. Although all three varieties evaluated in VVT showed a significant level of DMC, *Shafeta* variety had a dry matter content that was extremely similar to the positive check variety *Alamura*. It is a desirable level because Ethiopian farmers prioritize OFSP varieties with high DMC in their selection process (Gurmu *et al.,* 2017; Gurmu and Mekonen, 2019).

Another key trait of the OFSP variety is its beta-carotene (BCC) content, which functions as a precursor to vitamin A and is well-known for its potential to effectively intervene in areas where vitamin A deficiency is prevalent (Burgos *et al.,* 2009; Low *et al.,* 2017; Gurmu, 2019). In this study, Shafeta had comparable levels of BCC with one of the positive checks Alamura, with values of 7.46 and 7.76 mg/100 g, respectively, which is in line with the range of most favorable genotypes, which may be defined as orange/intermediate orange ranging from 5.08 to 8.36 mg/100 g on a fresh weight basis using the standard procedure developed by Burgos *et al.* (2009). Genotype evaluation for days to maturity is important in areas with irregular/erratic rainfall to ensure food availability in a short period of time, as well as to allocate that land for future crop planting. In this situation, genotypes that mature quickly, within 3 to 4 months, are preferred (Gurmu, 2019). The *Shafeta* variety (13NC9350A-9-3) had the shortest days to maturity (96-105 days), while *Alamura* had the longest (120-150 days). Early maturing genotypes are vital in today's ever-changing climate to provide food and nutritional security, particularly for smallholder farmers, while also providing options for intercropping and relay cropping to boost production and productivity.

Table 4. Combined mean performance of varieties for SPVD reaction, root yield-related traits, DMC and BCC evaluated in VVT in 2023.

Variety	SPVD (1-9)	NRPP (count)	RG (cm)	RL (cm)	DMC (%)	BCC (mg /100g)	DTM (days)	Flowering habit
Shafeta	1.16	5.17	6.38	14.60	30.00	7.46	96-105	Flowering Profusely enough
Alamura	2.60	4.17	5.54	14.40	31.00	7.76	120-150	Mostly not flowering
Kabode	1.33	2.8	5.00	14.24	28.20	5.46	120-126	Mostly not flowering
Mean	1.70	4.04	5.64	14.41	29.73	6.61	112-127	

Where, SPVD = Sweetpotato virus disease (1-9 scale, 1 = immune, 9 =Susceptible, hence 1-3 = resistant, 4 – 6 = medium and 7-9 = susceptible); NRPP=Number of roots per plant; RG=Root girth; RL=Root length; DMC=Dry matter content; BCC=Beta-carotene content on fresh weight basis; DTM = Days to maturity

Figure 1. Performance of *Shafeta* at one of the test locations in VVT (2023)

Conclusion

Development of early maturing crop varieties is important to meet human food and nutrition demands within a short production window. More crucially, global climate dynamics require the development of a resilient OFSP variety that can adapt to changing environments and shocks, which could assist efforts to improve food security and nutrition. The present study was designed with an emphasis on the development of orange-fleshed sweetpotatoes for early maturation in order to ensure sustainable production and food security under climate change. Thus, *Shafeta* variety was evaluated in a variety verification trial along with two currently growing OFSP varieties as standard checks (*Alamura* and *Kabode*). The result of the variety verification trial revealed that *Shafeta* variety showed outstanding performance over standard checks in terms of root yield, early maturation, tolerance or resistance to sweetpotato virus diseases, and adaptability to low moisture-stress areas. Additionally, *Shafeta*, with its semi-erect and non-twining growth habits, as well as its early maturity, can provide an opportunity for intercropping and relay-cropping systems. It also has an appealing root shape (the most market-preferred characteristic), which can also make it suitable for the export market. Therefore, *Shafeta* variety has been released and recommended for cultivation in the mid-to-lowland sweetpotato growing domains in Ethiopia.

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8. **Acknowledgments**. Acknowledgments given in a separate section immediately following the results and discussion. The donors should be properly acknowledged and the grant numbers (or project codes) should be included in the acknowledgement.

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3. References and citation

1. Inline citation

Single author: (Abbot, 1925)

Two authors: (Abdul Rahman and Ellis, 2019)

More than two authors: (Akpo *et al*. 2021)

2. Reference

Journal Article

Abbot, W. S. 1925. A method of computing the effectiveness of insecticides. J. Econ. Entomol. **18(2):265–267. (include "doi" if any)**

Abdul Rahman, S., and R. Ellis. 2019. Seed quality in rice is most sensitive to drought and high temperature in early seed development. Seed Sci. Res. **29(4):238–249. (include "doi" if any)**

Book

Akpo, E., C. O. Ojiewo, I. Kapran, L. O. Omoigui, A. Diama, and R. K. Varshney (eds.). 2021. Enhancing Smallholder Farmers ' Access to Seed of Improved Legume Varieties Through Multi-Stakeholder Platforms. Springer Nature Singapore Pte Ltd, Singapore.

Chapter in a book

Bernanke, J., and H. Köhler. 2008. The Impact of Environmental Chemicals on Wildlife Vertebrates. Pages 1–47. *In :* D. M. Whitacre(ed.) *Reviews of Environmental Contamination and Toxicology*. Springer Science + Business Media, LLC 2008.

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