Advances in Rice Research and Development in Ethiopia

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Advances in Rice Research and Development in Ethiopia

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Preface

Boosting agricultural production and productivity through enhanced availability and use of improved agricultural technologies has been one of the core agricultural sector development strategies in Ethiopia. In this regard, a sustained support for the development of the Agricultural Research System was made since its formal start in late 1950s. The establishment of new research centers and/or expansion of the agricultural research coverage in terms of commodity have been made over years.

The Fogera National Rice Research and Training Center (FNRRTC) as one of the federal research centers of the Ethiopian Institute of Agricultural Research (EIAR) was officially established in Woreta Town of south Gonder zone of Amhara Region and the center's facilities were inaugurated on Nov 15, 2018.

Linked with the occasion of the inauguration of the FNRRTC's facilities, an international conference was organized with the main objectives of documenting the status of rice research and development covering areas related with genetic improvement, crop management, pre and post-harvest technologies, processing and utilization, technology promotion and seed system, socioeconomics and, partnership in rice research and development.

This book presents the deliberations made during the stated international conference held from Nov 15 to 16, 2018 in Woreta at the vicinities of the FNNRTC by invited authors within the framework of documenting the current status, challenges and opportunities and the way forward in respective areas along with experiences as lessons learnt. The authors were invited based on their experience in the respective fields by the organizing committee/editors.

The editors would like to acknowledge everyone who directly or indirectly contributed in organizing the conference and the publication of this book. We wish to acknowledge duly EIAR, EthioRice project of Japan International Cooperation Agency (JICA), the Agricultural Growth Program (AGP II), MEDA (Mennonite Economic Development Associates) project, the Future Agricultures Consortium (FAC) through its Agricultural Policy Research in Africa (APRA) project, International Rice Research Institute (IRRI), AfricaRice, and AgroBIG (Ethio-Finland Agribusiness Induced Economic Growth) for their contribution in the conference and the publication of the book. We are grateful to all reviewers. We thank also all conference participants for their critical inputs.

Editors

Foreword

Agriculture plays significant role in the Ethiopian economy. The sector recruits the majority of the working force and serves as the source of food for the increasing human population and feed for the livestock sector. The country is endowed with ample genetic recourses, which would be useful for tapping genes for genetic improvement and develop suitable technologies for the diverse eco systems. In spite of the fact that agriculture has been practiced for many years in Ethiopia, the traditional way of farming, characterized by low use of improved technologies, inputs, and mechanization, is dominant. In relation to the diverse ecological niches, several biotic and abiotic factors and limited available technological options constrained crop production and productivity. In addition, introduction of new pest is threatening production of a number of crops. These factors have contributed for the lower agricultural productivity, which has resulted for prevalent food insecurity.

Ethiopia has an overarching policy framework called Agriculture Development Led Industrialization (ADLI), which aims to increase productivity of the crops and secure the food demand of the country, produce export commodities and fetching foreign currency, and expected to produce raw materials for the emerging agro processing industries. In the past decade, agricultural productivity has shown an increasing trend, which was associated to the increasing use of improved technologies such as improved varieties, management practices and fertilizer. However, the growth has not been commensurate with the growing population and there is still considerable gap between the demand and what is being produced. Despite the huge potential, the country is importing agricultural products to fill the deficit of which wheat and rice are the dominant ones. A number of factors are contributing for the disparity including lack of improved technologies and lack of integration among the different actors along the value chain are of the major challenges to bring transformation in the sector.

Rice is globally an important food crop and becoming an economically important crop in Ethiopia due to the shift in feeding habit and being integrated with the traditional food products. As rice is a recent introduction, it requires emphasis to strengthen research and development endeavors thereby reduce the limited foreign currency to import rice to satisfy the growing local demand. EIAR has been undertaking research on rice in collaboration with national and international partners. Fogera National Rice Research and Training Center established with the support of the Ethiopian and Japanese governments aiming at strengthening the research capacity to enhance rice production and productivity through the use of innovative approaches and new technologies. EIAR would like to thank those contributed for establishment of the center.

This book is the result of the past years research undertakings of the rice research program and partners engaged in rice research and development presented on the workshop organized to inaugurate the research and training center. It documents the major achievements on genetic improvement, management practices, extension, mechanization, and rice market and policy issues. It is highly expected that it will serve as a reference for future research and development interventions. I would like to congratulate the authors for the contributions to the scientific achievements and, reviewers and editors of the manuscripts to meet scientific standards and for their dedication to compile the book.

Mandefro Nigussie (PhD), Director General of EIAR

Message from JICA

Representing Japan International Cooperation Agency (JICA) Ethiopia Office, I hereby congratulate the publication of the book based on the deliberations of the first National Rice Research and Development Conference organized to mark the inaguration of Fogera National Rice Research and Training Center.

During the last few decades, rice has become a promising crop that contributes to food security and better livelihood of farmers in Sub-Saharan Africa. Today the region is a major destination of global rice export thanks to the growing market demand along with urbanization and population growth. As the market potential became evident, African countries have faced challenges on satisfying the consumer's appetite, both in volume and quality, with domestic rice productions rather than depending on imported rice from Asian countries.

Japan, the country that grows and consumes rice as a traditional staple food, has invested in the rice sector in Africa since prior to the millennium through JICA's cooperation programs. With accumulated knowledge and technologies of rice production such as plant breeding, seed production, pest control, and mechanization, JICA has played an essential role in advancing rice production in Africa and delivered impacts including popularization of NERICA varieties across the region.

In 2008, under a joint initiative of the Alliance for Green Revolution in Africa (AGRA) and JICA, Coalition for African Rice Development (CARD), a consultative platform was established with an aim to double rice production in Sub-Saharan Africa by 2018 from 14 million ton to 28 million ton. It was JICA's strong manifestation of commitment for long-term rice sector development in Africa not only by its own efforts but also by mobilizing resources and opportunities of other stakeholders to encourage better-coordinated development intervention to the sector.

Because of ten-year engagement by member countries and development partners, it was confirmed in 2018 that the CARD's objective was successfully accomplished. This year, at the 7th Tokyo International Conference on African Development (TICAD7) in Yokohama, Japan, CARD will officially launch the second phase that aims to further double rice production in the region by 2030 from 28 million ton to 56 million ton. This ambitious figure is not a naïve objective; it rather presents the target that should actually be achieved in order to fulfill the ever-growing demand for rice consumption in Africa.

Ethiopia joined CARD in 2009 and has formulated the National Rice Research and Development Strategy of Ethiopia (NRRDSE) in 2010, which paved a way for promotion of rice research and development including the establishment of National Rice Research and Training Center (NRRTC) in Fogera that now plays a role as a hub of rice research network in Ethiopia. The long time partnership between Ethiopian Institute of Agricultural Research (EIAR) and JICA brought about a momentum for formation of technical cooperation project to NRRTC in 2015, and today the EthioRice project provides face-to-face technical support from Japanese experts to Ethiopian researchers that compliment infrastructure development of NRRTC.

It is my great pleasure to witness the expansion of rice research in Ethiopia today led by pioneer rice researchers of EIAR. In the near future, rice will become a vital part of food life of Ethiopian people, thus it is necessary to prepare for feeding the future population through constant efforts. JICA is, and will be, pleased to work together with Ethiopian rice researchers for food security and farmers livelihood improvement of the country.

Makoto Shinkawa
Chief Representative, JICA Ethiopia Office

Rice Research for Development in Africa: Experience from AfricaRice

Harold Roy-Macauley
AfricaRice

Introduction

Rice is now a strategic commodity for food security in Africa. More than 750 million people in sub-Saharan Africa (SSA) consume it. Demand is growing faster than for any other food staple because of changes in consumer preferences, rapid urbanization, and population growth. Rice is the single most important source of dietary energy in West Africa and the third most important for Africa as a whole. Rice imports in SSA will continue to grow as rising demand outpaces increases in rice production. Despite significant increases in rice production in several African countries over the last few years, the continent still imports nearly 40% of its rice requirements. According to the FAO, in 2014, rice deliveries to Africa were estimated at 14.5 million tons, representing an all-time record and accounting for 34% of global imports.

The Africa Rice Center (AfricaRice) was established in 1971 by eleven West African countries, as the West African Rice development Association (WARDA) with the aim of increasing local rice production to close the widening gap between rice supply and demand. Results delivered by WARDA over the years led to its recognition as an important organization that could contribute to boosting the rice sector not only in West Africa but also in other African countries that were interested in rice production. This was marked by relevant research products such as varieties, methods and practices, tools and policy options delivered, which were contributing to the development of the rice sector in member countries and other countries from the other regions of Africa joining as members of WARDA to benefit from its results. The recognition of the importance of the research work carried out by WARDA, led to it being accepted as one of the 15 Centers of the CGIAR in 1987. The growth in membership, with requests form countries from all over Africa, led to a change in name in 2009 to AfricaRice.

AfricaRice considers the rice sector development as a potential engine for economic growth across the continent. To realize this vision it developed a ten-year strategic trajectory captioned "Boosting Africa's Rice Sector: A research for development strategy 2011–2020," which was approved by its council of Ministers in 2011. The objective of this strategy is to increase the productivity and profitability of the rice sector whilst ensuring the sustainability of the farming environment. The plan is implemented through four crosscutting continental rice research and development programs as follows:

- Genetic diversity and improvement;
- Sustainable productivity enhancement;
- Policy, innovation systems and impact assessment; and
- Rice sector development.

The Plan continues to deliver research products and services, which are relevant to developing the rice sector in countries. In addition, with the aim of accelerating the process of rice self-sufficiency and reducing the rising import bills of African countries, AfricaRice is implementing special strategic initiatives, which focus on increasing the performance of the rice value chain through strengthening involvement especially of the private sector.

Historical accounts of rice R4D

Strategic vision

AfricaRice is a pan-African research for development intergovernmental association of 27 African member states (Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Côte d'Ivoire, the Democratic Republic of Congo, Egypt, Ethiopia, Gabon, The Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Madagascar, Mali, Mauritania, Mozambique, Niger, Nigeria, the Republic of Congo, Rwanda, Senegal, Sierra Leone, Togo, and Uganda). Its highest governing body is the Council of Ministers of Agriculture or Ministers of Scientific Research of its member States. At the same time, it is also one of the 15 Research Centers of the CGIAR. AfricaRice has a Board of Trustees (BoT) like other CGIAR-supported Centers, which is composed of nominees from member states and non-member states. The BoT ensures that AfricaRice management conforms to the resolutions of the Council of Ministers and to the CGIAR guidelines on governance and management in implementing, the Center's approved 2011–2020 Strategic Plan (AfricaRice, 2011). This dual position, with strong African ownership, on one hand, and international support through the CGIAR, on the other hand, makes AfricaRice a unique center among the international agricultural research centers.

AfricaRice considers the rice sector as a key entry point to contributing to poverty alleviation and food security in the continent, knowing well that Africa has the natural resources—land, water, and human—to produce enough quality rice to feed its own population and, in the long term, export to other regions, thereby generating export revenues. For AfricaRice, rice sector development is therefore a potential engine for economic growth across the continent and represents the Center's strategic vision.

AfricaRice realizes this vision through its strategic and center development plans. The ten-year strategic trajectory captioned "Boosting Africa's Rice Sector: A research for development strategy 2011–2020," was approved by its council of Ministers in 2011. The development of this ten-year strategic trajectory was achieved through several interactions with partners and a rigorous priority-setting exercise that spelled out benefits per region, rice ecosystem, and discipline. In effect, the Strategic Plan aims specifically at increasing the productivity and profitability of the rice sector whilst ensuring the sustainability of the farming environment.

These specific objectives are achieved through research, development, and partnerships. The projected impact of the research outlined in the strategy was determined through an ex-ante impact assessment that looked at the contribution of the envisaged research against a baseline scenario without the 2011–2020 research agenda. The productivity-enhancing R&D activities presented in the strategy should, as a direct result of increased production of better-quality rice and lower prices on the market across the continent, deliver by 2020 the following:

- An additional 14.5 million tons of paddy rice;
- Declined rice imports by two-thirds to 4.6 million tonstons; and
- Overall, some 11 million people, comprising members of rice farming households and rice consumers, lifted out of poverty (on the basis of a US$ 1.25 poverty line in 2005) by the end of 2020.

Strategic trajectory

The Center's activities are being implemented through the following four crosscutting continental rice research and development programs:

- Genetic diversity and improvement;
- Sustainable productivity enhancement;
- Policy, innovation systems and impact assessment; and
- Rice sector development, with these programs being led by program leaders.

These programs focus on the following seven Priority Areas (PAs)

- Conserving rice genetic resources and providing smallholder farmers with climate-resilient rice varieties that are better adapted to production environments and consumer;
- Improving rural livelihoods by closing yield gaps and through sustainable intensification and diversification of rice-based systems;
- Achieving socially acceptable expansion of rice producing areas, while addressing environmental concerns;
- Creating market opportunities for smallholder farmers and processors by improving the quality and competitiveness of locally produced rice and rice products;

- Facilitating the development of the rice value chain through improved technology targeting and evidence-based policy-making;
- Mobilizing co-investments and linking with development partners and the private sector to stimulate uptake of rice knowledge and technologies; and
- Strengthening the capacities of national rice research and extension agents and rice value-chain actors.

AfricaRice is facilitating the implementation of its strategic trajectory through the following instruments

- The CGIAR Research Program on rice agri-food systems (RICE) is the second phase of the CGIAR Research Program on rice (2011-2016), which was also known as the Global Rice Science Partnership. RICE is led by six organizations with international mandate and a large portfolio on rice three members from the CGIAR—the International Rice Research Institute (IRRI, the lead institute), Africa Rice Center (AfricaRice), the International Center for Tropical Agriculture (CIAT)—and three other leading international agricultural agencies: Centre de Cooperation lnternationale en Recherche Agronomique pour le Développement (Cirad), L'lnstitut de Recherche pour le Développement (IRD), and the Japan International Research Center for Agricultural Sciences (JIRCAS). AfricaRice leads the RICE activities in Africa and mobilizes global knowledge to respond to the challenges and opportunities in the priority areas that form the rice R4D strategy for Africa.

- The Rice Task Force mechanism is an important vehicle for research collaboration, especially with and among the national agricultural research and extension systems (NARES). It enables research and development partners working together to reach critical mass in key thematic areas in the rice sector, and aims to reduce the time lag between the development and the release of new rice technologies across the continent, pooling scarce human resources and fostering a high level of national involvement. A major thrust of the Task Forces is building the rice research capacity at the regional and national levels. The Task Forces focus on the following six themes: breeding; agronomy; postharvest & value addition; mechanization; policy; and gender. The Breeding Task Force for instance seeks to accelerate the development of rice varieties through continent-wide varietal evaluation of nominated elite lines from AfricaRice and international and national partners.

- A network of Rice Sector Development Hubs, which are geographical areas where research products and services and local innovations are integrated across the rice value chain to achieve development outcomes and impact. These Hubs represent key rice ecologies and different market opportunities across African countries and are linked to major national or regional rice-development efforts to facilitate broader uptake of rice knowledge and technologies. AfricaRice is facilitating the establishment of innovation platforms (IPs) within these Hubs, which are expected to help identify rice value chain actors, examine weak links in the chain, improve linkages among actors, and identify business opportunities to improve market outcomes in the Hubs.
- AfricaRice's R&D activities are conducted in collaboration primarily with national agricultural research institutes (NARIs) as well as with academic institutions, advanced research institutes, development agencies, farmers' organizations, non-governmental organizations, and donors.

Staff and activities

The headquarters of AfricaRice moved from Liberia to Côte d'Ivoire in 1988, to Benin in 2005, and back to Côte d'Ivoire in 2015. The Center embarked on streamlining its workforce and facilities in 2017. In particular, new and rehabilitated facilities in the areas of biotechnology, grain quality and genetic resources (genebank and seed unit) came online at the main research station in M'bé, near Bouake, in Côte d'Ivoire. With about 22,000 accessions, AfricaRice holds the largest collection of African rice in the world. Rice genetic resource is a key to developing new products that address emerging challenges of the rice sector in Africa. The genebank, which has been upgraded to world-class standards, will become the 'Africa rice biodiversity center' in the future.

AfricaRice pursues a decentralized strategy, with activities located in several research facilities across the continent. Currently, AfricaRice staff members are located in Côte d'Ivoire and in AfricaRice Research Stations in Benin, Liberia, Madagascar, Nigeria, and Senegal.

Overview of rice R4D in Africa

An overview of rice research for development in Africa, with emphasis on the period 2009 - 2013 is presented in the book "Realizing Africa's Rice Promise" (Wopereis *et al.*, 2013). The book provides a comprehensive overview of Africa's rice sector and rice research and development activities. It also indicates priorities areas for action to realize Africa's rice promise. It provides information on Africa's rice economy and discusses trends in rice demand and supply before and after the 2008 rice crisis. The book gives detailed information on the development of rice varieties, designed for farmers' growth environments and market demand, and presents a systematic, continent-wide, and product-oriented approach to rice breeding in Africa to enhance farmer access to new varieties specifically designed for his or her rice-growing environment and market demand. It discusses Africa's highly diverse production environments and opportunities to enhance rice productivity in a sustainable manner, tackling the major yield- and productivity-reducing and -limiting factors.

The book also presents the various opportunities and challenges related to the development of sustainable and profitable rice value chains in Africa. It reviews the status of agricultural mechanization in SSA and presents mechanization options that could make a difference along the rice value chain. It discusses gender roles in rice farming in SSA, emphasizing the importance of women in rice farming and focuses on dimensions of rural learning in Africa, with a special focus on rice farmers. The book gives an estimate of the potential impact of rice research on income and poverty in SSA over the next 10 years and presents a list of priorities for action to boost Africa's rice sector in a sustainable and equitable manner.

This paper will focus on the overview of rice research for development in Africa during the period since 2013. The focus is on AfricaRice, but contributions from many other institutions and partners are acknowledged. The paper highlights some of the major institutional and technological challenges encountered and achievements obtained since 2013. Detailed information on a wide range of R4D activities conducted in partnership in Africa can be found in the AfricaRice annual reports for 2014 to 2017.

Partnerships

Partnerships have always been and will continue to be central to the implementation of the AfricaRice research for development strategy. From its core structure as an Association of African member states to collaborating in the field with farmers involved in research for development activities, it is partnerships all the way. The Center has a Board-approved partnership strategy, which provides guidance for developing partnerships at all levels. All partnerships entered into by AfricaRice are established to deliver the Center's objectives, defined in the Research for Development Strategy 2011–2020.

Capacity development

Capacity development has been an integral component of AfricaRice's mandate since its creation. The year 2016 marked the initiation of major changes in the Center's capacity development program, with a focus on reaching all the major value-chain actors across the continent. A Capacity Development Unit was created that will not only ensure the usual strengthening of the capacity of rice value-chain actors through training, but will also put emphasis on measuring the impact of training on the development of the rice sector.

The AfricaRice Regional Training Center, at Boudiouck, Saint-Louis, Senegal, was inaugurated in 2016. It offers short technical courses for various rice value-chain actors (including those from the private sector and NGOs), national researchers and extension agents, and can host groups of trainees for extended periods. Courses envisaged to be delivered there include season-long on-site training for young researchers and extension agents, and vocational training for youth who want to engage in rice business. The facilities are open to use by other organizations of the agricultural sector when not in use by AfricaRice.

In 2016, the Green Innovation Center for Benin, established by the GIZ-funded 'Grüne Capacity development Innovationszentren in der Agrar- und Ernährungswirtschaft' project (GIAE; ‘Green innovation centers for the agriculture and food sector’) in Cotonou, AfricaRice Benin Country Office, was inaugurated. It is designed to serve the whole agricultural sector in Benin. The Green Innovation Center, working together with the AfricaRice Knowledge Management Unit, trained graduates from Université d’Abomey-Calavi and agricultural technical colleges in Benin to become service providers for various agricultural technologies and services, using the AfricaRice Framework for Innovation in the Food Sector.

A new joint venture is the e-learning platform, managed by a staff member seconded from the Natural Resources Institute (NRI), as part of a project funded by GIZ. The platform hosts online courses from the AfricaRice Knowledge Management Unit in conjunction with the Green Innovation Center. Again, the platform targets the wider agricultural sector rather than just rice.

AfricaRice continues to host individual students for studies related to professional training and degrees from BSc to PhD.

Group training courses, held in target countries, are increasingly conducted within the rice sector development Hubs. This shift of emphasis has seen a huge increase in the number of direct beneficiaries.

Achievements

Research by AfricaRice and its partners has contributed significantly to boosting the rice sector in terms of policy advice, technical information and knowledge, capacity development and support to the development of rice markets and value chains in sub-Saharan Africa.

The new AfricaRice Regional Training Center, Boudiouck, Saint-Louis, Senegal.

The technologies rolled out by AfricaRice include the following:

Varieties

Over 200 improved varieties released in the last 25 years in Africa, including:

- A new generation of high-performing varieties released under the brand “Advanced Rice for Africa (ARICA)” for various ecologies (including varieties with resistance to the Rice Yellow Mottle Virus, parasitic weeds [*Striga* spp. and *Rhamphicarpa fistulosa*], or bacterial diseases, and others that tolerate drought, submergence, or salinity); the popular NERICAs for upland and lowland ecologies.
- NERICAs are planted on more than 1.4 million ha across Africa, showing positive impacts on rice productivity and farmers’ livelihoods.
- Sahel varieties and hybrids for irrigated farming. High-yielding Sahel varieties cover more than 80% of the Senegal River Valley.
- Some 50 new highly adapted hybrid lines have shown 15–20% yield advantage (paddy yield 10–13 t/ha), many of which mature early, have desirable grain quality and good milling recovery. Four of these lines were grown in large demonstration plots in farmers’ fields in Senegal, of which AR051H and AR032H were selected by farmers for release. In 2017, the aromatic hybrid rice variety, AR051H, was released in Senegal.
- In 2017, two submergence-tolerant lowland varieties - FARO 66 and FARO 67 (with yields of over 4 t/ha after nearly 2 weeks of submergence) – were released in Nigeria where 22% of rice production was lost in 2012 due to flooding.
- NERICA 4 (tolerant to drought, low phosphorus), is the most widely adopted upland variety, and is grown in Burkina Faso, Ethiopia, Mali, Nigeria, Senegal, Tanzania, Sierra Leone, Zambia, Uganda, etc.
- NERICA-L-19 is the most widely adopted lowland NERICA, grown in Benin, Burkina Faso, Liberia, Mali, Nigeria, Sierra Leone, Togo, Uganda, etc. NERICA-L-19 is adapted to both irrigated and rainfed lowlands and tolerant to iron toxicity.
- NERICA 10, NERICA 17 and SCRID090 from Madagascar were found to be resistant to *Striga*.
- Three NERICA and four NERICA-L varieties showed resistance to bacterial blight, both *Xanthomnas oryzae pv. oryzae* and *X. o. pv. oryzicola*.
- A third RYMV resistance gene was recently discovered and 12 highly resistant *Oryza barthii* accessions identified. We also have a pair of genes for durable resistance to blast.

AR051H was released in Senegal in 2017

Table 1: Update on Advanced Rice for Africa (ARICA) varieties (1 to 18)

Name	Ecology	Appealing point	Nominated in	Release (seed production)
ARICA 1	Rainfed Lowland	High Yield	Mali	
ARICA 2	Rainfed Lowland	High Yield	Mali & Nigeria	Guinea Conakry
ARICA 3	Rainfed Lowland	High Yield	Mali & Nigeria	Mali
ARICA 4	Upland	Drought	Uganda	Uganda
ARICA 5	Upland	Drought	Guinea Conakry Uganda	Guinea Conakry Uganda
ARICA 6	Lowland	Fe toxicity	Guinea Conakry Ghana Côte d'Ivoire	Guinea Conakry
ARICA 7	Lowland Irrigated	Fe toxicity tolerance	Burkina Faso Ghana	Burkina Faso
	Lowland Irrigated	Cold tolerance	Senegal	
ARICA 8	Lowland Irrigated	Fe toxicity tolerance	Guinea-Conakry Burkina Faso Côte d'Ivoire	Burkina Faso Guinea-Conakry
Name	**Ecology**	**Appealing point**	**Nominated in**	**Release (seed prodn)**
ARICA 9	Lowland Irrigated	Cold tolerance	Mali Senegal	Mali
ARICA 10	Lowland Irrigated	Cold tolerance	Mali Senegal	Mali
ARICA 11	Mangrove	Salt tolerance	Gambia	Gambia
ARICA 12	Irrigated Lowland	High yield	Senegal	Senegal
ARICA 13	Irrigated Lowland	High yield	Senegal	
ARICA 14	Upland	Drought tolerance	Cote d'Ivoire	
ARICA 15	Upland	Drought tolerance	Cote d'Ivoire	
ARICA 16	Upland	Drought tolerance	Benin, Burkina Faso, Mali	Benin, Mali
ARICA 17	High Elevation	Cold tolerance	Ethiopia	Ethiopia
ARICA 18	Rainfed Lowland	High yield	Cote d'Ivoire Guinea Conakry	Guinea-Conakry

Table 2. Lowland varieties released in 2017

Country	Total	Origin
Ethiopia	4	AfricaRice (2); CIRAD Madagascar (2)
Ghana	6	AfricaRice (1); Nigerian NARS (1); Ghanaian NARS (4)
Nigeria	2	AfricaRice (2)
Senegal	6	AfricaRice (3); CAAS (1); IRRI (1); Nigerian NARS (1)

CAAS, Chinese Academy of Agricultural Sciences; CIRAD, Centre de coopération internationale en recherche agronomique pour le développement; IRRI, International Rice Research Institute; NARS, national agricultural research system.

Crop management technologies and decision support tools

A suite of technological options and decision-making tools have been developed, such as:

- Location-specific integrated crop and resource management options; for example, Good Agricultural Practices (GAPs);
- Locally-adapted mechanization options (e.g., ASI thresher-cleaners, mini combine-harvesters, mechanical and motorized weeders, rice parboilers, gasifier stoves, and bricketing machines for converting rice husks for cooking/parboiling);
- An Android app-based decision-support tool called ‘RiceAdvice’ to provide each farmer with recommendations tailored to his/her own circumstances;
- An Android app-based decision-support tool called ‘Weed Manager’ to help African rice farmers find the most effective and cost-efficient weed management strategies;
- RiceAdvice has been tested in farmers’ fields in more than 9 countries. Results in irrigated conditions in Mali, Nigeria and Senegal showed an average of 1 tonne per ha yield advantage over farmers’ practice. Field testing is ongoing in Ethiopia, Madagascar and Rwanda;
- Smart-Valleys, a low-cost, participatory and sustainable approach to developing inland valleys for rice-based systems. Major advantages mentioned by farmers are increased water retention in their fields, less risk of fertilizer losses due to flooding, and increased yields. Participating farmers achieved significant yield increases - from less than 2 t/ha previously to more than 3.5 t/ha. In addition, their gross revenue had increased by about 80%. The approach is also being scaled out in Liberia and Sierra Leone and there are plans to do same in Côte d’Ivoire and Ghana;
- AfricaRice has prepared maps for four abiotic stresses (drought, cold, iron toxicity, and salinity) to assist development agents in targeting stress-tolerant varieties to those countries and areas that need them (van Oort, 2018); and
- Appropriate agronomic practices for controlling *Striga* and *Rhamphicarpa* include late sowing combined with short-duration cultivars for *Striga*; and early sowing combined with long-duration cultivars for *Rhamphicarpa*. Rotation and/or intercropping with leguminous

crops and zero tillage, combined with direct seeding into crop residues suppresses *Striga* growth.

A training session on use of the ASI thresher–cleaner in Kano, Nigeria

Policy options

Options for improving rice sector policies, information on farmers' technology needs, yields, input use, rice markets, and farm-level effects of technologies to support national and regional rice strategies. AfricaRice has provided technical backstopping to African countries to develop their national rice development strategies (NRDS) under the framework of the Coalition for African Rice Development (CARD). AfricaRice has, made broad policy recommendations geared toward boosting the rice sector in Africa. The recommendations involve a three-pronged approach

- Increase local production through both area expansion and productivity enhancements;
- Increase the competitiveness of local rice vis-à-vis imported brands. This means growing rice cultivars with similar characteristics to imported rice, in terms of shape, head-rice ratio, texture, and swelling capacity; introducing improved harvesting and postharvest facilities, equipment, and innovations especially for milling, cleaning and grading; and then differentiating quality local rice from imported brands via branding, labeling, and marketing;
- AfricaRice, national governments, and regional institutions need to identify policy instruments to finance upgrading of the domestic rice sector on a country-by-country basis; and
- The Center plays a key role in advising scientists and policy-makers in member states on critical rice production and marketing issues. For example, the rice shortage and price crises that began in late 2007 were predicted by the Center and member countries were alerted through the Council of Ministers.

Seed system

AfricaRice is also involved in development-oriented projects, such as seed systems development and capacity strengthening, which are important engines to out-scale technologies in, around, and beyond the Hubs. For example, in 2015, over 7000 tons of seeds of new varieties were produced across 11 countries under the STRASA project. As part of the CGIAR Partnership for Scaling of Improved Seed Varieties Program, AfricaRice and its partners initiated a ‘Seed scaling technical assistance project’ in Ghana, Liberia, Nigeria and Senegal, funded by the United States Agency for International Development (USAID).

Innovation systems

Innovation platforms (IPs) were initiated in the rice Hubs of 11 countries (Benin, Côte d’Ivoire, Ethiopia, Ghana, Madagascar, Niger, Nigeria, Senegal, Sierra Leone, Tanzania and Uganda under the ‘Multinational CGIAR support to agricultural research for development on strategic commodities in Africa’ (SARD-SC) project funded by the African Development Bank (AfDB), which was launched in 2013. These IPs already improved the productivity and turnover of stakeholders throughout the rice value chain by 2014, less than 2 years into the project. The example of the two IPs of the Glazoué Hub in Benin is given in Table 3 (AfricaRice, 2015).

Table 3. Changes brought about by innovation platforms (IPs) in the rice value chain (2014)

Stakeholder	Before IP	With IP
Farmers/producers	3.5 t/ha	5.0 t/ha
Women parboilers (Bante IP)	1.0 t paddy/month (during harvest)	10 t paddy/month (during harvest)
ESOP processor (Bante IP)	1.5 t paddy/day (during harvest)	5 t paddy/day (during harvest)
Processors (SONAPRA millers)	500 t paddy (during harvest)	1000 t paddy (during harvest)
Traders	Sold 15 t/month	Sold 20–25 t/month
Mini rizerie (Glazoué IP)	25% increased income	50% increased income
Extension (CARDER)	Reached 100 rice farmers	Reached 250 rice farmers
NGO (MRJC)	Reached 4 villages	Reached 9 villages
Microfinance (CLCAM)	FCFA 10 million	FCFA 21 million
Policy (local government)	Cotton + maize as cash crop	Cotton + maize + rice as cash crop

Rural learning

AfricaRice is helping to package knowledge from research into formats that can be diffused on a wide-scale. It has in place a system for face-to-face interaction (innovation fairs), virtual access (Rice eHub), and user-adopted tools (rice radio programs, mobile phone technology and farmer-to-farmer video) to disseminate and communicate the potential and use of its scalable technologies through development partners, such as non-governmental organizations, extension systems and with support from private-sector companies.

AfricaRice developed its own series of farmer-to-farmer videos in the form of its RiceAdvice collection on DVD (Table 4). They use simple language and clear visuals, and incorporate lessons from participatory learning and action research (PLAR). They are ideally suited to build human and institutional capacities within the rice sector in

Africa. These videos are available in English, French and in more than 30 African languages.

Table 4: Farmer-to-farmer videos

Title	Authot(s)
Seed sorting: Spotted seed means diseased seed.	Rural Development Academy, Bogra and TMSS, Bangladesh.
Flotation: Seed sorting by flotation.	Rural Development Academy, Bogra and TMSS, Bangladesh.
Seed drying: Well dried seed is good seed.	Rural Development Academy, Bogra and TMSS, Bangladesh.
Seed preservation techniques: Rice seed preservation.	Rural Development Academy, Bogra and TMSS, Bangladesh.
Land preparation.	Africa Rice Center, Benin and Institut de l'envrionnement et de recherches agricoles (INERA), Burkina Faso.
Seedbed: The seedbed.	Africa Rice Center, Benin; Institut d'économie rurale (IER), Mali; Intercooperation – Sahel; Institut de l'environnement et de recherches agricoles (INERA), Burkina Faso; and farmers in Niona, Zamblara, Zéguesso and Zianso, Mali.
Transplanting: Rice transplanting	Africa Rice Center, Benin; IER, INERA, Intercooperation – Sahel, Burkina Faso; and farmers in Niona, Zamblara, Zéguesso and Zianso, Mali.
Rice weed management: Effective weed management	Africa Rice Center, Benin; IER, INERA, Intercooperation – Sahel, Burkina Faso; Institut sénégalais de recherches agricoles (ISRA), Senegal; Société d'Aménagement et d'Exploitation des terres du Delta et des vallées du fleuve Sénégal et de la Falémé (SAED), Senegal; and farmers in Niona, Zamblara, Zéguesso and Zianso, Mali.
Soil fertility: Managing soil fertility for healthy rice.	Africa Rice Center, Benin; IER, Mali; Intercooperation – Sahel; farmers in Niona, Zamblara, Zéguesso and Zianso, Mali; and farmers in Ouèdèmè, Benin.
Improving rice quality.	West Africa Rice Development Association.
Parboiled rice: Cashing in with parboiled rice (2005)	WARDA; Sasakawa Global 2000; Songhai; and INERA, Burkina Faso.
Striga management. 21 min 26 s. (2015).	Africa Rice Center, CIRAD, FOFIFA, an GSDM. Available in five languages - English, French, Malagasy, Swahili and Portuguese on AfricaRice YouTube site.
Multi-stakeholder platforms to promote collective action in inland valleys	Africa Rice Center
Using the rotary weeder in lowland rice	Africa Rice Center
Safe and correct use of herbicides	Africa Rice Center

Impact assessment

A recent study by AfricaRice of trends in rice yields in 24 African countries, based on United States Department of Agriculture (USDA) data from 1960 to 2012, shows that an impressive 74% of total harvested rice area has witnessed positive rice yield growth rates of greater than 35 kg/ ha/ year. Factors such as high per-capita rice consumption, greater proportions of rice-growing area under irrigation, and number of new varieties available to farmers are related to accelerating rice yield growth rates at national level.

The study indicated that raising rice yields requires continued investment in rice research on technology development, development, or rehabilitation of irrigation schemes, and upgrading of the existing rainfed lowlands to irrigated or partially irrigated systems.

An analysis of the impact of improved rice varieties on poverty reduction and food security in Africa, based on a metadata analysis of published impact assessments for the period 2000–2014 and data from farm household surveys undertaken in 2014 in 16 countries (Arouna *et al*., 2017), revealed the following

- The adoption of NERICA varieties by farmers had increased from 10% in 2000 to about 53% in 2014, with a huge leap observed after the 2008 rice crisis. Due to a combination of increasing number of adopters and increasing area planted with improved varieties by adopters, the area under NERICA varieties grew from 200,000 hectares in 2006 to 650,000 ha in 2008 and then to 1.4 million ha in 2014;
- Rice yields, however, decreased over time, which could be attributed to the fact that rice farmers still save grain as seed for the next season. Since rice is a self-pollinating crop, it ‘breeds true’; however, the viability of saved grain used as seed decreases over time;
- Income generated from the sale of rice has increased over time, due to increasing grain price on the market and farmers increasing the areas cultivated with improved varieties. The income of farmers who have adopted NERICA varieties increased from an average of US$ 25 per capita in 2004 to $58 per capita in 2014; and
- The adoption of improved rice varieties has resulted in about 1 million households (corresponding to 8 million people) in 16 countries in Africa having been lifted out of poverty and 0.9 million households (corresponding to 7.2 million people) are no longer food-insecure.

Challenges

- With high food and fuel prices predicted to last well into the coming decade, relying on imports is no longer a sustainable strategy. Climatic conditions in particular are affecting the rice production of major rice exporting countries, such as India and this may affect world market rice in the future;
- Big gap exists in average rice yields between the world and SSA. In 2018, difference in global and SSA yields increased to 2.29 t/ha with global yield at 4.51 t/ha and SSA yield at 2.22 t/ha;
- A recent analysis by AfricaRice shows that rice consumption in SSA has been increasing faster than production. Between 2008 and 2018, rice consumption increased by 81% while production increased by 55%;
- Rice self-sufficiency has decreased from 61% to 52% in SSA countries between 2008 and 2018. Only three countries (Tanzania, Madagascar, and Mali) have more than 85% of self-sufficiency; and

- Based on the annual growth rate of rice consumption over the last decade of 6.2%, consumption is projected at 49.25 Mt in 2025 in SSA. To realize rice self-sufficiency up to 2025 in SSA countries, production must increase by an annual growth rate of 16.5%. This requires increased investments and strong policy measures.

An important lesson learned from the food crisis that hit Africa in 2008 was that relying on the world market for the supply of rice to Africa is a very risky, expensive and unsustainable strategy. To reduce food insecurity, avoid an economic downturn and the risk of civil unrest, there is an urgent need to further increase rice production in Africa.

Future direction/issues

The Center remains committed to grow as a pan-African center of excellence for rice research, development, and capacity-strengthening. We draw on worldwide expertise and knowledge to develop solutions to challenges across Africa. Our strategic priorities for effective research delivery will include the following;

- Strengthening partnerships;
- Developing the capacity of rice value-chain actors including youth and women;
- Improving access to markets for rice producers;
- Raising the profile of rice science in national policy agendas; and
- Increasing investments in research for development for the rice sector in Africa.

While continued investments by countries have led to improvements in their rice sectors, there is indeed an urgent need to accelerate the process if Africa is to reach its target dates of attaining rice self-sufficiency. Three key actions initiated for this are considered to be promising

Continental Investment Plan for Accelerating Rice Self-Sufficiency in Africa (CIPRiSSA): The CIPRiSSA studies are now being used to target investments in the rice sector. Moreover, a Support System for Accelerating Rice Self-Sufficiency in Africa (SSARSSA) has recently been established within the AfricaRice Strategic Support Unit (under the Director General’s Office) to sustain the momentum of CIPRiSSA and its expansion to other countries.

Pan-African breeder and foundation seed capital in M’bé: The establishment of a Pan-African breeder and foundation seed capital, of the most popular improved rice varieties on the market, was initiated in M’bé by AfricaRice and its partners. It is based on a public–private partnership business model that the Center has developed to enhance the rice-seed value chain. The model creates synergy between agribusiness and smallholders to meet the seed needs for food security and generate value addition and jobs for youth and women.

Rice Value Chain Resource Center (RVC-RC): The RVC-RC is a framework that integrates research goods and services into rice-producing communities in countries, within the context of an orchestrated rice value chain (linking, through contractual arrangements the various actors of the rice value chain, including banks, insurance brokers and viable markets), and which will result in the creation of business entities and employment; especially for youth and women. This model will also help every actor of the rice value chain in Africa recognize the importance of research in contributing to the establishment of lucrative businesses. AfricaRice needs to position itself so that it could be recognized as an institution that can do relevant and meaningful development work to boost member countries' rice sectors and economies. This means that the research that has to be done should strictly respond to the demands of member states, their investments in AfricaRice's research in particular, and its sustainability in general.

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Towards Rice Self-sufficiency in Africa

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Introduction

Rice constitutes a major part of the diet in numerous countries in sub-Saharan Africa (SSA). It is the single most important source of deity energy in West Africa and the third most important staple for the whole of Sub-Saharan Africa. Average per capita consumption across SSA is about 40 kg/ year, with large variation between countries, reaching over 140 kg per annum in Madagascar. In recent years, the demand for rice continued to increase at a rate exceeding that of any other food staple in the region. Production also continued to increase, but at slower rate than that of the demand. About 25% of the improvement in production before the 2007-2008 food crises was attributed to yield increase and 75% to expansion in harvested area. Following the food crises, significant increase in production was observed, reaching a rate of 8.4% between 2007 and 2012 (2013 USDA), with yield improvement contributing 70% of the increase in production and area expansion contributing 30%; showing clear signs of adoption of modern technologies, including high yielding varieties and better production methods.

The growth in consumption however, also continued to increase, reaching 7.9% between 2007and 2012 in SSA (2013 USDA), effectively absorbing any improvement in overall production. As a consequence, the imports stayed high, at about 11-12 million t/year costing the region an average of about US$ 5 billion annually, which is a huge burden on local economies. More recently, the gap between production and demand continued to widen, and in 2018, the region imported about 16 million tons of milled rice at a cost of US$ 6 billion.

Several factors are contributing to this increase in demand and the inability of rice producing countries to bridge this gab to reduce dependence on imports. In most countries, rainfed farming predominates, covering about 75% of the rice area, with unreliable water resources and prevalence of several abiotic stresses including drought, floods, and soil problems. Most of the varieties being used by farmers in both rainfed and irrigated systems are old, and sometimes landraces are still being used by farmers because of their resilience and quality characteristics, but with very low yields. Traditional production, post-harvest and processing systems still persist leading to low revenues for farmers because of labor costs and poor quality of their produce. Agricultural policies are mostly old and need to be amended to provide conducive conductions for faster progress and growth, learning from countries currently leading in rice industry, especially in South and Southeast Asia.

Genetic improvement of rice varieties together with sustainable natural resources management intensification, and expansion of farming lands will allow food production to largely keep up with the increasing demands in Africa. This is mostly accomplished in Asia since the 1970s as a consequence of the green revolution. Even in Asia, the rate of genetic gain in rice production seems to have decelerated considerably compared with rates achieved during the "Green Revolution", a trend mostly attributed to diminishing investments in agricultural research, and continued use of old breeding and seed dissemination methods (Ismail and Atlin, 2019). Modern approaches for developing and delivering modern rice varieties combining tolerance of abiotic stresses and improved yield potential are critical to enhance productivity of farming systems in Africa, and to help adapt to climate change adversities while meeting the increasing demands for food.

Marginal or less favorable lands are becoming increasingly important as potential sources for food because of the steady loss of productive lands to urbanization and industrial use, besides the continued deterioration of arable lands due to irrational use. Both steady increases in productivity in favorable areas as well as investment in improving rice resilience through improving tolerance of abiotic stresses are required to enhance and maintain food security. Development of less favorable areas for food production requires substantial investment in crop improvement and agronomy to make these lands economically and sustainably productive and to halt further degradation. Africa still host significant resources of land and water that can provide sufficient food for the continent. While over 130 million hectares of inland valleys in SSA are suited to rice only about 10 million hectares are currently in use with lower yields of 1-2.5 t/ha. These yields can at least be doubled and area expanded to increase production and halt or at least significantly reduce imports.

Opportunities for rice sector development in Africa

Replacing old cultivars with resilient, high yielding modern varieties

Development of modern high yielding rice varieties that are responsive to input use started in the 1960s in Asia. The successful adoption of these varieties, together with the use of chemical fertilizers triggered the Green Revolution in South and Southeast Asia and in Latin America. These varieties, together with their succeeding improved versions were subsequently adopted, leading to considerable increase in yield and productivity, compared with older cultivars being used by farmers (Evenson and Gollin 2003). Adoption of these varieties was mainly confined to favourable areas in Asia, where water resources are assured either through irrigation or favourable rainfall conditions. Several rounds of breeding and variety replacement cycles delivered improvements in traits that were deficient in the initial Green Revolution varieties, including resistance to insects and diseases, and better grain quality, leading to more adoption and productivity (Evenson and Gollin 2003; Ismail and Mackill 2014). However, these gains in favourable areas did not benefit farmers in unfavourable environments, especially in areas affected by drought and floods, soil problems including excess salts, nutrient deficiencies or toxicities and cold and heat stress. This is because the breeding programs that led to the Green Revolution focused mainly on improving grain yield under optimal conditions. For these reasons, Sub-Saharan Africa did not benefit from the Green Revolution. New resilient varieties that can tolerate particular weather or edaphic stresses while maintaining higher yields and market quality are needed for SSA.

Several abiotic stresses are dominating the region like drought, submergence, salinity; iron toxicity and cold. Varieties that tolerate these conditions were developed for Asia (Ismail et al., 2013; Ismail and Horie, 2017). Locally adapted varieties are also being developed through IRRI breeding programs in collaboration with AfricaRice and national partners in SSA. Over twenty of these varieties were recently released in several countries in East and South Africa, and some more released in West and Central Africa through the Africa-wide Rice Breeding Taskforce (ARBT). The knowledge attained in recent years in developing and disseminating stress tolerant verities in Asia can be used to develop locally adapted high yielding varieties that meet local consumer and market preferences.

Diseases are major problems in SSA; an extensive network of hotspot evaluation need to be established to capture resistances to local biotypes and effectiveness of particular genes. Grain quality is important for acceptance of new varieties and for the development of niche markets and trade in the region. Developing resilient varieties with high yield and quality will provide assurance to farmers to invest in inputs and take better care of their crops, with the target of at least doubling productivity. Development of new breeding material is being streamlined using modern breeding approaches. Once developed under current climates, these varieties will be more resilient and will reduce risks of crop failures and significantly enhance and uphold productivity. Besides, these varieties will provide entry for system-based improvements through good agronomy, mechanization, postharvest and value addition, including better processing, packaging, branding, and marketing.

Breeding programs in SSA need to be restructured to introduce new breeding technologies to shorten breeding cycles and to enhance grain yield gains in farmers' fields (van Ginkel and Ortiz 2018; Ismail and Atlin 2019). In developing countries, breeding programs are still using old techniques and approaches that are limiting the rate of genetic gain delivered to farmers. Breeding cycles are too long, and selection pressure for yield in multi-environment trials is usually inadequate. Breeding strategies are now being optimized in public rice breeding programs in Asia to increase genetic gains by shortening breeding cycles, increasing selection pressure for yield, phenotyping through high throughput, data digitization, and the application of molecular markers in forward breeding (Thomson et al., 2010; Atlin et al., 2017).

All national breeding programs in SSA need to be modernized and equipped with modern technologies to speed varietal development to replace old varieties. A modern breeding facility is now available in Burundi as part of the IRRI Regional Crop Improvement Hub, to provide sufficient breeding material for the region. This facility produces 3.5 generations per year and is being used as a training facility for breeders in east and south Africa. The services of this facility will soon be extended to the whole of SSA. Our objectives are to modernize all breeding programs especially in the regional centers of excellence in Africa and in selected national programs where there is potential for capacity and need for large breeding programs.

Crop and system management strategies

Proper agronomic and crop management strategies need to be in place to narrow the current and future gaps between attainable yields and farmers' yields These gabs are considerably wide in SSA and can reach over 40% in some countries. Management principles should be geared toward maximizing the potential of the new varieties and maintain their performance within efficient and sustainable production systems that optimize resource use and augment farmers' revenues. Considerable gains could be made by replacing the current traditional production systems with modern agronomic principles and practices. Several areas need to be tackled for further improvements

- Increase the use of agrochemicals: Soils in SSA are mostly depleted and degraded, yet, fertilizer use is extremely low, averaging 10 kg/ha (compared with over 70 kg/ha in Asia) and fertilizers are expensive and scarce. Adoption of the Maputo Declaration across the region could make fertilizers more available and affordable to farmers, by allowing free movement across boarders and omitting tariffs. Herbicide and pesticide use is also limited because of scarcity and expense. Private sector involvement should facilitate access to agrochemicals and the provision of information on their proper and safe use.
- Introduction of mechanization options suited to smallholder farmers: Most rice farmers in SSA are still using traditional methods for land preparation, planting, weeding, and other production practices, limiting the production area, increasing production cost, and reducing productivity and quality of the produce. Most cultural practices, harvest, and post-harvest operations should be mechanized. Experience and expertise from Asia should be mobilized for this purpose, to fast-track rice mechanization- from land preparation to harvest and post-harvest activities. Private sector should be engaged to provide proper equipment and services and ensure local possibilities for repair and maintenance. Replacing traditional production systems with modern technologies will essentially reduce costs and relief labor "bottlenecks", improving product quality and market value for smallholder farmers and households.
- Reduce postharvest losses: there are still considerable losses in quantity and quality during postharvest, estimated between 15 and 25% across SSA. Options like cost effective dryers such as flat beds and solar bubbles are relatively inexpensive for smallholder farmers and communities. Hermetic storage facilities developed by IRRI are effective for preserving the quality of seeds and grains. There is a dire need for better and accessible mills at villages' level, together with benefit, including branding and packaging, which can be facilitated through public-private sector arrangements.
- Production systems need to be intensified by exploring potential for multiple rice crops per year, and also diversified by introducing additional crops adapted to local conditions and

have good market value. This will help sustain the production system, reduce farmers' risk by providing multiple options, and enhancing their nutritional diet and income.

Improving seed systems to deliver quality seeds

Rice seed systems are lagging behind other crops in both Asia and Africa, and large proportion of farmers still rely on their saved seeds, resulting in considerable losses to productivity and quality. Effective seed systems in SSA need to be developed and strengthened. The public sector seed systems are relatively weak in Africa compared with that in Asia, which had evolved over several decades, wherein the role of private sector becomes indispensable. The informal seed sector—farmers saved seed and farmer-to-farmer exchange—still dominates the rice seed system in SSA, covering over 80% of the seed share, and leading to poor quality and low yields. Strategic intervention are required to develop effective seed systems through strengthening the private sector role and catalyzing enabling policies for public-private and private sector engagements. These policies should facilitate faster varietal replacement and trigger gradual ascendency of an effective formal seed systems to provide affordable high quality seeds of resilient varieties, timely for farmers. Most seed companies in Africa are engaged in marketing seeds of high value crops for better returns. The marginal profit from inbred rice seed sector is relatively small because of the dominance of the informal sector and the slow adoption of hybrid rice varieties. Stronger public-private sector partnerships are necessary to ensure far-reaching networks along the value chain, supported by effective capacity strengthening, awareness and communication and monitoring programs to empower this partnership.

National and regional enabling policies

Reforms of agricultural policies and regulations, both at national and regional levels are necessary to safeguard enabling environments for sound progress, effective knowledge sharing and germplasm exchange and to support inclusive growth. Over the last decade, most South Asian countries were successful in enforcing policy reforms that support faster varietal testing and commercialization. Some governments are providing incentives, credit and input subsidies, assuring minimum price for farmers, and providing support for marketing. Some countries also agreed to exchange information and varieties as part of "seed without boarder" agreement, now ratified by 7 countries in south and Southeast Asia. The main highlights of this agreement are free exchange of information and data on germplasm evaluation. Varieties released in one country can immediately be released in similar ecologies in other countries without further testing, saving 3-4 years of evaluation. The agreement is now extended to include all food crops including cereals vegetable and oil crops, and commercial crops like oil seeds, fiber crops and sugarcane. The agreement is also open to all countries in Africa to join Asian counties, with considerable benefits from access to modern varieties and knowledge. Reform in rice seed sector policies in SSA is a requisite for rice sector transformation.

Research leaders and policy advisors in SSA are calling for rapid access to reliable sources of information for foresight and decision-making, especially when dealing with issues related to national food security and when responding to natural calamities and human-influenced disasters. The progress in policy reforms in South Asia can easily be transferred and repeated in SSA, by catalyzing reforms in local and regional policies to accelerate commercialization of new agricultural products align relevant partners in the seed chain and improve farmers' access to markets. Attention should be made to ensure gender inclusiveness, with women constituting over 70% of the smallholder farmers in SSA. Support is needed to provide opportunities for youth to engage in modern farming by providing services and knowledge to minimize migration to urban areas and abroad. Our ultimate goal is to develop resilient and sustainable rice-based production systems that produce sufficient nutritious food in the face of worsening climate and shrinking natural resources. Availability of inputs, especially fertilizers and other agrochemicals, credit and marketing channels that assure rewarding prices will support the growth of rice sector in Africa.

Capacity strengthening and resource mobilization

Unlike Asia, rice is relatively young in SSA, and only recently, it became a priority crop in some countries. Enhancing the capacity for rice research, validation, and delivery is therefore, indispensable for rice sector development. A critical mass of trained post-graduate researchers is required to lead local activities and programs of partners, including governments, private sector, and NGOs. Technical staff could be trained through short-term hands-on courses to fill in the current gaps in expertise or through degree training in pertinent areas. Lack of trained personnel coupled with the continued drain of skilled technicians by the vast number of development and relief agencies in Africa will continue to be a challenge unless major emphasis is placed on capacity building to saturate these needs and assuring attractive compensations by government programs to retain and empower trained staff.

Exchange of visits and working tours for officials, heads of private sector companies, NGOs and farmers' organizations engaged in rice sector will help in awareness and provision of support. IRRI established an education department (IRRI Education) with the intention to meet the specific training and education needs of partners by providing tailored and general courses in skills related to rice sector development. Sufficient resources need to be mobilized through governments, funders and development agencies in partnerships with IRRI, AfricaRice and other CG centers, and to capitalize on South-South and South-South and Triangular cooperation to secure funding and provide effective means for knowledge, successes and material sharing between countries across SSA and with Asia.

Way forward

Most rice producing countries in SSA participated in the first phase of the efforts coordinated by the Coalition for African Rice Development (CARD) and developed their ten-year National Rice Development Strategies (NRDS), with the aim of doubling rice production. The success in this phase was substantial and the region produced over 26 million tons in 2018, reaching over 90% of the target. The second phase of NRDS is now being developed by member countries, with the objective of bringing production to 56 million tons of milled rice by 2030. With our mandate of supporting African countries to achieve self-sufficiency, IRRI, AfricaRice, and other stakeholders will be working jointly with governments to meet this target. Particular emphasis will be placed on capacity strengthening of the national programs' infrastructure for research and technology transfer and for building the skills of personnel through degree and non-degree training. Measureable impact is expected through modernizing current production technologies and by strengthening the value chain and improving access to markets to increase farmers' income and profit.

Rice seems to have several advantages over other cereals in Ethiopia - higher yields and suitability for preparation of several national dishes, together with availability of natural resources for significant expansion. With the government recognition of rice as the 'millennium crop', this places rice as a strategic crop for food security, poverty reduction and for enhancing farmers' income. The country retains large resources for expanding rice production. Recent estimates suggest that 5.6 million ha are highly suited to rice farming in rainfed ecosystems and 3.7 million ha in irrigated systems. The current national strategy outlines a plan to increase rice production by 8- fold, to reach 3.95 million tons. With these targets, Ethiopia is well placed to play a major role towards reaching rice self-sufficiency in SSA.

The prospects for growth of rice sector in SSA are enormous, to satisfy local needs and even turn some countries into net exporters. This will meet the growing demand within the continent and further contribute to international trade, especially for middle eastern countries. Replacing existing varieties with new high-yielding types that resist local biotic and abiotic factors, together with modern production practices have the potential to at least double rice production in the region. Opportunities for area expansion also exist in most countries, as in Ethiopia, Mozambique, Tanzania, and Kenya. Together with supporting policy reforms, SSA could significantly narrow the gap in food supply and significantly reduce imports.

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Historical Perspectives and Trends of Rice Research and Development in Japan

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Introduction

Rice is the single crop, which has supported the life of the Japanese as a principal food for years. Some 1,500 years ago, tax revenue from passage rice took the leading part of the national revenue, which indicates the profound relationship of rice with state formation (Fujino, 1993a). The importance of rice in the food supply is not also different at present. The unique collaboration of rice producers in the cultivation process of the rice: planting, harvesting, land reclamation, maintenance of irrigation channels, has created continuous engagement of community members that has gradually resulted in the formation of villages, which can be called rice village society. The festivals and the religions are deeply related to rice cultivation, which can be highly associated with Japanese culture and lifestyle (Fujino, 1993b).

There are various views about the start of rice cultivation in Japan. Some indicate that rice was brought to Japan from South China in the Jomon period about 3,500 years ago. Others report that it was dryland rice that was introduced first and paddy rice production started to spread to all parts of Japan during the Yayoi Era about 2,600 years ago. However, since Yamato Court during the 3rd to 7th century, rice cultivating was placed as a basis of state operation, which gave emphasis for flood control and development of a new paddy field in all parts of Japan (Oishi, 1973). Rice production increased substantially from the middle of 16th century to the end of 18th century. In the Edo Period, an effort was made for the development of rice cultivation. The middle of the 16th century, the production was 2.7 million tons of rice from 1.5 million ha of planted acreage. At the end of the 18th century, it increased to 3.9 million tons of rice from 3.0 million ha of planted acreage (Kikuchi, 1958).

The production declined due to shortage of labor after the Second World War. Self-sufficiency rate 100% was achieved after 1967 (MAFF, 2019) as a result of the maintenance of a production foundation and the production promotional activity such as breeding. The rice consumption after the Second World War kept decreasing because of westernization of eating habits, and it is 59.8 kg/per/year in 2017 (Official Statistics of Japan, 2007). The production and the consumption of the rice in Japan have changed by the situation of the social economy. Agricultural policy, agricultural technology development, and the state of the agri-community have also changed with this change.

This paper presents the main public measures put in place to enhance rice production and productivity in Japan as a lesson for Ethiopian rice sector development. The paper is structured into four main parts. The first part presents the major rice related policies, followed by the rice research and development efforts, the third part documents the trend in rice production and productivity, and the last part presents the main lessons from Japanese rice research and development efforts.

Rice sector development policies

Japanese agricultural administration after the Second World War can be roughly divided into three phases: after the end of the war to Agricultural Basic Act establishment, (1945-61); the agricultural administration development which is down Agricultural Basic Act (1961-80); and Development of internationalization and establishment of Basic Law on Food, Agriculture and Rural Areas (1980-99). The embodiment of a policy based on the idea of Food, Agriculture and Rural Areas Basic Act (1999-2008).

The first phase is the period after the end of the war from 1945 to 1961, when the Agricultural Basic Act was enacted, for social democratization and food production increase, democratization in an agricultural district by an agrarian land reform, purchase of tenanted land by a government, a large number of independent farmers were born by selling a farmland to other farmers. The following part presents the key policies/laws that were enacted and effected in different periods to enhance and regulate rice production in Japan

Staple Food Control Law (1942-1969)

The law ensured rice and wheat as main food crops for national securement of food, sets what need to be done to ensure the stability of supply and demand and stability of the national economy. It also presented the control measures for adjustment of the supply and demand and price and the indirect and direct regulation mechanisms covering the whole country.

Agrarian Reform (1946-1950)

The reform covered farmland property system, which almost abolished the landlord system and prohibited payment of land rent using agricultural products that created emergence of land owning farmers. Farmland committees established following the reform were responsible to monitor and approval land transfers from landlords to farmers.

Agricultural Seed Act (1947)

The Act ensured the registration of varieties along with ownership protection of the registered varieties. The act allows the developer of varieties in the area of marine, agriculture and forestry can receive registration following the fulfillment of requirements.

Agricultural extension system (1948)

It was in 1948 that a formal agricultural extension system started to improve the performance of agriculture and advance the improvement of a farmer's livelihood.

Cropland Act (1948)

This act presented the protection in farmland and serves as a fundamental law about land right relations. It determines whether the farmland is suitable for cultivation and sets measures than need to be increase of agronomic performance. It was established facilitate the outcome of postwar agrarian land reform (dissolution of a landlord system and protection in farmland and cultivator's status stability).

The second phase was the period from 1961 to 1980 when the agricultural administration development was set up. Agricultural Basic Act was also established in 1961 for agriculture to ensure differential correction of the productivity with other sectors and maintaining the living standard of the farmers with the one of the remarkable economic growth after the end of the war. Expansion of the production with increased demand for livestock, fruit, and vegetable, etc. and promotion of the scale expansion were part of the act, which ensured that farmers can secure income levels, which balances with another economic sector esp. industry.

Main Crop Seeds Act (1952-2018)

This act was about the protection of seed and its stable supply for rice, soybeans, and wheat, which were considered major important crops.

This was enacted to ensure availability of seed of the crops to farmers because, the private seed businesses were not engaged in supplying seeds of the crops due to the limited commercial viability. Recognizing this, the act mandated prefectural governments to provide quality seeds of the crops. The government, however, abolished the act in 2018 under the Agricultural Competitiveness Enhancement Support Program aiming to privatize variety development and seed supply thus lower the production cost of the crops.

Act on Promotion of Agricultural Mechanization (1953-2018)

The primary objective of the act was to promote mechanization for productivity improvement. Research and development, practical trial production, testing and provision of fund for those activities were stipulated in the act. Shared use was promoted through low interest loan. The act also encouraged local governments to support in training and provide guidance for introduction of machineries.

Agricultural Basic Act (1961)

This was a law designed to advance modernization of Japanese agriculture by agricultural structure improvement policy and investment of large agricultural machinery to boost farm productivity and to rise of income of farm households and to correct income disparity with other economic sectors.

During its third phase starting 1980, Japan achieved a significant change by rapid economic growth and remarkable development of internationalization.

Food, Agriculture and Rural Areas Basic Act (1999)

The Basic Act for Food, Agriculture, and Rural Areas was enacted in 1999. The basic act and the subsequent five-year plans developed and implemented aimed at ensuring food security, improving food self-sufficiency rate, and attaining rural multiple functions including environment sustainability to be fully exerted through sustainable agricultural development and rural development. The basic plan has been revised every five years.

Rice Research and Development

Agricultural research system

It was in 1903 that full-scale breeding of rice started in Japan. The Japanese rice research targets four major climate zones, which are frigid, cold, temperate, and warm in north and south along with a research network by different mandate zones.

National research institutes are responsible for advanced basic research and developing new breeding technologies in addition to preservation, management, and provision of rice genetic resources. National research institutes cooperate with a prefecture research centers in the mandate zone and shares management of a genetic resource, exchange and use in the development new varieties with official approval of the unique quality and the applicability of the genetic material. The brand name for developed product/variety, which meets the demands in the mandate zone, has been developed originally at a prefecture research center.

Ministry of Agriculture Fishery and Forestry (MAFF) take the lead in public breeding of Japanese rice. Moreover, a national institute and prefecture research centers perform systematic cooperation in exchange of genetic resources and breeding material, and in the official approval system.

The national and prefectural research centers works for development and establishment of cultivation technologies such as planting, fertilization, disease control, weeding control, water management, harvesting, and post-harvesting along with development of improved rice varieties. They also carry out the extension services to farm households. National budget is allocated for the rice development project by the national institute and dispatch cultivation specialists to a prefectural research centers to support the breeding process and the promotion of rice production. The main research objectives of the prefectural research centers are breeding new varieties for agro-ecological suitability and for quality to fulfill market demands; development of fertilizer recommendation suitable for the different varieties and cultivation technique; and engagement in technology promotion through different extension activities.

In 2017, there were 5 national institutes and 270 prefectural research centers in Japan. There were 8,400 researchers in these research centers and 730 researchers work on rice research and development activities (MAFF, 2017).

Achievement of the research

The policy for rice breeding at the national experimental station was put in place in recognition to the need to address the challenges of the rice in Japan as a modern state. Rikuu 123 was a typical variety as a research output developed at a national agricultural experimental station in Akita Prefecture in 1921 (MAFF, 2017). The variety was a hybrid with high cold tolerance that saved farmers, who suffered from frequent cold-weather damages. The improved rice varieties developed by national research centers so far reached 400 varieties. There are more than 300 varieties released by prefectural centers, with 700 improved rice varieties. At present about 300 varieties are grown nationwide (MAFF, 2017).

Since 1955, protected semi irrigated rice nurseries were established as a case of technical innovation of rice cultivation (NARO, 2019). Damage by cold weather was severe at a northern Japanese district. Farmers found that the rice early planting prevents damage from cold weather. Through cooperation with a prefectural researchers, in addition to early planting, covering the rice seedbed with an oil paper to keep warm was found important to address the challenges of cold weather. Later, the covering material was changed from oilpaper to vinyl. This new technology was able to advance rice planting and expanded a northern limit of rice cultivation as well as was strong in protecting damage from cold weather and ensuring an increased income for farmers. cultural chemicals by an unattended helicopter has been put to practical use.

In the 1980s, block rotation became popular due to the reduction policy of production acreage of rice. Part of paddy lots is concerted to other crops in rotation in few year cycles. History of rice variety breeding is about 150 years old, and many varieties have been bred.“Koshihikari” developed in 1956 has maintained the country's largest cultivation area and production for more than 60 years. Planting of varieties with good taste such as “Koshihikari” and “Sasanishiki” sharply increased from around 1975. Due to vulnerability to disease and lodging, water management, split nitrogen application, and milling technology for fine quality grains were developed and promoted. Rice cultivars that strengthened cold resistance typified increased by the Great Cool Damage in 1993.

In the area of rice mechanization, the introduction of diverse types of machines contributed in reducing the labor demand for rice cultivation. A power tractor begins to spread after 1950, and plowing and paddling work were shifted to the power machine from animal power. Similarly, miniaturized tractors spread after 1955, which were used for plowing and soil preparation work. A power sprayer for pest control spread. Power ripper appeared starting from 1953, and a binder from 1965. The rice-planting machines, for which development and the spread were late, were introduced since 1965. Rice dryer was developed during the same period. After 1970, different medium-sized machines were introduced in performing from rice planting to rice reaping, threshing and drying. Following the introduction of agricultural machineries with large and high performance, working time has been further reduced. The average working hours per 0.1 ha in rice production was 174 hours in 1991, out of which transplanting accounted 27 hours. MAFF supported Farmer Research Groups and private companies to advance development of rice transplanters. The first commercial rice transplanter was on sale in 1964 and quickly spread throughout the country by mid 1980s. The machine had reduced the transplanting time to 3 hours/0.1 ha, which was one ninth of the time spent in 1960s (Hokimoto, 1998).

The irregular shape of farmland was adjusted to improve the efficiency of farm operation by agricultural land improvement project. The project improved and installed a flume, irrigation canal, drainage facilities, and farm road that have contributed to the improvement of productivity. The agricultural land improvement project promoted a large-scale land improvement, land reclamation, and promoted the adoption of chemical fertilizer, and various measures.

Challenges in technology development

The main challenges of rice cultivation after the Second World War in Japan are related to aging society with a low birth rate and various demands from the product market. The decrease in the number of farmers and a growing proportion of seniors and a successor problem of rice farmers has become conspicuous. It has become the biggest challenge for the maintenance of village functions as rural community depending on agriculture. There is also a downward trend in the consumption of the rice due to changes in consumer's taste, the spread of noodles and increased demand for meal with bread. On the other hand, there is an increased demand for processed rice as rice powder to make processed food, making liquor and increased demand for animal feed.

In recognition to these challenges, the MAFF is working further in different ways to ensure cost reduction and adaption to the observed trends. In this regard, scale expansion of farm management activities through promotion of corporation system and accumulation/ aggregation of farmland for the next-generation farmer; supporting the introduction of large farm machineries; and development of new and modern machineries, which uses GPS and the robotics technology.

Production and productivity trends

Overall, rice production and productivity in Japan has shown consistent increase over years. MAFF has been putting in place different measures to improve rice production and productivity after the Second World War. These include promotion of seed production and varietal protection, supporting the increase in number of land owing rice farmers, protecting farmland, implementation of a large-scale agricultural land improvement project, developing improved varieties of rice, developing cultivation techniques to enable stable production, support use of chemical fertilizer, development of a farm machineries and provision of extension services. The continuous crop improvement activities, scientific application of different types of fertilizer and agricultural chemicals, and appropriate pre-harvest, harvest and post-harvest technologies have ensured sustainable increase in rice production and productivity over years. after the second world war (Figure 1)

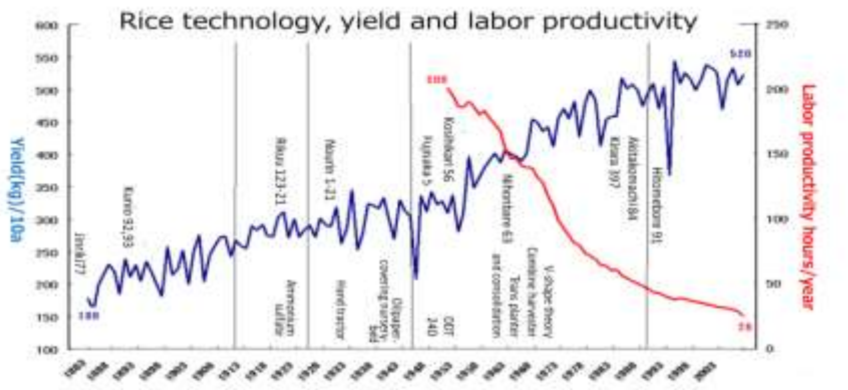

Fig-1 Rice yield improving and labor productivity
Source: MAFF "The crop statistics (rice)"

Rice production in Japan, the peak was 12.76 million tons in 1962, (acreage 3.13 million ha, unit yield 435kg/0.1ha), most significant plant area was 3.17 million ha in 1969 (production 13.8 million tons, unit yield 435kg/0.1 ha), the highest unit yield was 544kg/0.1 ha in 1994 (production 11.96 millon tons, acreage 2.2 million ha) (Official Statistics of Japan, 2017).

In terms of labor productivity trends, the working hours in the farm were 170 hr/10a in 1960, but it is 24hr/10a in 2015, which is 1/7 compared to 1960. The main reasons for the dramatic increase in labor productivity are related with:

- Continuation of improvement of the rice varieties and higher use of certified seed;
- The vigorous extension activity on cultivation techniques;
- The high rate of diffusion of the farm machineries esp. rice-planting and a harvesting machineries for which adoption was almost 100 % in the 1980s (Official Statistics of Japan); and
- The promotion of land improvement, which contributed to an increase of crop and labor productivity (Figure 2).

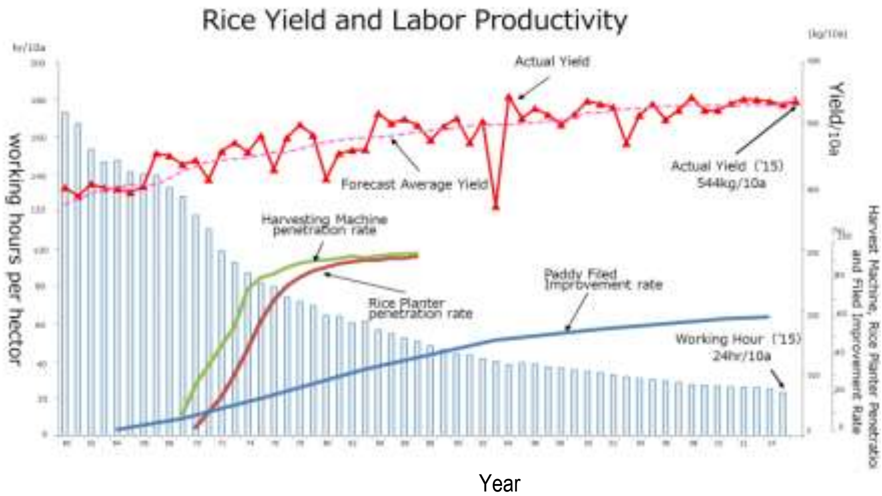

Fig-2 Labor Productivity and Agri-machine penetrate rate, land improvement
Source: Forecast Average Yield, Actual Yield, "2016 crop statistics", Working Hours "rice production cost statistics (2008)", Penetration rate of the harvesting machine and rice planting machine, "Survey of the grain section", Paddy field improvement rate, "Regarding the improvement situation of the agricultural production base"

Key lessons

The successive governments through the diverse support mechanisms and policies have well promoted the rice cultivation as a means of rural livelihood improvement in Japan. The research and development of improved varieties and agronomic recommendations in each socio-ecological system have been continued steadily for securement of the production, productivity, and quality of rice as the national staple food.

Development of rice-related machineries was accomplished by the strong research and development efforts by the private sector with support from the public research system. The productivity of rice was improved through the promotion of broader adoption of improved rice-planting machines and harvesters. The technological improvement has been a continuous process to meet the changes in the production environment.

The agricultural development direction as a nation has been reviewed and updated periodically to support the rice production with appropriate policies and institutional set up both at national and prefectural levels covering land ownership and land development, mechanization, research and extension and measures related with addressing the disparity in income levels of household engaged in agriculture and other economic sectors. Thus, it will be mandatory for Ethiopia to ensure adequate flexibility in designing continuously relevant policies and support mechanisms for the rice sector development, which has a huge potential.

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Rice Cultivation, Processing, and Marketing in Ethiopia

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Introduction

Rice is a recent introduction to Ethiopia, which was firmly linked with the quest for addressing various challenges of different public interventions during the Derge regime, which were mainly related with settlement and food security. The first areas of rice introduction were Gambella (1973 – 1982), Pawe (1985 – 1988), and Fogera plain (early 1980s). Its production spreads in many suitable rice production areas in the coutry including in Amhara, Oromia, Benshangul, Southern Nations Nationalities and Peoples, Gambela and Tigray regional states. However, of these areas, Fogera plain remained one of the major rice production areas that has demonstrated huge agrarian changes associated with rice introduction and its commercialization.

This paper presents the challenges and opportunities in rice cultivation, processing and marketing in Ethiopia. Specifically, it deals with the importance of rice in the country, the trends in rice production, imports and domestic consumption, the general research and development efforts made to capture the opportunities rice offers to the country; and the key challenges and the way forward.

Factors of rice importance

Several factors that present the importance of rice in Ethiopia either independently or in combination are those related with:

- The trend in the expansion of rice production linked with agro-ecological suitability and existing potential;
- The compatibility of rice in the local farming systems and traditional foods;
- The economic incentives of rice production (comparative advantage);
- The rapid increase in domestic rice consumption and associated burden on foreign currency due to rice imports; and
- The favorable public policy environment and support of development partners.

Agro-ecological suitability and existing potential

It is estimated that the country is endowed with about thirty million ha (5.6 million ha highly suitable and about 25 million suitable) for rain-fed rice production. In addition, about 3.7 million ha of land is estimated as irrigable suitable for rice production distributed around the ten river basins in the country (Figure 1) (MoANR, 2010)

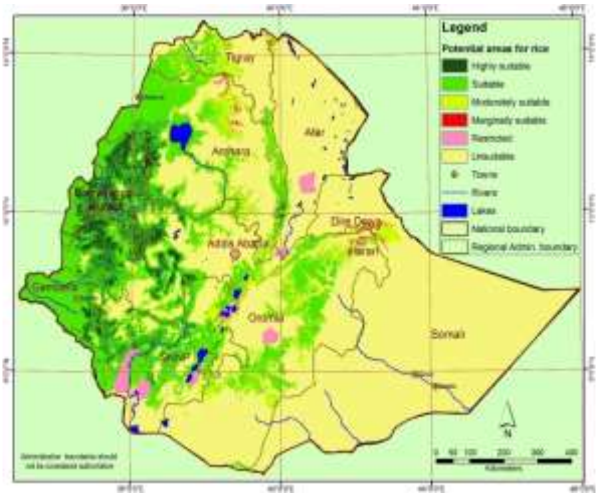

Figure 1 Suitability map for rice production under rain fed condition
Source: MoANR (2010)

In this regard, the recent expansion of rice production in different parts of the country following the successful agrarian changes linked with rice in Fogera plain demonstrates the agro-ecological suitability and the overall potential of rice in the country. The national rice research strategy recognizes about seven rice research and development hubs. These are;

Fogera Hub: this covers the west central highlands of Amhara Region mainly covering Fogera, Gonder Zuria, Dembia, Takusa, Achefer and Metema Districts as main niches;

Pawe Hub: this is an area covering northwest lowland areas of Amhara and Benshangul Gumuz Regions mainly Jawi, Pawe, and Dangur Districts;

Abobo Hub: this covers niche areas in Gameblla regional state mainly Abobo and Etang Districts;

Gura Fereda Hub: this covers rice producing areas in the south and southwest Lowlands of SNNPR mainly Beralee, Weyito, Omorate, Gura Ferda, and Menit Districts;

May Tsebri Hub: this covers rice producing area in the North west part of Tigray;

Gode Hub: this covers the Southern part of Somali Region mainly engaged in irrigated rice; and

Chewaka Hub: one of the major rice producing areas covering Southwestern highlands of Oromia Region, which include Illuababora, East and West Wellega and Jimma Zones.

Compatibility of rice in the local farming systems and food recipes

Following its introduction in 1970s and 1980s to the different parts of the country, rice has become compatible not only in the farm systems but also well adapted to the local food recipes. In addition to the created opportunity in utilization of abandoned areas due to flooding, rice production has expanded to upland areas creating dynamisms in local production systems. Considering Fogera plain as an example, rice has brought two distinct farming system dynamics, which are related with dynamisms in the wetlands and upland areas.

Farming systems dynamism in the wetlands of Fogera plain

The wetlands were areas where rice was first introduced into the area. Before that time, land use was dominated by extensive grazing of the indigenous Fogera cattle, which has a large frame, copes with waterlogged conditions, and is one of the best native milk cows in Ethiopia. The area was characterized by swamps in rainy season for about a quarter of the year, after which it was devoted almost exclusively to grazing.

The identification of wild rice in the wetlands of the Fogera plain, and the subsequent introduction of a cultivated rice variety shifted the dominant land use activity from cattle grazing to rice cultivation. As the rice cultivation expanded, the land used for grazing of the Fogera cattle and production of other crops began to shrink, resulting in significant changes in local farming systems.

As rice has grown in importance in the farming system, there has been a significant decline in the production of noug, chickpea, wheat, and oats in the wetlands. The production of noug in the wetlands ended towards the end of 1990s following the expansion of rice. Tef production is restricted in pocket areas. There was also emergence of new crops such as vegetables, and maize in the wetlands, which is associated with the expansion of irrigation in the wetlands. Grass pea is also coming to picture with the rice-grass pea relay cropping system. As farmers' income from rice has increased, they started to invest mainly in supplementary irrigation for rice production. This has in turn created the opportunity of production of other crops under irrigation, which has further increased household income. Some farmers were able to invest in deep wells and install motor pumps on their plots of land. Fogera *wereda* Office of Agriculture has also played an important role in the promotion of household-level investment in irrigation systems. Normally farmers use irrigation to supplement rain-fed rice production and fully for onion, tomato and maize, which is often undertaken after harvesting of rice and grass pea. These have provided more opportunities for farmers to generate supplementary incomes.

Farming systems dynamism in the uplands of Fogera plain

Rice production in the uplands started recently since 2006 following the introduction of upland rice varieties by the national research system (there were four upland rice varieties released before (MoANR, 2016) and the felt benefits of rice production by farmers in the wetlands with plots of land in the upland areas of the Fogera Plain. In general, upland areas used to be characterized by mixed crop livestock farming systems where diverse types of crops are produced. With the expansion of rice in the upland areas of the Fogera Plain, the following trends were observed:

- Considerable decline in the production of tef and sorghum from cereals, noug from oil crops and lentil from pulses due to the shift in land allocation to rice. This is reported to be due to the relatively high economic returns rice provides per unit area versus other crops;
- Relative increase in the production of grass pea, finger miller, maize and chickpea and introduction of common beans, which is reported to be associated with the expansion of rice. Farmers' reported that these crops are good successors after rice favoring double cropping practices; and
- Considerable decline in livestock production in the uplands of Fogera plain. The expansion of rice linked also with the expansion in overall crop production associated with population pressure, has demonstrated a trend of considerable decline in importance of livestock.

In addition to the compatibility of rice in the farming systems, rice has found its way in getting to the traditional food and drink making. Observation indicates that in many parts of the country especially in areas were rice is produced; *enjera* is made by mixing rice with tef. The mixing is favored due the high preference for whitish color of *enjera*, which rice provides and also the reduction of the unit cost of *enjera* making**.** During the earlier periods there was increasing trend of *tella* and *arekie* making from rice, however, due to increased price, farmers now shift to use of purchased maize using the revenue made from sell of rice.

The economic incentives of rice production

The economic incentive that rice production provide to farmers emanates from the productivity levels, high demand for rice, and unit price it fetches as compared to other cereals with high unit price like tef. In addition, rice provides the possibility of production on fields considered as waste (waterlogged) during main season. The diverse byproducts of rice have additional economic benefits are animal feed and also fuel (straw, bran, and husk)

Burden on foreign currency – rice imports

Ethiopia is dependent on export of selected agricultural commodities mainly coffee, pulses, oil seeds (sesame) and in recent years flowers. Recent trends also show that export of industrial products is growing steadily though still its contribution is minimal. All imports on the other hand are made from the foreign currency generated from the export of these limited types of agricultural commodities. In this regards, the government has provided different types of export incentives including incentives to enhance domestic production of imported commodities like fiber crops, oil crops, and rice. Rice imports have shown considerable increase in the last ten years reaching 311,827 tons of rice costing the country 170.69 million USD in 2016.

Public policy environment and support of development partners

The recognition of the importance of rice has been reflected by the preparation of the national rice research and development strategy that has played crucial role in guiding the overall rice research and development in the country (MoANR, 2010). In effort to enhance research a national rice research and training center at Fogera is established as one of the 17 research centers of the Ethiopian Institute of Agricultural Research (EIAR) in 2013. This has enhanced to establish a well-organized rice research program in the country. The support from development partners has been considerable esp. following the country's members in CARD (since 2010) and Africa Rice (since 2016). Considering the importance, a number of land concessions were made to ensure also large-scale commercial farming for rice including the 300 thousand ha of land concession for the Saudi Star PLC for commercial rice production in Gambella Region.

Trends in rice production, imports and domestic consumption

Domestic rice production

The area coverage in domestic rice production has increased considerably linked with expansion of production from wetland areas mainly in the Fogera plain to upland and irrigated areas with the introduction of suitable rice varieties for these agro-ecologies. The national research system has released in collaboration with AfricaRice and IRRI 35 improved rice varieties (MOA, 2018). As a result, the production levels have been increasing consistently over years. Central Statistics Authority (CSA) data indicate that rice production increased from 71,316.07 tons in 2008 to 126,806.45 tons in 2016 (Figure 2).

Rice import

Rice import to Ethiopia has increased considerable in recent years (Figure 2). According to the data from Ethiopian Revenue and Customs Authority (ERCA), rice import increased from 22,500 tons in 2008 to 311,827 tons in 2016; which is 12.07 million USD in 2008 to 170.69 million USD in 2016. There are four main types of rice imported into the country, which are recognized by Ministry of Trade and ERCA. These are broken rice, husked brown rice, rice in the husk (paddy or rough), and semi-milled or wholly milled rice. However, there is no figure these are further categorized into Japonica type and Basmati type. The major rice exporting countries to Ethiopia are India, Pakistan, China, United Arab Emirates, Thailand, Sri Lanka, and Indonesia. When compared with other countries, India takes the lion share of all rice imported in Ethiopia with about 50% of average share over years.

Domestic consumption and self-sufficiency

Considering domestic consumption as the sum of domestic production and imports, the total consumption of rice in Ethiopia has grown considerably. This is in line with the trend in consumption observed in all African countries (Seck *et al*., 2013; Wopereis *et al*., 2013). The trend in domestic production and imports indicate that the rate of increase was considerably higher for rice imports compared to domestic production, which has results in considerable decline of the rate of self-sufficiency in rice consumption in Ethiopia. The estimated rate indicates that self-sufficiency in rice consumption in Ethiopia has decreased from about 70% in 2008 to about 30% in 2016 (Figure 2).

The trends in rice imports reflect the increased demand for rice the country and helps in stabilizing the domestic grain markets. However, the trend indicates the following key implications:

- The increased rice import will have negative implication on local rice production as rice production in the country is at infant stage both in terms of research and development making it less competitive in the national rice market;
- The increased import of poor quality rice in terms of broken rice reduces the incentive for domestic production as competitiveness will be low;
- There is no any information whether the imported rice is purchased at world competitive price or dumping price; and
- There is no any measure as to the quality of the imported broken rice for human consumption. The main purpose of the imported broken rice is for preparation of *enjera* by mixing with tef.

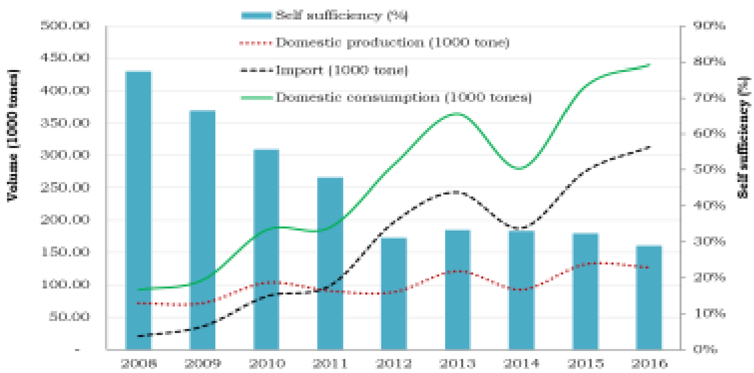

Figure 2 Trends in rice production, imports, consumption and level of self–sufficiency

Research and development efforts

Since the declaration of rice as millennium crop in 2007, a number of rice specific public and private measures have been put in place. The first and most important measure was the development of rice specific national rice research and development strategy followed by establishment of organizational setup to ensure the implementation of the strategy. The government of Ethiopia with the support from JICA and CARD has set a national rice research and development strategy in 2010, which defined and guided:

- The national rice R&D efforts at national and regional levels;
- The governance of the implementation of the strategy;
- Identification of priority investment areas; and
- Setting of targets to ensure self-sufficiency and in later stage rice export.

The implementation of the national rice research and development strategy has been overlooked by a national steering committee supported by the national technical committee. The steering committee has been chaired by the State Minister of Agriculture and the members were from both federal and regional bureaus of agriculture, research institutes, private actors, and development partners. To facilitate the smooth operation of the steering committee, a national rice research and development secretariat has been operational based at the Ministry of Agriculture since 2010. A policy advisor to the Ministry assigned by JICA has managed the secretariat. The technical committee is composed of experts from federal organizations: EIAR, Ministry of Agriculture (MOA), Agricultural Transformation Agency (ATA), Ethiopian Seed Enterprise (ESE), and Development partners (JICA, SG 2000, and MEDA). At regional level, the rice focal persons were assigned by respective regional bureaus of Agriculture to link the works of the steering and technical committees with the regions. Though, the organizational setup indicates the emphasis given to rice, the performance is reported to decline over years depending up on the attention the specific State Minister at the federal level and the focal person at regional level provide. This implies the need to further institutionalize the organizational setup with full responsibility and accountability.

Given the recent introduction of rice to the country and associated gaps in rice research and development, the priority intervention identified in the national rice strategy was establishment of a national center of excellence for rice research and capacity building. Accordingly, the national rice research and training center was officially established in 2013 as one of the federal agricultural research centers under EIAR. With the generous financial and technical support of the Japanese government, the center's physical facilities were constructed and inaugurated on Nov 15, 2018. It is expected that the center will play a crucial role in accumulation of knowledge and skill along with technologies from elsewhere the world and transfer of them to relevant end-users.

In parallel with these efforts, the country has been engaged with international initiatives to ensure the transfer of knowledge and skill for effective rice research and development. In this regards, the membership of Ethiopia in CARD initiative

(Coallition for Africa Rice Development) in 2010 and the membership in Africa Rice center in 2016 play important role. The engagement in CARD initiatives allowed the country to share experiences from other African countries, get access to relevant capacity development opportunities especially in short term trainings for rice researchers and extension workers. CARD initiative targets doubling of rice production in Africa with associated development of the rice value chains.

The membership in Africa Rice center has created the opportunity of international linkage in germplasm exchange and short and long term training opportunities. AfricaRice is a pan-African intergovernmental research for development association of 24 member-states and a member of the Consortium of International Agriculture Research Centers (CGIAR). The Center's mission is to contribute to poverty alleviation and food security in Africa, through research, development, and partnership activities aimed at increasing the productivity and profitability of the rice sector in ways that ensure the sustainability of the farming environment.

Development partners have shown also interest in support of the development of rice sector in Ethiopia. The three most important programs supported by development partners are the EthioRice project supported by JICA, MEDA supported by CIDA, and AgroBIG project supported by Finland Government.

EthioRice project targets ensuring the full functionality of the National Rice Research and Training Center through facilitation of the development, accumulation, and transfer of rice related research outputs (technologies), capacity development for researchers to undertake research and provision of training to relevant stakeholders and establishment of a system of rice related information sharing to all relevant stakeholders. The project under implementation since 2015 and its first phase will end by 2020.

EDGET project (Ethiopians Driving Growth Through Entrepreneurship and Trade) implemented by MEDA with the support of the Government of Canada has implemented rice related activities (2010 – 2015) related with:

- Improving rice input supplies, awareness about improved techniques, irrigation, including efficient micro-irrigation technologies, and rural credit;
- Rice post-harvest handling related with storage, grading and market segmentation as well as improved technologies for value added activities; and
- Rice market linkages through consolidation/bulking and other strategies to deal more effectively with traders and development of selling/marketing strategies to new markets.

The second phase of the project EMERTA (Ethiopians Motivating Enterprises to Rise in Trade and Agri-business: 2016 - 2020) targets promotion of agribusinesses with a motto of “Creating business solutions to poverty” focusing on rice, gem and vegetable sectors with the objective of increasing employment and income for women and men in the Amhara region in Ethiopia.

AgroBIG is implemented as a bilateral cooperation between governments of Ethiopia and Finland. It targets scaling up of successes of the first phase of the program (2013 – 2017) in promoting business induced growth by working closely with smallholder farmers, agricultural cooperatives, private actors and other value chain actors with particular emphasis on youth and women. The current program will be implemented until 2021 targets eight districts around Lake Tana of Amhara Region, where one of the major target commodities is rice with its value chain actors. Among the eight districts, the main rice producing districts of the Fogera plain namely Fogera, Libokemkem, and Dera are included.

Key challenges

Rice sector in Ethiopia faces a number of challenges along the value chain. In this regards, the 2010 national rice research and development strategy (MoANR, 2010) and the 2017 Rice Seed Sector Development Strategy (MoANR, 2017) have clearly identified the main challenges. These are related with following issues

Performance of the rice seed sector and other inputs

The contribution of the formal seed sector in rice is very limited and in general the supply of certified seed of rice is limited to few farmers’ cooperative unions with almost no participation of private actors. The overall institutional coordination and alignment of rice seed related interventions amongst EIAR, RARIs, MoANR’s extension services, BoAs and ATA remain weak (MoANR, 2017). This has resulted in considerable use of poor quality seed among rice farmers.

Limited contribution of commercial rice production

A number of commercial farms received license to engage in rice production mainly foreign investors like Karuturi Global Ltd and Saudi-Star with 300 thousand ha of land concession each in Gambella region. However, it is only Saudi-Star, which has managed to make operational 5000 ha land for rice production. The Saudi-Star is also the first commercial farm with modern large-scale processing facility at Bishoftu Town.

Competition of imported rice with the local production

Though there have been attempts to get the domestic rice to the supermarkets in big cities like Addis Ababa, still there are challenges mainly linked with quality and sustainability of paddy supply to the processing and packing companies. Most of the domestic rice is marketed and utilized in local markets of the major rice producing niches. In general, in major markets especially big cities and town, imported rice of different types including broken ones are much preferred compared to domestic rice. The main reasons identified in this regard are related with:

- The small-scale nature of production affecting the quality in terms of grain size, maturity and purity related with diversity in farmers' rice production practices;
- Lack of awareness and shortage of pre-harvest and production management skills;
- Shortage of post-harvest mechanization, and inadequate awareness on post-harvest management and utilization; and
- Huge demand for broken rice that are sold locally at dumping price from exporting countries.

Limited skilled human resources and research facilities

As rice is a recent introduction to the country, there is no strong traditional skill and knowledge among the value chain. The research facilities and human resources are still to be developed. The expertise in rice extension is in general very weak. The skill and knowledge in rice processing has developed by itself through trial and error process. In this regard, developing the research and training capacity of the Fogera National Rice Research and Training Center (FNRRTC) of EIAR at Fogera is very crucial. It is in recognition of the skill and knowledge gaps that the center is provided a mandate of provision of training on rice.

For the timely provision of required services and products, the FNRRTC still needs to be equipped with:

- Required training facilities;
- Availing for demonstration and possible access rice related pre- and post-harvest and processing technologies;
- Develop a training curricula relevant for smallholder farmers, commercial farms, processors, extension agents, and researchers; and
- Designing mechanisms for sustainable provision of services.

Inadequate infrastructure for commercialization of rice production

The commercialization of domestic rice is highly hindered mainly due to the lack of proper technological options in rice processing. There have been a number of attempts to introduce better rice procession facilities and emerging few rice processing technology importers but still there no any local manufacturer who can supply good performing processing facilities. Due this challenge, much of the domestic production goes to flour making mixed with tef for enjera making.

Inefficient marketing system

The domestic rice marketing system is dominated by localize markets mainly facilitated by local processors as main buyers and sellers in each of the rice production niches. On the other hand, the imported rice especially the high quality rice has a well-established distribution system.

The marketing behavior of the different actors engaged in the process is also challenging esp. the marketing relation of smallholder farmers with processors is highly disfavors farmers as most of the processors/traders deliberately misbehave in terms of:

- Informing the right weight;
- Increasing the extent of breakage of rice seed to ensure reduced price due to quality; and
- Setting up different payment arrangements for rice processing like free processing by retaining the broken rice and husks.

As the domestic rice production expands, it will be important to develop better marketing system along with market information system to boost the bargaining power of smallholder rice producers.

Conclusion

The consistent increase of domestic demand for rice that has resulted in huge imports in the last decade requires due attention at all levels (research, development and policy). In addressing this negative trend, it will be important to provide due attention for the following issues:

- Urgent need to build domestic rice research and development capacity to ensure competiveness of domestic rice;
- Huge opportunity to adopted technologies and practices from all over the world that can be easily adapted to Ethiopian condition;
- Need for immediate tapping to existing technological opportunities from AfricaRice membership and IRRI as one of the CGIAR centers;
- Need for immediate operationalization of the FNRRTC esp. in building local capacity to all actors;
- Verification of the safety and regularity of the import of broken rice;
- Strengthening the functions of the National Rice research and development steering and technical committees at National level and focal persons at regional level;

- Explore the expansion of engagement of relevant development partners; especially, from Asia in support of rice research and development in the country; and
- Bench-marking of experiences from countries like Thailand and others in rice research and development efforts

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Status and Directions of Rice Research in Ethiopia

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Historical Perspectives

Rice cultivation is a recent phenomenon in Ethiopia. The discovery of wild rice in Fogera plain and Gambella areas has motivated different governmental and nongovernmental organizations to start adaptation trials on cultivated rice in different parts of the country (Gashaw, 1989; Zegeye et al., 2004; Mitiku, 2011). The earlier rice research endeavors in Ethiopia was started in the late 1950's and early 1960's (Assefa 2012; Gashaw, 1989; Sewnet, 2005). In 1957, a sugar cane plantation started rice growing at Metehara, along with the Awash River. Various authors documented that different governmental and nongovernmental organizations, Institute of Agricultural Research (IAR), Agricultural Development Department (ADD) of the Ministry of Agriculture, Tana Beles Project, Ethiopian Water Construction Authority (EWCA), Addis Ababa University and the North Korean agricultural experts (Ethio-Jigna project) were involved in rice research and development activity in Fogera plain, Chefa, Gambella, Werer, Lante and Pawe areas up to 1980s and they came up with the encouraging results and recommendations (Sewnet, 2005; Mitiku, 2011).

Emphasis on rice research was given in 1985/6 with the establishment of Pawe and Abobo research centers during the then massive resettlement program. Japan Oversea Cooperation Volunteers (JOCV) has supported the Agriculture bureau and the research dealing with rice research in Gambella between 1984 and 1998. In Pawe area, the Italians have done a successful rice research and production activities through the Tana-Beles Project. As a result, some improved varieties had been released informally and disseminated into the resettlement areas in Gambella and Pawe for demonstration and large-scale production (Zegeye *et al*., 2004). In the early 1980s through the technical support of North Korean experts', research on rice was initiated in Jigna (Dera *woreda*) and Shaga (Fogera Woreda) cooperatives (Zegeye *et al*., 2004; Tilahun *et al*, 2018; Tilahun, 2018). Following past unsuccessful endeavors of introducing rice into the area by different organizations and the government, in July 1984, a team of North Koreans composed of nine experts come to Fogera with a project entitled "Ethio-Jigna Development Project". The project came with the objective of starting and promoting rice and horticultural crops (Tilahun *et al*, 2018). The Koreans started their research on rice and horticultural crops. Concerning the rice, in addition to the rice genotypes they introduced from North Korea, they also evaluated rice genotypes from earlier endeavors by other researchers. After the evaluation of all the genotypes, one variety, which is latter named *x-Jigna* introduced from North Korea was found to be appropriate for the area. The Koreans helped the farmers in Fogera to start large-scale production of X-jigna, which is still under production for about thirty years in the area. However, due to the liquidation of farmer's cooperatives and evacuation of rice producers from the resettlement areas in 1991, the rice research, extension and production activities were weakened for a while. In 1994, the development activity was reinitiated by South Gondar zone and Fogera woreda agricultural office with the strong personal commitment of the late Mr Getachew Afework (Tesfaye 2009; Tilahun *et al*, 2018; Tilahun, 2018). Mr. Getachew has obtained some seeds of the variety introduced by North Korean, from farmers in Jigna kebele, which later renamed as X-jigna due to lack of proper documentation. After multiplying the seeds of this variety, Mr. Getachew introduced it to other farmers through demonstration plots. After Mr Getachew joined Adet Agricultural Research Centre as researcher he developed more rice varieties (Gumara and Kokit) and rice management technologies (Zegeye et al., 2004; Mitiku 2011).

Following the reestablishment of the rice research at Pawe and Adet, Pawe Research Center released M-55 as Pawe-1 in 1999 and the Adet/Amhara Regional Agricultural Institute released three improved rice varieties (IAC-164 as Gumara, IREM 194 as Tigabe, and IRAT 209 as Kokit) in 2000 (Mitiku, 2011). After the reinitiating the rice research program, EIAR gave due attention for the crop and the research activities were revitalized at Pawe Research Center. Consequently, the National Rice Research program was initially coordinated by Pawe Research Center. However, in 2003 Adet Research Center took over the mandate of the national rice research coordination until the establishment of Fogera National Rice Research and Training center on August 7, 2013.

Rice research in transforming farmers' life

Beside its higher yield per unit area, rice has a higher market value that is equal or some times higher than that of nationally popular crop, tef (SG2000, 2002). Generally, rice has great potential and can play a critical role in contributing to food and nutritional security, income generation, poverty alleviation and socio-economic growth in Ethiopia. Subsequently, rice is classified as the fourth "National Food Security Crop" after wheat, maize and tef in the country (Biruhalem, 2010).

Rice production has brought a significant change in the livelihood of farmers and created job opportunities for a number of citizens in different areas of the country. At the Fogera plain, rice plays an important role in relaxing the problem of food-insecurity of the farming community (Astewl, 2010). Before the introduction of rice, farmers at the Fogera plain were mainly engaged in livestock production and smaller proportion of crops production. Since the area is waterlogged during the main rainy season, it was unsuitable for crops production, as traditional crops cannot grow in such condition (Tilahun *et al*, 2018). They only grow some crops after the water recedes with residual moisture. Since the introduction of rice in the area, which grows wonderfully in the waterlogged condition, the farmers lives has tremendously transformed from only livestock production focus to rice production focus. The engagement in the rice production has transformed the lives of the farmers from being the poorest in the region to richest farmers with surplus production on top of the household food security granted. Moreover, the rice production has created business opportunity for actors along the rice value chain such as rice processers and traders' private businessmen (Dawit *et al.*, 2018).

EIAR has recognized the importance of rice and had FNRRTC in 2013. The center is mandated to coordinate the rice research in the country. At present 12 federal and regional centers including Fogera, Pawe, Gondar, Tepi, Bonga, Assosa, Maytsebri, Werer, Bako, Jima, Gode, and Abobo Research Centers, are involved in rice research activities across the country. There are also some agricultural universities like Mizan-Tepi and Debre Tabor engaged in the rice research.

In 2010, the Extension Directorate of MoARD developed the National Rice Research and Development Strategy of Ethiopia in collaboration with JICA and Sasakawa Global 2000 (SG 2000) (MoARD, 2010). The document has clearly elaborated the rice production potential, the importance of the crop and research directions. Moreover, to strengthen the rice research of the country, EIAR has developed a 15 years "Rice Research Strategy" which is under implementation starting 2017.

Achievements in rice research

Long before the establishment of FNRRTC, the national rice research project in collaboration with different governmental and non- governmental organizations has generated and promoted different rice production technologies. Until 2018, 35 improved rice varieties have been released for three rice ecosystems (15 for rainfed upland, 11 for rainfed lowland and 9 for irrigated).

Farmers are not only involved in rice production but also varietal development as they have developed two varieties (one lowland and one upland rain-fed type) through selection. The two farmer-selected varieties (*Demwoze* and *Nechu Ruz*) have been grown widely in Fogera area (rainfed lowland) of the Amhara Region and in Guraferda area (upland) of the SNNP regions (Sewagegn, 2011).

Various location specific rice crop management technologies have been generated with respect to fertilizer rate and application time, seed rates, row spacing, planting methods across the major rice producing regions. Consequently, a number of crop protection recommendations are given to different rice growing locations. Similarly, information related to crop protection has been generated on rice disease, insect pests and weeds distribution and prevalence. Moreover some mechanical implements like row weeders, harvesters,and threshers were evaluated and introduced to rice producers. In general, best fit rice technologies are frequently demonstrated, popularized, and pre-scaled in major rice growing regions.

Constraints in rice research

The rice research and development sector of the country has many challenges that have been constraining the progress. The major challenges are inadequate financial resources; and poor infrastructure such as laboratiry facilities, green houses, and quarantine sites.

Future direction

- So far, variety development has been conducted exclusively on selection of pure lines from introductions. Future varietal development effors should consider advance hybridization and molecular techniques;
- The varieties developed were mainly for rain-fed upland and lowland and to some extent irrigated ecosystems. The irrigated rice should be given due attention to address the growth of irrigated agriculture in the country;
- Demand driven variety development approach should be followed;
- Strengthening ecosystem-oriented research approach in the development of crop management technologies related to agronomy, cropping systems and crop protection;
- Agricultural mechanization and food science research interventions should be strengthened;
- Seed multiplication and dissemination of improved varieties should be given due attention;
- The available rice technologies should be promoted extensively so that they can reach the users rapidly and timely;
- Due attention should be given to capacity building both in terms of human as well as physical resources; and
- The positive trends of strong linkages among the different development partners should be further strengthened and sustained.

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Rice Genetic Improvement for Different Ecosystems in Ethiopia

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Introduction

Rice (*Oryza sativa* L.) belongs to the family Poaceae, and tribe Oryzeae. The tribe Oryzeae consists of 12 genera and more than 70 species, of which Oryza is a modest sized genus consisting of 20 wild species and 2 cultigens. The two cultivated species are *O. sativa* L., which is the principal cultivated species in the world and *O. glaberrima* Stud., which is indigenous to the upper valley of Niger River (John and Sons, 2003). Most of the species are diploid, having 12 pairs of chromosomes. Seven species are tetraploid (2n =4 x = 48). The chromosomes of rice species are small and deficient in morphologic markers, rendering them difficult to discern and identify (John and Sons, 2003).

Rice is a universal food feeding more than half of the world's populations (Yoshida, 1981). It is the most important food grain in the diets of hundreds of millions of Asians, Africans, and Latin Americans living in the tropics and subtropics. In these areas, population increases are high and will likely remain high at least for the next decade. Rice will continue to be their primary source of food.

In Africa, rice also constantly increasing as staple food and there has been increasing demand in Africa in the past three decades from 1999-2018; however, these demands have not been commensurate with the total production and most of African countries are net importer of milled rice, which costs 6.4 billion USD annually (Africa rice, CIPRiSSA, 2018). For instance, in 2015, 36 % of consumed rice was imported (Africa rice, CIPRiSSA, 2018). In spite of the huge potential for rice production in Africa, productivity is very low mainly because of inadequate investment in improved technologies and irrigation schemes.

Rice was introduced to Ethiopia in the 1970s. Emphasis on rice research in Ethiopia was given following the establishment of Pawe and Abobo research centers in 1986, which was targeted to support the settlement program. Like other major commodities, rice received due emphasis and categorized as one of the strategic food security crops in Ethiopia. The National Rice Research and Development Strategy of Ethiopia (NRRDSE) revealed that the rainfed rice cultivation potential is about 30 million ha (5 million ha highly suitable and 25 million ha suitable) (MoARD, 2010). Moreover, 3.9 million ha are suitable for irrigated rice production. Rice ranks second after maize in terms of productivity among cereals, which proved as it will play a significant role for food security in Ethiopia (MoARD, 2017).

Importance of rice research and development in Ethiopia was recognized due to the considerable expansion of small-scale rice production, recognition of the potential of production in the country and the huge increase for imports over time (Dancer and Hossain, 2018). The Ethiopian government considered rice as a millennium crop for its productivity and the potential to alleviate food security issues in the country. In line with the increasing production, rice consumption in Ethiopia has increased.This plays important role in contributing for increasing farmers income, creating employment opportunity, as well as sources of animal feed (Teshome and Dawit, 2011). There is an increasing trend in area coverage and volume of production of rice in the country (CSA, 2016). However, an increasing trend in importing rice proved that demand of rice is quite higher than the domestic production. For instance domestic production increased from 11,244.3 tons (2007) to 126,806.4 tones (2016) (CSA, 2007 and 2016) however importing of rice from abroad increased from 22,500 tones (2008) to 311, 827 tones (2016, which charged the country more than 170 million USD (ERCA, 2016). This scenario calls a concerted effort to sustainably increase the volume of rice production, which is mainly a function of increasing area of production and improving productivity per unit area. The mean national rice productivity (2.8 t/ ha) of Ethiopia is quite low compared to the global average productivity (4.4 t/ ha) even though 6 tones ha^{-1} has been reported on research fields (Dessie *et al.*, 2018). However, the rice research and development is still constrained among other things, by shortage of farmer-preferred varieties, lack of improved agronomic packages, low input utilization, terminal drought, low temperature effect, biotic stresses, soil fertility decline, lack of irrigation facilities, erratic rain fall pattern and, pre and post-harvest management problems (MoANR, 2010). This paper presents the research efforts and achievents in rice variety development along with trends in rice production and productivity in the country.

Achievements

Germplasm acquisition

As rice is an exotic crop to Ethiopia, the source of germplasm until now is through introduction. Since the inception of rice research, a number of germplasm were introduced from different countries. The major source of germplasms includes Africa Rice Center, International Rice Research Institute (IRRI), IRRI_ ESA (Tanzania, Kenya, and Burundi), China and Japan. Since 2007, a total of 3336 germplasms (Table 1) for rainfed upland, rainfed lowland and irrigated rice ecosystems have been introduced with the major objectives of high yielding, early maturing, high biomass, white caryopsis, abiotic stress tolerance (cold and salinity), biotic resistance (blast, brown spot and sheath rot) and pass through a series of evaluation stages for variety release.

Table 1: List of germplasm introduction to Ethiopia from different sources

No	Origin	Ecosystem	No. of germplasm	Year of introduction
1	IRRI	Irrigated	72	2007
2	AfricaRice	Irrigated	39	2009
3	IRRI	Irrigated	162	2010
4	AfricaRice	Lowland-Cold tolerant	132	2011
5	AfricaRice	Lowland	99	2011
6	AfricaRice	Irrigated	78	2012
7	IRRI Tanzania	Lowland	122	2012
8	IRRI	Irrigated	107	2013
9	IRRI-ESA-Burundi	Lowland	107	2014
10	AfricaRice	Lowland-Cold tolerant	33	2013
11	IRRI- Tanzania	lowland	84	2013
12	AfricaRice (Tanzania)	Upland	72	2013
13	AfricaRice (Tanzania)	Lowland-Cold tolerant	60	2013
14	Burundi (IRRI-ESA)	Lowland	107	2014
15	China (CAAS)	Lowland-Cold tolerant	6	2014
16	Tanzania (IRRI-ESA)	Lowland	112	2014
17	Tanzania	Lowland -commercial	4	2014
18	IRRI (GSR)	lowland	40	2014
19	AfricaRice	Upland MET	102	2014
20	AfricaRice Tanzania	Lowland-Cold tolerant	60	2014
21	IRRI-GSR	Lowland	65	2015
22	China (CAAS)	Lowland-Cold tolerant	8	2015
23	AfricaRice (Bennie)	Lowland and Upland	11	2015
24	AfricaRice	Upland PET	32	2015
25	IRRI, Egypt	Irrigated	111	2015
26	AfricaRice (KAFACI)	Lowland	99	2016
27	Africa rice	Lowland	59	2016
28	Tanzania- PRiDe	Lowland	17	2016
29	AfricaRice	Upland	70	2016
30	AfricaRice, Nigeria	Lowland	100	2016
31	AfricaRice	Lowland-Cold tolerant	80	2016
32	IRRI	Lowland	150	2016
33	IRRI	Upland	15	2016
34	IRRI	Irrigated	93	2016
35	IRRI - ESA- Burundi	Lowland	32	2017
36	IRRI	Irrigated	48	2017
37	IRRI	Lowland	55	2017
38	IRRI	Upland	50	2017
39	IRRI	Lowland -Temperate	16	2017
40	IRRI	Lowland -Soil stress	70	2017
41	IRRI	Lowland -Blast	73	2017
42	AfricaRice, Senegal	Lowland	118	2017
43	IRRI-Kenya-ESA	Lowland	43	2017
44	China-YAAS	Upland	4	2017
45	Madagascar	Upland	47	2017
46	IRRI	Irrigated	118	2017
47	Japan Gene Bank	lowland	26	2018
48	KAFACI	Lowland	49	2018
49	AfricaRice- Madagascar	Lowland –Cold Tolerant	45	2018
50	IRRI-ESA- Burundi	Lowland	34	2018
	Total		**3336**	

Variety development

Before the start of formal rice breeding in Ethiopia, adaptation trials were started in 1980s through Tana Beles project for the upland rice ecosystem in Pawe area and the varieties IAC-164, IAC-147 and IRAT-216 were recommended for cultivation without the approval of the national variety release committee. However, investors and farmers used these varieties for more than six years despite low yielding, low tillering capacity and lodging problems. Later, through the coordination of Pawe research center, the first variety called M-55 (Pawe-1) has been released in 1998 and recommended for Pawe and similar agro-ecologies.

Both laboratory and field quarentines are required before variety evaluation. The variety evaluation strat with field observation nursery and followed by preliminary variety trial (PVT) and national variety trial (NVT) for one and two years, respectively. The best candidate/s selected based on performance and agronomic merits will be verified for one year for possible release and deployment for production. From introduction to release of a variety, a total of five years are required. Usually at early stage (Observation and preliminary variety) evaluation takes place in the coordinating center for both upland and lowland ecosystem. Currently, the national rice breeding program is conducting multi-location variety trials targeting the major potential areas in the country (Figure 2). For agronomic and morphological data collection, the standard evaluation system (IRRI. 2013) is adopted. Through these stages, different type of data analysis tools/management systems have been used.

In the varietal development, high yielding, early maturing, white caryopsis, resistance against key biotic (Blast, sheath rot, brown spot) and abiotic (cold, drought, salinity) stresses are the major traits taken into consideration. Until 2018, 15 rainfed upland, 11 rainfed lowland and nine irrigated upland rice varieties were released (Table 2) for cultivation by farmers and other end users. Of the released varieties, NERICA-4, Chewaka, Pawe-1 and NERICA 13 in the upland rainfed; and Ediget, Shaga, Wanzaye and Gumara in the lowland rainfed ecologies are under production and brought some impact in improving livelihood of thousands of farmers.

The breeding research efforts are made to develop improved and high yielding varieties mainly through multi environment evaluation of rice genotypes. However, the incidence of G × E interaction complicates the selection of a rice variety with superior performance and adaptability to diverse environments (Lakew et al, 2016; Sewagegne et al, 2016; Solomon et al., 2017). The G x E interaction may arise when specified genotypes are grown in diverse environments (Zobel, 1990; Yan and Tinker, 2006). It is important for breeders to identify specific genotypes adapted or stable to different environment(s), thereby achieving quick genetic gain through screening of genotypes for high adaptation and stability under varying environmental conditions prior to their release as cultivars (Yan and Kang. 2003). Multi-environment variety trials have been conducted to select high yielding varieties with wider adaptation with major disease resistance and early maturing characters (Dessie *et al*, 2018; Lakew et al, 2017). Beside to the multi-environment breeding trials, a number of regional variety trials have been conducted and a number of varieties along with management practices recommended for production for specific location. Through these processes, a number of varieties has been released and recommend for cultivation for the three ecosystems (Table 2).

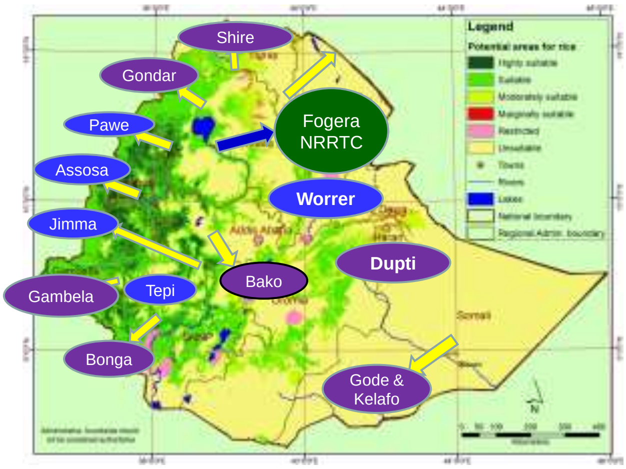


Figure 2: Rice variety testing sites targeting the different growing environments in Ethiopia

Of the 35 released varieties, 20 (12 upland and 8 lowland) were released nationally; 12 varieties under regional research centers (1 upland variety by OARI/Bako research center, 2 upland varieties by TARI/Shire research center and 9 irrigated varieties by SOPARI/Gode research center). The other 3 lowland varieties were registered by private.

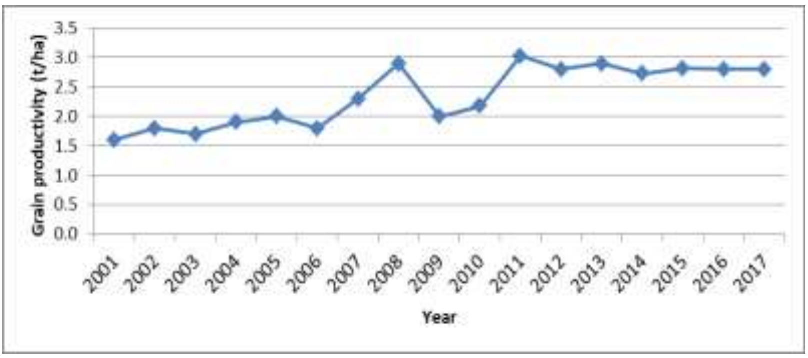
Table 2. List and description of released rice varieties

Variety	Year of release	Growing ecosystem	Days to maturity	Grain yield (t/ha)		Released by
				Farmers field	Research station	
Shaga (Scrid017-1-4-4-4-1)	2017	Lowland	110-120	3.9-5.0	4.9-6.8	Fogera/EIAR
Wanzaye (Scrid006-3-2-3-2)	2017	Lowland	120-130	3.5-3.9	4.5-6.5	Fogera/EIAR
Erib (WAB880-1-32-1-2-P1-HB)	2017	lowland	115-125	3.0-4.1	4.7-5.3	Fogera/EIAR
Abaye (ARCC16Bar-21-5-12-3-1-2-1)	2017	Lowland	130-145	3.5-4.0	4.4-5.3	Fogera/EIAR
Fogera 1(ART15-7-16-30-2-B-B)	2016	Upland	105-120	3.2-3.9	4.2-5.0	Fogera/EIAR
Fogera 2 (KOMBOKA)	2016	Lowland	131-139	3.7-4.9	4.2-6.1	Fogera/EIAR
Adet (WAB450-1-B-P-462-HB)	2014	Upland	112-120	2.4	4.2	Fogera/EIAR
NERICA 13	2014	Upland	104	3.3	3.8	Maitsebri/TARI
NERICA 12 (WAB880-1-38-2-17-P1-HB)	2013	Upland	101-132	2.3-3.4	3.5-4.1	Adet/ARARI
Hiber (IRGA370-38-1-1F-B1-1)	2013	Lowland	105-141	2.6-3.6	3.4-4.7	Adet/ARARI
Chewaqa (YIN LU20)	2013	Upland	160	3.3	4.2	Bako/ORARI
Hidassie(WAB515-B-16A1-2)	2012	Upland	100-130	2.2-3.2	3.0-4.2	Adet/ARARI
Ediget (WAB189-B-B-B-HB)	2011	Lowland	132.8	3.2	5.2	Adet/ARARI
NERICA-15	2011	Irrigated	80-91	5.0	6.2	Dolla/SOPARI
NERICA-6	2011	Irrigated	90-110	5.5	6.3	Dolla/SOPARI
NERICA-14	2010	Irrigated	80-90	5.0	6.2	Gode/SOPARI
Kallafo-1(FOFIFA3737)	2010	Irrigated	90-100	5.0	6.5	Gode/SOPARI
Getachew (AD01)	2007	Upland	97-125	2.1	3.0	Adet/ARARI
Andassa (AD012)	2007	Upland	111-135	2.5	3.8	Adet/ARARI
Tana (AD048)	2007	Upland	109-135	2.4	4.4	Adet/ARARI
NERICA-1	2007	Upland irrigated	80-90	3-4	4.7	Gode/SOPARI
NERICA-2	2007	Upland irrigated	80-90	3.5	5.5	Gode/SOPARI
Shebelle(IR688059-76-3-3-3-2)	2007	Upland irrigated	120-135	4.5	5.9	Gode/SOPARI
GODE-1(BG-90-2)	2007	Upland irrigated	120-135	4.3	5.7	Gode/SOPARI
HODEN (MTU-1001)	2007	Upland irrigated	120-135	4.0	4.7	Gode/SOPARI
NERICA-3(WAB-450-IB-P-28-HB	2006	Upland	110	2.9	4.5	Pawe/EIAR
NERICA-4(49WAB-450-IB-P-9/1)	2006	Upland	110	3.0	4.8	Pawe/EIAR
SUPERICA-1(WAB-4507)	2006	Upland	115	2.3	5.1	Pawe/EIAR
Gumara(IAC-164)	1999	Lowland	130	3.0	3.8	Adet/ARARI
Tigabe(IREM-194)	1999	Upland	90-97	3.2	3.7	Adet/ARARI
Kokit(IRAT-209)-	1999	Upland	90-97	2.8	3.6	Adet/ARARI
Pawe-1(M-55)	1998	Upland	125-135	2.0	3.0	Pawe/EIAR
VRH 606	2013	Lowland	121		6-7	ViBHA Seeds Eth.(PLC)
VRH 640	2013	Lowland	119-121		6-6.8	ViBHA Seeds Eth.(PLC)
VRH 654	2013	Lowland	130-135		7.5-8.6	ViBHA Seeds Eth.(PLC)

Productivity trends

The overall national mean grain yield of rice in Ethiopia showed a constant increase from 2001 (1.6 t/ha) till 2008 (2.9 t/ha) and followed by a sharp drop in 2009 because of terminal drought during reproductive stage. After 2009 a constant and progressive increment was recorded. It indicated that the overall rice productivity increased from 1.6 t/ ha in 2001 to 2.8 t/ ha in 2017, which was increased by 42.9 %, with 2.5% annual productivity gain the last seventeen years (Figure 3). This could be related to the increased use of improved production and management practices. However, in comparison to the yield obtained on the research station of 5 tons per hectare, the productivity is less by half (Figure 4).

The productivity of rainfed upland rice variety under research station confirmed constant increase from 1998 (3.0 t/ha, Pawe-1) until 2016 (4.6 t/ha, Fogera-1), rising by 34.8 % and proved that 1.9 % annual productivity gain. For rainfed lowland rice, grain yield increased from 1999 (3.8 t/ ha, Gumara) until 2017 (6.8 t/ha, Shaga), 44.1 % yield increase and 2.5 % annually (Figure 4). Similarly, there is also an increment on grain productivity on irrigated rice varieties from 2007 (4.7 t/ ha, HODEN-1) to 2011 (6.5 t/ ha, Kalafo-1 or FOFIFA 3737). The overall gain in productivity of rice variety across ecosystems have not yet portioned into the components due to genetic and management, efforts have not yet made to determine how much genetic has been achieved through breeding.



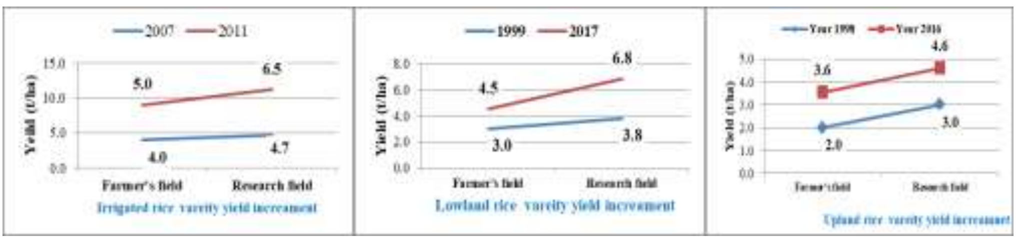


Figure 4: Released rice variety productivity trend for the three ecosystems in Ethiopia

In comparison to the major cereal crops in Ethiopia, the productivity of rice is second after maize since 2001/2. This scenario revealed that rice could be a potential crop for Ethiopia not only for self-sufficiency also for export purpose (MoARD, 2010). It will be a good opportunity to Ethiopia to export rice to African countries, as all are importer of rice.

Status of rice variety improvemnt

Rice variety improvment in Ethiopia is at its early stage of development in terms of facilities, human resources, and research approach. There are a number of improved varieties developed since the start of the rice research. However, the status of adoption of these varieties is low. This might be because of the poor extension service on improved technologies, lack of seed system, lack of mechanization and absence of irrigation facilities especially for irrigated rice ecosystem (unpublished data).

So far, the rice-breeding program entirely relies on introduction of germplasm and passes through serious of evaluation/selection stage. To release a variety, a total of five years can take from introduction to release. Augmented and alpha lattice designs are used at observation and preliminary variety selection stage. Usually for national variety trial randomized completely block design is used. The major traits which considered at different stages includes grain yield, resistance to blast, sheath rot, and brown spot diseases, early maturing, grain quality—white caryopsis, high tillering capacity and high biomass. The method of data collection system is manual which needs advanced methods like electronic data capturing system for quality data.

The revenue getting from rice farming is below compared to the potential. To make use of the huge potential and to maximize use of the crop, 15 years rice research strategy has been developed across disciplines. The strategic issues across different disciplines identified and interventions for the strategic issue designed. It is planned to address priority challenges of the crop through strong and coordinated research.

Challenges

So far, the program has developed varieties following trait-based selection, giving priority to grain- and biomass-yield. However, there is a need to shift from trait- to product-based variety development. Product-based variety development requires incorporation of multiple traits in to the existing adapted rice varieties and elite lines, as a result different screen houses, and crossing blocks are necessary. As a national coordinator, the center needs to have cold rooms as it is managing a great deal of genotypes, and maintains and keeps large amounts of different classes of seeds. The program has one-hectare quarantine field from Andassa Livestock Research center, but it is not only inadequate but also not suitable for lowland ecosystem. Although most of the research centers are dealing with rainfed rice research, only few, Werer, Gode, and Dubti are engaged in irrigated rice research. It is, therefore, necessary to develop irrigation facilities to strengthen the research. It will speedup variety development and seed production. Lack of green house for hybridization and variability creation; lack of experienced researchers, and lack of rice germplasm for different quality traits are major challenges for the program. Human resource development is still a big challenges and should be given due emphasis, both in quality and quantity. Some research disciplines like food science are not functioning. It is, therefore, necessary to recruit new researchers and upgrade the existing ones. The rice research program is lacking a number of facilities like biotechnology, pathology, entomology, physiology, and food science laboratories, screening facilities for biotic and abiotic stresses, and green house for off-season crossing activities.

Conclusion

A number of improved varieties targated for the three main rice ecosystems has been released. The recently released varieties performed as high as 5 t/ha grain yield in research managed fields. However, replacemnt rate of old varieties is quite low. This could be evidenced by the long time cultivation of X-Jigna, a variety introduced from North Korea in the 1990s. X-Jigna is a japonica type variety which farmers prefer it for the reason that it has good *enjera* making quality, a premium price in the market because of its white caryopsis and higher biomass. This suggests that *enjera* making quality is an important quality trait to be included in the rice variety development. Furthermore, it also suggests that it is quite necessary to properly characterise the users' and market preferences. Product based and demand oriented rice breeding program is critical to deliver prodcuts that sutisfay the demends of both the users' and the market. Breeding piplines to realize the prodcuts are accordingly crucial.

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Rice Mega-Environment Characterization in Ethiopia

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Introduction

Genotype by environment interaction (GEI) is a common phenomenon in crop production; and remains an important issue in genotype evaluation and recommendation. Meaningful genotype evaluation would not be possible without an understanding of the target environment. Thus, mega-environment analysis is a prerequisite for genotype evaluation. A mega-environment is defined as part of the growing region of a crop represented by a group of sites among which there is no major repeatable crossover GEIs (Gauch and Zobel, 1997). Consequently, for a given mega-environment there exists a cultivar that performs best at all sites when evaluated over several years. Following this definition, a mega-environment can be simple or complex (Yan et al., 2007). A simple mega-environment involves no crossover GE interaction at all, whereas a complex-mega-environment involves crossover GE interactions that are not repeatable over years. For a simple mega-environment, one or a few test sites would be sufficient for effective cultivar evaluation. For a complex mega-environment, distinct test sites are required to select cultivars that are superior across the whole region over years.

Mega-environment analysis has a long-term impact on genotype evaluation and cultivar recommendation and it must be based on multiyear data (Yan et al., 2000). Mega-environment analysis does not necessarily lead to the division of the target environments into mega-environments, which depends on the relative magnitude of G versus GL. It will definitely lead to a better understanding of the target environment (region), however, which will lead to more rational and efficient breeding and cultivar recommendation strategies. GGE biplots are among the widely and acceptable methods of mega-environment analysis. It displays both G (genotype main effects) and G × E (genotype × environment interaction) components, which are the two important sources of variation that are relevant to cultivar evaluation and have to be considered simultaneously for appropriate genotype and environment evaluation (Yan, 2014).

The effectiveness of genotype evaluation as part of breeding is influenced by understanding of genotype by environment interaction; and the degree to which the environments sampled in the multi-environment testing trials (MET) represent the production environment. In environments, which experience significant temporal and spatial variability, genotype ranking varies greatly among locations and seasons, which limits the potential rate of genetic gain by decreasing the effective heritability for selection (Basford and Cooper, 1998).

Rice constitutes a major part of the diet in numerous countries in sub-Saharan Africa (SSA). It is the third most important staple for the whole of sub-Saharan Africa. Rice is believed to be introduced to Ethiopia in the 1970s. It is one of the target commodities that have received due emphasis in Ethiopian agriculture and is considered as the "Millennium crop" expected to contribute to ensuring food security in the country (MoARD, 2010). Ethiopia has vast suitable rice growing ecologies that includes lowland rain-fed, upland rain-fed and irrigated rice growing ecosystems (MoARD, 2010). There is an increasing trend in area coverage and volume of production of rice in the country (CSA, 2016). However, the country increasingly (22,500 tons in 2008; 311, 827 tons in 2016) continued importing rice, which costed it more than US $ 170 million. This scenario calls a concerted effort to sustainably increase the volume of rice production which is mainly a function of increasing area of production and improving productivity per unit area, in which both are possible and have been identified and targeted.

Formal rice research in Ethiopia is in its young age and dates back to the 1980s. However, 35 (15 rain fed upland, 11 rain fed lowland and 9 irrigated) improved rice varieties have been released and/or registered, and have been made ready for production. The national rice research program targets lowland rain-fed, upland rain-fed and irrigated rice growing ecosystems, which are classified based on biophysical parameters mainly water availability to the rice crop. However, other biophysical characters such as elevation also highly affect rice adaptability and performance. Since this type of classification does not involve genotypic responses of the crop of interest, its results may not be directly relevant to the breeding and cultivar recommendation of the crop. This has been evidenced by the inconsistent—sometimes failed to set seed—to performance of different genotypes from various sources targeted to those ecosystems. Mega-environment analysis based on particular crop performance approach has been instrumental in various crops including in rice (Krishnamurthy 2017; Sewagegne, 2017).

This study was carried out with the objective to fine tune the present biophysical based rice ecosystems with performance based mega-environment characterization thereby advise the national breeding program.

Materials and Methods

Study sites

The experiment targeted both lowland and upland rain fed ecosystems. The lowland experiment was conducted in Fogera, Fogera-Kokit, Libo Kemkem-Bura, Pawe, Pawe-village -17, Assosa, Keshmando, Bako, Chewaka, Jimma, Shebie, Gojeb, Bonga, Shirie-Mythebri and Borekie during from 2013 to 2017 growing seasons. The locations represent most lowland rice growing environments. Detail descriptions of these locations are provided in Table 1. Similarly, the upland experiment was conducted in Fogera, Metema, Pawe, Pawe-village -17, Assosa, Kemash, Bambasi, Bako, Chewaka, Shebie, Gojeb, Guraferda, Bonga, Shirie-Mythebri and Mezekire during from 2013 to 2017 growing seasons. The locations represent most upland rice growing environments. Detail descriptions of these locations are provided in Table 2.

Table 1. Description of study locations for lowland ecosystem

Location	Altitude (m)	Latitude	Longitude	Annual rainfall (mm)	Temperature (°C)	
					Maximum	Minimum
Fogera	1810	11°58’N	37°41’E	1300	27.9	11.5
Pawe	1050	11°09’N	36°3’E	1457	32.8	17.2
Assosa	1590	10°03’N	34°59’E	1120	28.0	14.5
Keshimando	1415	NA	NA	NA	NA	NA
Shire/Mytsebri	1350	11°08’N	38°08’E	1296	36	15.0
Borekie	1104	13°55’N	38°3’E	NA	NA	NA
Bako	1650	NA	NA	NA	NA	NA
Jimma	NA	NA	NA	NA	NA	NA
Gojeb	1235	7°15’N	36°0’E	1710	24.0	16.7

NA, not available

Table 2. Description of study locations for upland ecosystem

Location	Altitude (m)	Latitude	Longitude	Annual rainfall (mm)	Temperature (°C)	
					Maximum	Minimum
Fogera	1810	11°58’N	37°41’E	1300	27.9	11.5
Pawe	1050	11°09’N	36°3’E	1457	32.8	17.2
Assosa	1590	10°03’N	34°59’E	1120	28.0	14.5
Kamashi	1250	10°04’N	34°56’E	1200	31.5	17.0
Metema	750	12°54’N	36°15’E	1100	29.0	22.0
Bambasi	NA	NA	NA	NA	NA	NA
Chewaka	NA	NA	NA	NA	NA	NA
Shebie	NA	NA	NA	NA	NA	NA
Gojeb	1235	7°15’N	36°0’E	1710	24.0	16.7
Guraferda	1138	6°50’N	35°17’E	1332	39.0	25.0
Shire/Mytsebri	1350	11°08’N	38°08’E	1296	36.0	15.0
Mesekrie	1126	13°55’N	38°49’E	NA	NA	NA

NA, not available

Plant materials

For the upland, 16 rice genotypes out of which 12 released varieties and four promising candidates were considered. Thirteen lowland rice genotypes—two released varieties, two cultivars and the rest seven promising lowland rice genotypes—were included for the lowland experiment. Descriptions of the materials are provided in Tables 3 and 4.

Table 3. Upland rrice varieties used in the study

Name and designation	Origin	Remark
Hidasie(WAB515-B-16A1-2)	Africa rice	Variety
Getachew (AD01)	NA	Variety
Andassa (AD012)	NA	Variety
Tana (AD048)	NA	Variety
NERICA-3(WAB-450-IB-P-28-HB	Africa rice	Variety
NERICA-4(49WAB-450-IB-P-9/1)	Africa rice	Variety
SUPERICA-1(WAB-4507)	Africa rice	Variety
Kokit(IRAT-209)-	IRRI	Variety
NERICA-12	Africa rice	Variety
NERICA-13	Africa rice	Variety
ARCCU16Bar-12-12-16-3-B-B	Africa rice	Genotype
UPLAND NERICA-15	Africa rice	Variety
UPLAND NERICA-18	Africa rice	Genotype
FOFIFA-4129	Africa rice	Genotype
FOFIFA-3737	Africa rice	Variety
FOFIFA-3730	Africa rice	Genotype

Table 4. Lowland rice varieties used in the study

Name and designation	Origin	Remark
Ediget (WAB189-B-B-B-HB)	Africa Rice	Variety
Gumara(IAC-164)	IRRI	Variety
X-JIGNA	North Korea	Cultivar
DEMOZE	IRRI	Cultivar
ROJOMENA271/10	NA	Genotype
IRGA370-38-1-1F-B1-1	IRRI	Genotype
PSBRC92	NA	Genotype
FKRS	NA	Genotype
IR75502-5-1-1-B	IRRI	Genotype
WAB95-B-B-40-HB	Africa Rice	Genotype
IR76999-52-1-3-2	IRRI	Genotype
WAB502-8-5-1	Africa Rice	Genotype
WABC165(IAC165)	Africa Rice	Genotype

Experimental design and field management

Two sets of experiments—lowland and upland—were carried out under rain fed conditions. Randomized complete block design with three replications was employed for both experiments. Plot size was $6m^2$ (5 m x 1.2 m) with six rows. Seeds were drilled in a 0.2m spaced rows with a seed rate of 60 kg ha^{-1}. Urea and DAP fertilizers were applied with a rate of 100 kg/ha for each location. Urea was applied in splits while DAP applied all at planting. Two to three times hand weeding and other agronomic and plant protection management practices were applied uniformly across the plots for the duration of the experiment.

Data collection and analysis

Data were collected on phenological and agronomic traits including grain yield. Grain yield was measured from four central rows in grams per plot and expressed as kilogram per hectare after adjusted to14% grain moisture content. The grain yield performance data was used for this analysis. The data were checked for mistakes and outliers. Location year combinations were used to represent an environment. Partitioning of the G × E was performed using the GGE model, which is inbuilt in GEA-R and META-R statistical software (Alvarado et al., 2015; Pacheco et al., 2015). The GGE refers to the genotype main effect and the G × E, which are the two most important sources of variation for cultivar evaluation in multi environment trials (Yan et al., 2007). A GGE biplot displays the genotypic main effect and G × E of a genotype by environment dataset (Yan et al., 2000). This biplot is specially and perfectly used for mega-environment analysis based on genetic correlation between environment and the which-won-where pattern (Crossa et al., 2002). The vector view and the which-won-where pattern biplots of the GGE were used for mega-environment analysis. The GGE biplot was constructed using the first two principal components (PC1 and PC2) derived from subjecting environment centered yield data (Yan et al., 2000).
The GGE model used was

$$Y_{ij} - \mu + \beta_j = \lambda_1 \xi_{i1} \eta_{j1} + \lambda_2 \xi_{i2} \eta_{j2} + \varepsilon_{ij}$$

where Y_{ij} is measured mean yield of genotype i (=1,2,….,n) in environment j (=1,2…,m), μ is the grand mean, β_j is the main effect of environment j, $\mu + \beta_j$ being the mean yield across all genotypes in environment j, λ_1 and λ_2 are the singular values (SV) for the first and second principal component (PC1 and PC2), respectively. ξ_{i1} and ξ_{i2} are eigenvectors of genotype i for PC1 and PC2, respectively. η_{1j} and η_{2j} are eigenvectors of environment j for PC1 and PC2, respectively. ε_{ij} is the residual associated with genotype i in environment j.

Results and Discussion

The environment vector view of the GGE biplot facilitates visualization of the genetic correlations between test locations in ranking genotypes based on yield. Lines that connect the biplot origin with environment markers are known as environment vectors and the angle between the vectors of two environments is related to the correlation coefficient between the environments, which is approximated by the cosine of that angle. Acute angles indicate a positive correlation, obtuse and right angles show negative and no correlation, respectively (Yan and Kang, 2003). Visualization of the 'which-won-where' pattern in the polygon view is helpful to estimate possible existence of different mega-environments in the target environment (Yan and Rajcan, 2002; Yan et al., 2000). The polygon was drawn on genotypes placed away from the biplot origin so that all genotypes are contained in the polygon. The perpendicular lines radiating from the origin divide the biplot area as well as the test locations into sectors.
The mega-environment analysis was made based on two biplots of the GGE and Dendrogram clustering using GEA-R package of R developed by CIMMYT. For the lowland rice, most of the environments appeared to be positively correlated while some of the environments showed negative correlation (Figure 1a). The "which-won- where" pattern biplot divided the environments into 8 sectors in which only 5 have environments fell- in. This could suggest presence of different mega-environments (Figure 1b). It is important to note that conclusions from mega-environment analysis have a long term effect on breeding and cultivar recommendation and must be based on multiyear data (Yan,2014); and both the location vector view and the 'which-won-where' forms of the GGE biplot for mega-environment delineations are useful and should be used complementarily. However, in the present study both biplots suggested different number of mega-environments. Furthermore, the grouping was not clear in either of the biplots. To substantiate this result, Dendrogram grouping was analyzed using GEA-R and it showed two major mega-environments of the lowland rice ecosystems of Ethiopia (Figure 1c). Considering the complementarity of all these results, we suggest two mega-environments of the lowland rice ecosystem of Ethiopia. It was becoming apparent that Fogera represents one of the groupings, while the second one includes Pawe and Bako. Nevertheless, this suggestion should be supported with other historic performance data and with edaphic (water and soil) and environmental factors (temperature) that significantly affect rice growth, development and overall performance.

For the upland rice, most of the environments appeared to be positively correlated while some of the environments showed negative correlation (Figure 2a). The "which-won- where" pattern biplot divided the environments into 5 sectors in which only 4 have environments fell in. Different mega-environments (Figure 2b). A study by Tadesse et al (2017) claimed different upland rice mega-environments in northwestern

Ethiopia are claimed by Tadesse *et al*. (2017). Dendrogram grouping showed two major mega-environments of the upland rice (Figure 2c). However, these results should be used complementarily. Thus, we suggest two mega-environments of the upland rice ecosystem of Ethiopia. In line with the current study, Sewagegne (2017) suggested two upland mega-environments in northwestern Ethiopia. Similarly, with the lowland rice, it was becoming apparent that Fogera represents one of the groupings, while the second one includes Pawe, Assosa, and Bako. Nevertheless, this suggestion should be supported with other historic performance data and with water, soil, and temperature that significantly affect rice growth, development and overall performance.

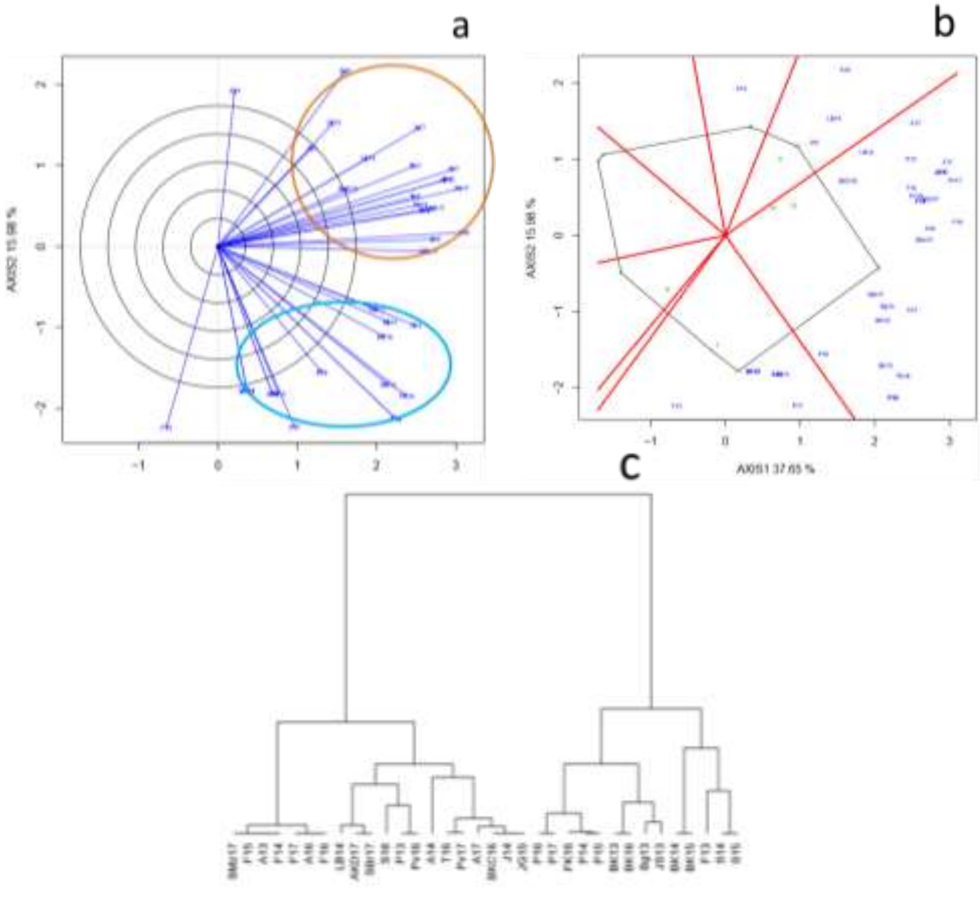

Figure 1. Biplots and a dendrogram for lowland rice mega-environment analysis. a) Interrelationships among different environments; b) Which-won-where pattern; and c) Dendrogram grouping of environments. S15, SMz17 are codes to represent environments (location by year combination); abbreviated letters represent locations designated as S, Shire; F, Fogera; BK, Bako; JS, Jimma-Shibie; Bg, Bonga; P, Pawe; FK, Fogers-Kokit; JG, Jumma-Gojeb; J, Jimma; BKC, Bako-Chewaka; A, Assosa; PV, Pawe village-7; T, Tepi; SBr, Shire- Borekie; AKD, Assosa-Keshmando; LB, Libo Kemkem; SMz, Shire-Mezekire; and the suffix numbers to each abbreviated locations represent the years that the experiment was conducted.

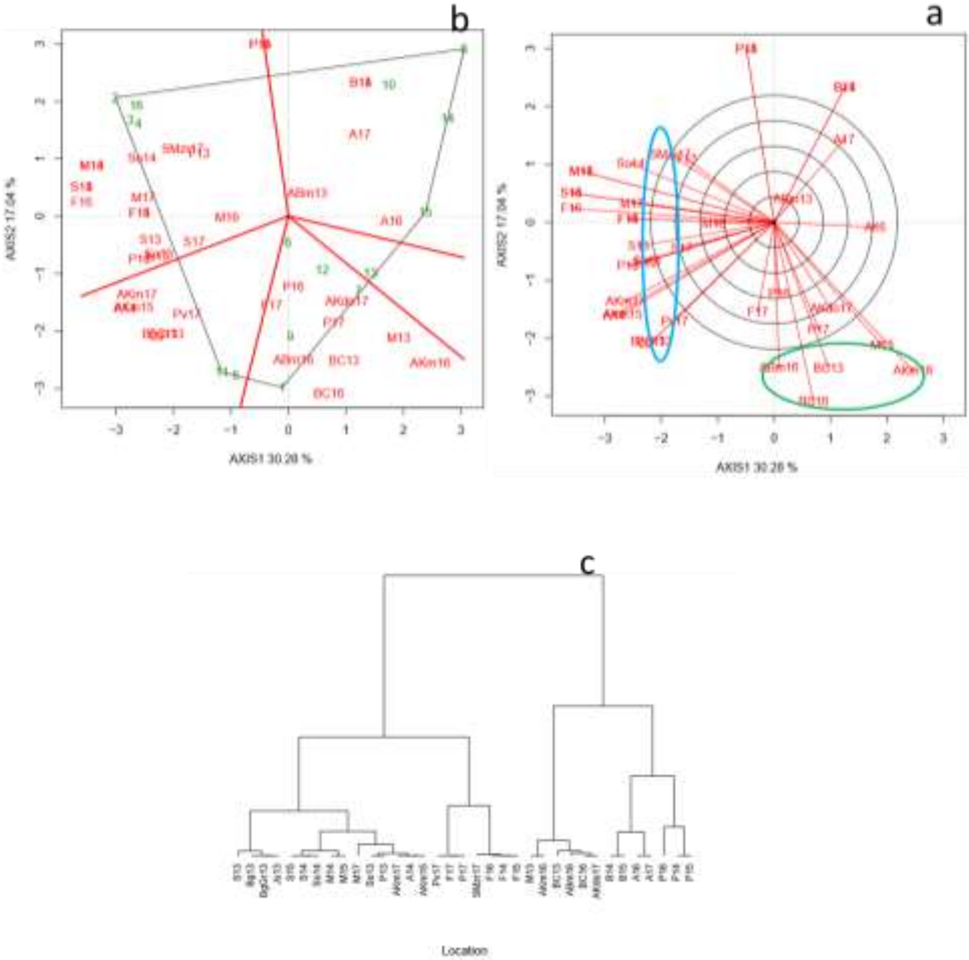

Figure 2. Biplots and a dendrogram for upland rice mega-environment analysis. a) Interrelationships among different environments; b) Which-won-where pattern; and c) Dendrogram grouping of environments. P15, S13 are codes to represent environments (location by year combination); abbreviated letters represent locations designated as P, Pawe; A, Assosa; B, Bako; AKDO, Assosa-Kashmando; BC, Bako-Chewaka; ABm, Assosa-Bambasi; AKm, Assosa-Kemash; M, Metema; F, Fogera; SMzr, Shere-Mezekire; PV, Pawe village-17; SO, Shire-Onfarm; S, Shirie; JS, Jimma-Shibie; BgGr, Bonga-Guraferda; Bg, Bonga; and the suffix numbers to each abbreviated locations represent the years that the experiment was conducted.

Conclusion

Mega-environment analysis did not strictly follow the biophysical environment, i.e., ecosystem, both in the lowland and in the upland. Generally, two mega-environments recovered in each of the ecosystems considered in this study, i.e., lowland and upland. Nevertheless, this suggestion should be supported with other historic performance data and with water, soil, and temperature that significantly affect rice growth, development and overall performance. However, Fogera and Pawe consistently stands in a distinct and different grouping in both upland and lowland rice ecosystems of Ethiopia and could be considered as two different test locations in the national rice research program.

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Molecular Breeding and Biotechnology for Rice Improvement in the Developing World

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Historical accounts

The existing biodiversity is the product of continues genetic changes that were necessary to adapt to their dynamically changing environment. The process was gradual that took hundreds of years before visible changes occurred. Humans' ability to domesticate plants and the knowledge to breed them gave way to speedy evolution of domesticated crops (ISAAA, 2014). Plant breeding as a science began with the work of Gregor Mendel (Garland 1978). Conventional breeding approach relies on selection of plants with desirable traits after cross–fertilization between two parents. Since the industrial revolution where the demand for agricultural crops both for consumption and as industrial inputs grew exponentially, it was obvious that classical plant breeding techniques needs radically different approach to meet the demand efficiently. Biotechnology is one of the modern tools the enables scientists to induce some changes in the plant system to generate a particular product of interest in a desired quality and/or quantity (ISAAA, 2014).

Biotechnology is not a single technology. Though essential process involves; working with living cells and their molecules, and there are different approaches to achieve this; mutation breeding, tissue culture and micro-propagation, molecular breeding or marker assisted selection, genetic engineering, gene editing and molecular diagnostic tools (Keener, 2007). Recently, further to conventional breeding approaches rice breeders in many instances integrated biotechnology and molecular breeding tools in their breeding programs. Various plant tissue culture techniques have been applied for rice crop improvement for more than 30 years. While in vitro fertilization can be used to avoid physiological incompatibility in both interspecific and inter-generic crosses, embryo rescue technique has been utilized against post-zygotic embryo abortion due to poor endosperm development. African home grown rice varieties, NERICAs, are the product of embryo rescue techniques as they were generated through interspecific crosses between African cultivated rice *O. glaberrima* and the *O. sativa* (Zenna et al., 2017).

The first green revolution began in the 1960s with the development of higher yielding varieties of wheat and rice that prevented massive global food shortages around the world. That giant leap to producing more food involved the cross-breeding of unrelated varieties of rice to produce new varieties of rice that grew faster and produced higher yields, mainly by being able to respond better to fertilizer and management practices. However, recent climate change that keeps destroying paddies through floods, drought and storms while at the same time pests and diseases that evolve to resist herbicides and pesticides become a big menace to rice production necessitating multidisciplinary approaches to address production constraints.

The availability of the rice genome sequence has greatly advance rice improvement in several fronts the increase in molecular markers and identification of markers near annotated genes enable researcher to predict gene-trait associations. The reduction in DNA sequencing costs that allowed researchers to re-sequencing additional rice accessions and call nucleotide variations relative to the reference genome; in-depth sequence-based analysis of variation in cultivated and wild rice that allow breeders to better understand and exploit genetic variation and increase in genetic gain; and molecular understanding of the genetic basis fertilizer use efficiency such as; N and P-use, allows rice researchers to engineer varieties with fewer inputs (Jackson, 2016).

Rice is the first fully sequenced cereal crop in 2002. The impact this genome sequence made on rice genetics and breeding research was immediate, as evidence rampant DNA marker use. Furthermore, the sequence information accelerated the product development for both biotic and abiotic stresses through transgenic and non-transgenic approaches. The list of the references and the markers so far developed on rice attached in the Appendix I recognizing the enormous potential of DNA markers in plant breeding, many agricultural research centers, and plant breeding institutes have invested on their capacity for marker development and marker-assisted selection (MAS) programs. There were also rapid developments in marker technology and statistical methodology for polygenic traits by identifying the quantitative trait loci (QTLs) to address largely to abiotic stress tolerance issues in rice (Collard and Mackill, 2008).

The rapid advancement registered in molecular technologies and the need to address the emerging global rice production challenges necessitates rice research institutions to transform their mode of operations. Consequently, in 2010 the Global Rice Science Partnership (GRiSP) was established as an initiative of the CGIAR to bring together research and development partners from around the world for synergistic effort in rice research. It is an impact oriented partnership with the aim to solve the common global problems of food security for present and future generation, sustainable rice-based production; climate change, efficiency and equity of the rice sector. The research activities are aligned with 900 research and development partners in the rice-growing world especially from developing nations. GRiSP is being led in Asia by the International Rice Research Institute (IRRI), in Africa by the Africa Rice Center (AfricaRice), and in Latin America by the International Center for Tropical Agriculture (CIAT); in addition to the CGIAR centers, three non-CGIAR organizations, CIRAD, IRD from France and JIRCAS from Japan are also involved in the initiative (GRiSP, 2010).

GRiSP has also introduced a Global Phenotyping Network in 2011 to accelerate the discovery of useful genes and alleles for molecular breeding at a large scale. The Network also aims to bring together the community of rice scientists to work together towards enhancing the power of phenomics—the measurement of traits on plant populations carrying diversity—for important traits such as yield, resource use efficiency, and responses to major environmental stresses. All partners are working on the same diversity panels and share data that would enable genome-wide association studies (GWAS) and analysis of G x E and trait x trait interactions. Field and controlled-environment based phenomics experiments are ongoing in different countries including in the laboratories of Australia, the US and Japan (GRiSP, 2012). This initiative also provided unique opportunity for researchers from developing countries to obtain short and long-term trainings and be part of the global consortium to address the challenges.

Major achievements and current status

Improvement for abiotic stress tolerance

Global climate change has threatened the production of many agricultural crops including rice. Abiotic stresses such as drought, flooding, soil salinization, extremely low and high temperatures, and other adverse environmental conditions result in major loss to rice yield. Though high-yielding varieties are mostly susceptible, wide variation exists in rice gene pool, which is being utilized to improve the cultivated varieties.

Drought

Drought is one of the major causes of severe food scarcity in the developing countries. This stress is commonly observed in rainfed areas, upon failure of rain or a long interval between two rains. Drought can occur at any of the rice growth cycle, however, when it occurs at reproductive stage it causes substantial yield loss (O’Toole 1982). Courtois et al. (2000) identified 42 QTLs for drought-related traits in rice among which 11 were for leaf rolling, 10 for leaf drying, 11 for relative water content, and 10 for relative growth rate under stress. Due to the complex polygenic nature of drought tolerance, major QTLs have been considered for effective tolerance. The first large-effect QTL, *qDTY12.1*, for grain yield under reproductive-stage drought was reported in the Vandana/Way Rarem population explaining nearly 51% of the genetic variance (Bernier et al. 2009, 2007; Dixit et al. 2015). Major QTLs have also been reported for grain yield under lowland drought stress conditions explaining 32 and 36 % of the genetic variance (Kumar et al. 2007; Venuprasad et al. 2009). Other major QTLs for grain yield under reproductive-stage drought stress have been identified (Appendix I).

Salinity

One-fifth of irrigated arable lands in the world are affected by high soil salinity (Negrão and Courtois 2011). Excessive use of irrigation water without proper drainage system and poor-quality irrigation water are major causes of salinity in this ecology. Though rice is relatively tolerant to salinity during germination, active tillering, and maturity, seedling and reproductive stages are highly susceptible to the salinity (Ismail et al. 2007; Munns 2008; Singh and Redoña 2010). There are wide range of reaction to salinity in the rice germplasm. Molecular studies indicated that salinity tolerance at different growth stages are controlled by different genes and several QTLs associated with salinity tolerance in rice has been identified (Appendix I). The major QTL Saltol/SKC1 is identified in the short arm of chromosome 1 (Lin et al. 2004) and since then used to improve many popular varieties in Asia.

Flood and submergence

Flooding and submergence are important problems in lowland rice farming ecologies. A major QTL was finely mapped near the centromere of chromosome 9, designated as Submergence *1* (Sub1*)*, the locus showed 70 % of phenotypic variation in submergence tolerance. This QTL has been proven to help plants survive up to three weeks of continuous submersion. IR64-Sub1cultivar carrying QTL/Sub1 gene was successfully used in backcross breeding programs to alter the submergence tolerance of improved high-yielding Vietnamese rice cultivars (Lang et al., 2013; Lang and Buu, 2011).The sub1 gene is also used to improve popular verities in Africa and some improved varieties have already been released in Nigeria.

Improvement of biotic stress resistance

Rice is attacked by plethora of diseases and yield loss due to pests and diseases ranges between 24 and 41 % (Sparks et al. 2012). There were exciting progresses made through molecular techniques to reduce the yield loss and maintain the grain quality of the crop.

Blast disease

Rice blast *Magnaporthe oryzae* is at the forefront of the most devastating diseases in most of rice growing ecologies. The fungus causes disease at seedling and adult stages on the leaves, nodes, and panicles. Conventional genetic and advanced molecular analysis techniques have resulted in identification of more than 100 genes for resistance to *blast* (Sharma 2012) and some have been designated as *Pi1-Pi62*, *Pii*, *Pia*, *Pib*, *Pik*, *Pi-kh* (*same as Pi54*), *Pit*, *Pita*, *Pita 2*, *Pitp*, *Pish*, etc. (Wang et al. 2014a). Through marker-assisted backcross breeding technique resistance genes, viz., Piz-5 and Pi54, from the donor lines C101A51 and Tetep into the genetic background of PRR78 were introgressed (Singh et al. 2012). Different researchers (Appendix I) also identify other relevant genes for blast genes.

Sheath blight

Rice Sheath blight produces toxin that induces characteristic symptoms on rice leaves and wilting of seedlings and inhibits rice radicle growth. This disease is prominent in cold prone ecologies. Accessions from both *O. glaberrima* and *O. sativa* have been identified with resistance to sheath blight. The relatively high-resistant accessions belonged to mixed genetic groups. Several researchers have also explored wild accessions or their derivatives for Sheath blight resistance (Lakshmanan 1991; Prasad and Eizenga 2008). Six QTLs for sheath blight resistance are identified from Teqing/Lemont breeding lines (Li et al. 1995) (Appendix I).

Bacterial *l*eaf *b*light

Bacterial leaf blight (BLB) or bacterial blight (BB) caused by the pathogen *Xanthomonas oryzae pv oryzae* (Xoo) is one of the most destructive bacterial diseases of rice (Rao and Lakshminarasu 2002). Several dominant and recessive genes were identified that operates in gene for gene host-pathogen interaction (Mew 1987; Vera Cruz 1989) (Appendix I). Four *Xa* genes have been cloned and six others have been tagged with molecular markers and employed for marker-assisted selection and release of resistant cultivars in several countries. Huang et al. (1997) pyramided four resistance genes into IR-24 background. A broad spectrum bacterial blight resistance gene *Xa-21* was identifed from the wild species *O. longistaminata* and introgressed into *O. sativa* background (Khush et al., 1989). Through marker-assisted selection approach Sanchez et al. (2000) introgressed three bacterial blight resistance genes *Xa-5*, *Xa-13*, and *Xa-21* into three promising new plant types. The same set of genes were also pyramided into a popular varieties in India (Sundaram and Vishnupriya 2008; Singh et al. 2001).

Virus resistance

Rice Tungro virus (RTV) is a predominant virus in Asia. Although several source of resistance and QTLs were identified for this virus, the markers assisted breeding work is not efficiently implemented due to the complexity of the virus and lack of major QTL for the resistance (Cabauatan et al., 2009; Encabo et al., 2009; Dia and Beachy 2009). Rice grassy stunt virus (RGSV); rice hoja blanca virus (RHBV) (Lentini et al., 2003)and rice stripe virus (RSV) (Maeda et al., 2006) are also detrimental viral diseases causing havoc in Asia and Latin America. In Africa, Rice Yellow Mottle Virus (RYMV) is a predominant virus that is found across the continent (Zenna et al., 2017). Three genes were identified for the resistance; *Rymv1-1*, *rymv1-2*, *rymv1-3* and these genes are successfully introgressed into popular varieties genetic background and field tested in both East and West African countries (Ndjiondjo et al., 2013).

Herbicide tolerance

Considerable efforts have been invested to produce herbicide tolerant crops to simplify weed management and to alleviate problems that arise from herbicide residues. Currently three major herbicide tolerant systems are commercialized. These products are based on resistance to herbicides inhibiting amino acid biosynthesis, which include imidazolinone (IMI), glyphosate, and glufosinate resistance (Duke 2005). Reports have showed that all the three systems have been deployed in rice (Scarabel et al. 2012; Tsai et al. 2006; Wang et al. 2014b). The potential of biotechnology to successfully reduce pesticide use has been one of the major points stressed by the supporters of genetically modified (GM) crops.

*Lodging r*esistance

High-yielding varieties with natural plant height generally suffer from lodging while dwarf plants have relatively less lodging problem. In addition to plant height, lodging resistance also depends on the physical strength of culms (Ookawa and Ishihara 1993). Recent development of the disomic derivatives of *Oryza latifolia* in the background of *O. sativa* has shown high culm strength, and these are being considered as lines with potential to improve lodging resistance in cultivated rice stem (Angeles-Shim et al. 2014).

Yield component traits

Yield is one of the most complex traits in the genetic improvement of rice. Efforts have been exerted for many years to implement functional genomics in rice. Cloning and functional characterization of genes that may be associated to or directly related to yield traits have led to considerable progress in the understanding of molecular and biological processes underlying yield related traits in rice. Grain yield of a rice plant is determined by three major traits: number of tillers/panicles per plant, number of grains per panicle, and grain weight. In recent years, advances in molecular marker, genome mapping, and quantitative trait loci (QTL) analysis technologies have greatly facilitated the studies on the genetic bases of these yield components (Biswal et al., 2017).

Number of tillers/panicles per plant

Several major QTLs have been identified to influence the number of panicles (Appendix I). Two QTLs affecting the number of panicles on chromosomes 4 and 6 in both populations were identified and designated as *pn4* and *pn6*, respectively (Rahman et al. 2008). In addition, genome-wide association study (GWAS) has employed three multi-parent advanced generation intercross (MAGIC) populations from elite *indica* lines to identify QTLs for several yield traits and has revealed a QTL for panicle number designated as *qPN2* (Meng et al. 2016).

Number of *g*rains per *p*anicle

Number of grains per panicle is the function of three physiological events: panicle development, rate of spikelet formation, and duration of panicle differentiation (Tripathi et al. 2012). Panicle development is the start of reproductive phase and is influenced by interaction of phytohormones and several genetic factors. Functional genomics study Komatsu et al. 2003 identified two main regulatory genes of axillary meristem formation in rice. These include the LAX PANICLE1 (*Lax1*) and SMALL PANICLE (*SPA*) genes. Another study has suggested that Ghd7 positively regulates both tiller and panicle branches in a density-dependent manner, indicating that Ghd7 influences the control of branch development in response to environmental conditions (Weng et al. 2014).

*Grain w*eight

Grain weight is highly correlated to yield potential. Grain length, grain width, and grain filling determine the nature of grain weight. Studies in QTL mapping and cloning have made significant progresses on identification of genes and major QTLs regulating grain weight. The major genes/QTLs reported to regulate these parameters are GW2, GS3, and GIF1 (Tripathi et al. 2012).

C4 rice

Photosynthesis, the basic process by which plants use the sun's energy, water, nutrients, and carbon dioxide, has been identified as a potential area to increase innate productivity of the rice plant. For instance, C4 photosynthesis is one of the most remarkable adaptations within the flowering plants. The maximum energy conversion efficiency of C4 photosynthesis mainly depends upon its CO_2 concentration mechanism in contrast to the common C3 photosynthesis systems of the most of the terrestrial plants including rice (Kellogg, 2013; Wang et al., 2014b).

In all plants, CO_2 is fixed by the enzyme ribulose-1,5-bisphosphate carboxylase/ oxygenase or Rubisco. In C3 plants, this process occurs in the mesophyll cells located on the surface of the leaf. In fact, C4 photosynthesis has been proposed as a polygenic quantitative trait (Westhoff & Gowik 2010). Currently, the phase III of the C4 Rice Project is underway, which may allow for a more refined genetic toolkit that has been assembled in the previous stages and a greater understanding of the regulatory mechanisms that establish the pathway in C4 plants (Zhu eat al., 2010).

Genetically modified rice

Genetic engineering technology is another tool with a capacity to introduce useful genes from non-rice gene pool into rice with least disruption to rice genome. Several rice verities have been improved to withstand against biotic and abiotic stresses through genetic engineering. Iran, the first country to approve commercial growing of transgenic rice in 2005, is growing Bt rice in about 0.1 million hectare. Though China has completed the field trials of Bt rice, it is yet to start commercial cultivation. India also undertaken limited field trials of GM rice for resistance to yellow stem borer (Bt rice), sucking insects like BPH resistance (with lectin) and bacterial blight resistance (with Xa21) were field tested, these are yet to be released for commercial cultivation (Zhi et al., 2004). Recently "Golden rice" (fortified with Vit A) engineered for the production of provitamin A (Ye et al. 2000) and iron fortified rice developed through enhancing the capacity of rice to uptake and store of iron (Murray-Kolb et al. 2002; Takahashi et al. 2001; Jahan et al., 2013) that promises to enhance the nutritional quality of rice to fight malnutrition, have been approved for field testing in the Philippines.

Status, challenges and opportunities

Technical challenges

Molecular biology studies have also their own challenges, for instance discovery of QTLs but with a minor effect on the phenotype, and identification of major QTLs that works across the rice germplasm are posing some difficulty for the breeders to use QTLs routinely to rice improvement and make selections in a field conditions (Gowda et al. 2011). Secondly, scarcity of QTL mapping studies using populations from intraspecific crosses in order to exploit interspecific crosses for novel alleles. Thirdly, the scarcity of adequately and uniformly distributed molecular markers for large effect QTLs fine mapping. The current genome sequencing approach that make use of high-density SNP genotyping platform along with next-generation sequencing (NGS) are expected to boost molecular breeding approach for rice improvement (Biswal et al., 2017).

Controversies over GM rice

Several concerns regarding the possible drawbacks on genetically modified (GM) rice have been raised. Some of these issues involve environmental and ecological safety, food safety, and ethical and economic issues. On an environmental and ecological perspective, the evolution of resistant pests and weeds termed as *superbugs* and *super weeds* raises an issue on the consequences of GM rice (Bawa and Anilakumar 2013). This is based on the uncertainty of whether the pest-resistant characteristic of these transgenic crops can escape to their weedy relatives causing resistant and increased weeds. Similarly, herbicide-resistant transgenic crops are also speculated to cause the surrounding weeds to develop resistance as well. This has led to the topics regarding prevention of gene flow from transgenic crops to wild type. These concerns highlight the importance of biosafety regulations if large-scale adoption of transgenic varieties is to be carried out (Biswal et al., 2017).

Another major concern of GM crops, such as rice, is in its safety for human consumption as health risk may arise from consumption of GM foods that may consist toxins and allergens (Bajaj and Mohanty 2005). There is still a great amount of uncertainties, especially in the large-scale adoption of GM rice. Thus, it is understandable that the incorporation of GM rice into agricultural production will continue to be debated. All of these show the significance of weighing the immense potential benefits of GM rice in food supply and the possible risks that it entails. As a result, GM products are subjected to strict regulatory obstacles. Nevertheless, new gene editing techniques using CRISPR/Cas 9 protocol has proven to increase the efficiency of precise gene transfer and thus may simplify the process of genetically modified crops with less cumbersome biosafety regulations (Jaganathan et al., 2018). Unlike the transgenic approach, which leads to random insertions and very often random phenotypes, genome editing methods produce precise insertion or deletion events. Genome edited crops have an additional advantage over transgenic plants since the gene to be modified is already existing in the plant DNA (Malzahn et al., 2017). The product from this technology can be used directly without much of the issues that have been raised with the GM crops and hence it requires relatively lesser regulatory procedures (Waltz, 2018). The benefit of biotechnology has also encouraged many private corporate to participate; however, the major challenge would be the intellectual property rights claims by these companies. Intellectual property right biological organisms and their components, including seeds that puts question on the appropriateness of property rights associated with nature (Herdt, 1997).

Opportunities for developing countries

Conventional breeding is the basis for the development of essentially all varieties of plants used in African agriculture today, which is slow and can take up to 10 years before a new variety is released. Developing an efficient and sustainable agriculture in the face of major global threats including climate change, soil degradation, water scarcity, and biodiversity erosion coupled with a continual population growth represents an imperative for establishing a coherent strategy that ensures food security. Marker-assisted rice breeding has made remarkable progress for varietal improvement as well as functional studies. The ability to screen several genotypes for several traits at once setting through High-throughput and cost effective marker techniques, such as SNP chips would be essential ingredient to accelerate breeding program in developing countries. Countries can also capitalize on the knowledge and resources available at the

Consultative Group for International Agricultural Research (CGIAR) Centers, while developing homegrown capabilities to adapt biotechnology as a mainstream crop improvement protocol (Herdt, 1997).

Application of the new gene editing techniques using CRISPR/Cas9 method promised to result in the development of non-genetically modified (Non-GMO) crops with the desired trait that can contribute to increased yield potential under biotic and abiotic stress conditions (Jaganathan et al., 2018). CRISPR/Cas9 method of gene editing has been adopted in nearly 20 crop species so far (Ricroch et al., 2017) for various traits including yield improvement, biotic and abiotic stress management. Functional Studies of Biotic and Abiotic Stress-Related Genes A CRISPR/Cas9 targeted mutation in the ethylene responsive factor, OsERF922 in rice, has been successfully established to increase resistance to blast disease caused by *Magnaporthe oryzae* (Liu etal.,2012).

Future direction

In addition to the two fundamental components to enhance agricultural productivity; advances in technical skill and knowhow and strong background on biological sciences and its application (genetics, plant physiology, biology of biotic and abiotic stress, in developing countries context establishing sustainable agricultural system through the use of biotechnology tools would require three major conditions

Resources: biotechnology is a highly sophisticated process requiring a certain critical mass of intellectual, technical, and financial resources. This may also require networking and outsourcing not only at the national levels, but also at the regional, continental, and global level.

Product concept: this helps the breeding program to have clear direction through understanding on the types of product to emphasize; trait prioritization based on market size and which biotechnological tools to use; the combination of products required by growers, processors, marketers, and consumers; and the extent to which product development interventions are consistent with beneficiary requirements, country priorities and policies (Kebede and Lambrides 2018 unpublished).

Public - private partnership (PPP); in the developing countries, private-sectors are the key to delivering quality seeds to the farmers; public-sector is usually not efficient. Furthermore; the local seed industry has the potential to get involved in improving crops ignored by the major companies, which are nevertheless much adapted to the local environment and cater to the local tastes. This in turn may empower the local people by way of recognition and enhanced employment opportunities, and through conservation of biodiversity "conservation through use". These contributions could add on the agricultural sustainability agenda and could play important role in ensuring food security (Taggar 2017).

It is a fact that biotechnology has a key contribution in product development in modern agriculture. The recent integration of advances in molecular biology, genomic research, transgenic breeding, and molecular marker applications with conventional plant breeding practices has introduced ‘precision’ breeding tools. For a developing nations to become beneficiaries of this technology concerted efforts from local governance, private companies and international communities is required by making the technology affordable and accessible to developing world researchers. The empowered researchers can contribute efficiently towards addressing major United Nations new Sustainable Development Goals such as: sustainable food system, health and wellbeing, climate restoration, and economic growth through partnership for a common goal.

In most cases, geneticists and breeders are mainly exploiting genomic selection strategies for more efficient marker assisted crop improvement. For instance marker assisted breeding technique was used to integrate eight QTLs markers for improving grain weight and spikelet number per panicle into a single genetic background (Zong et al., 2012); four blast resistance genes into Thai rice (Suwannual et al., 2017); and three drought yield QTLs, qDTY2.2, qDTY3.1, and qDTY12.1 into Malaysian rice (Shamsudin et al, 2016). Several QTL markers that can be used in pyramiding of genes for the rice improvement are also presented in Appendix I. Furthermore, the abundance of rice sequencing data has laid a solid foundation for establishing a high-throughput genotyping system. This is important for gene identification and molecular breeding works and hence various SNP assay platforms are now used for genotyping (Thompson, 2014). This technology can be accessed through collaborative arrangements with biotech platforms in developed nations.

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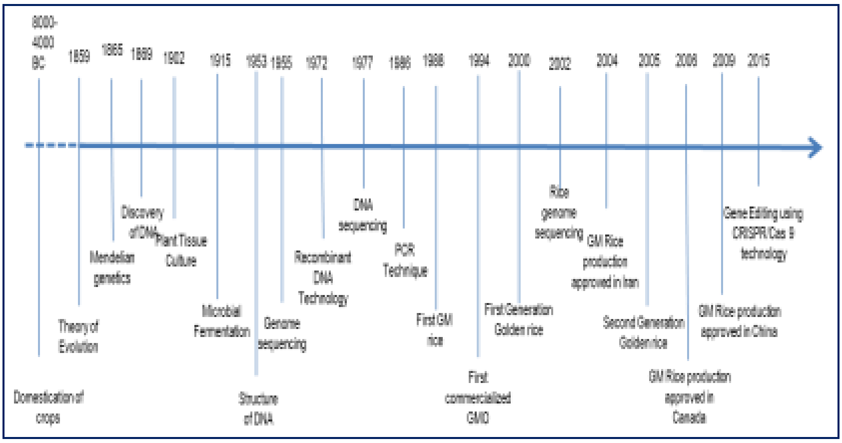
Appendix I.

List of QTLs used in rice crop improvement

QTL	Function	Cross	References
Abiotic stress tolerance			
qDTY12.1	Controls grain yield under reproductive-stage drought stress	Vandana and Way Rarem	Bernier et al. (2009), Bernier et al. (2007)
qDTY1.1	Controls grain yield under reproductive-stage drought stress	N22 crossed with Swarna, IR64, and MTU1010	Vikram et al. (2011)
qDTY2.2, *qDTY4.1*, *qDTY9.1*, and *qDTY10.1*	Major-effect QTL for improved grain yield under drought stress	IR64 and Aday Sel	Swamy et al. (2013)
qSKC-1	Controls rice salt tolerance	Nona Bokra and susceptible *japonica*, Koshihikari	Lin et al. (2004)
qSNC-7	Controls rice salt tolerance	Nona Bokra and susceptible *japonica*, Koshihikari	Lin et al. (2004)
Saltol	Controls Na/K ratio and seedling-stage salinity tolerance	Pokkali and IR29 (*indica*)	Gregorio (1997)
Sub1	Controls submergence tolerance	Submergence-tolerant *indica* line (IR40931-26) and susceptible *japonica* line (P1543851)	Xu et al. (2006)
qRL6.1	Major QTL for root length; promoted root elongation under a range of NH4+ concentrations	Koshihikari (*japonica*) and Kasalath (*indica*)	Obara et al. (2010)
QTL 2	Increased root penetration and deep root weight under well-watered conditions	Bala/Azucena RIL	Steele et al. (2013)
QTL 7	Increased root weight parameters and maximum root length	Bala/Azucena RIL	Steele et al. (2013)
QTL 9	Increased deep root thickness under both well-watered and drought conditions	Bala/Azucena RIL	Steele et al. (2013)
QTL 11	Increased root length and root penetration	Bala/Azucena RIL	Steele et al. (2013)
Biotic stress tolerance			
pi	Rice blast resistance	Lemont and Jasmine 85	Jia and Liu (2011)
qSB-11	Sheath blight resistance	Lemont and Jasmine 85	Liu et al. (2009)
qStv1, *qStv 7*, and *qStv11*	RSV resistance	Kinmaze and DV85	Ding et al. (2004)
qSTV7	RSV resistance	Nipponbare/Kasalath/Nipponbare	Zhang et al. (2011)
qSTV11KAS	RSV resistance	Nipponbare/Kasalath/Nipponbare	Zhang et al. (2011)
qBph4.2	Brown planthopper (Bph) resistance	Zhenshan 97 and IR65482-17 (*Oryza australiensis*)	Hu et al. (2015)
Yield trait improvement			
pn4	Controls panicle number	Junambyeo and introgressed *indica* IR71033-121-15	Rahman et al. (2008)
pn6	Controls panicle number	Junambyeo and introgressed *indica* IR71033-121-15	Rahman et al. (2008)
qPN2	Controls panicle number	Three MAGIC populations from elite *indica* lines (DC1, DC2, and 8 way)	Meng et al. (2016)
Ghd7	Controls grain per panicle, plant height, and heading date	Zhenshan 97 and ZS(tq7) near-isogenic lines	Xue et al. (2008)
Ghd8	Controls grain per panicle, plant height, and heading date	Zhenshan 97 (*ZS*) and HR5	Yan et al. (2011)
DTH8	Controls yield, plant height, and flowering time	CSSL61 and Asominori	Wei et al. (2010)
GW2	Controls rice grain width and weight	WY3 (*japonica*) and Fengaizhan-1 (high-quality elite *indica*)	Song et al. (2007)
GS3	Major QTL for grain length and size; minor QTL for width and thickness in rice	Minghui 63 (large grain) and Chuan 7 (small grain)	Fan et al. (2009)
GIF1	Controls grain filling	*gif1* and Zhenshan97 (*indica*)	Wang et al. (2008)

Appendix II

Historical evolution of molecular biology and biotechnology with emphasis on rice crop



Modified from Fraiture et al., 2016

Association of Traits of Lowland Rice Genotypes in Northwestern Ethiopia

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Introduction

The major cultivated species of rice, *Oryza sativa* (2n = 2x = 24), was originated in Southern and South Western Tropical Asia. The other species of cultivated rice, *Oryza glaberrima* (2n = 2x = 24), is indigenous to the upper valley of the Niger River and it is cultivated only in Western Tropical Africa (Ansari, *et al.*, 2015). Rice is providing two thirds of calorie intake for more than three billion people in Asia and one-third of calorie intake of nearly 1.5 billion people in Africa and Latin America (Khan *et al*., 2015).

In Ethiopia, rice is a source of income and employment opportunities for rice farmers. It is used in the preparation of local foods such as *enjera*, *dabo*, *genfo*, *kinchie*, *shorba* and local beverage like *tella* and *areke* (Gebrekidan and Seyoum, 2006; Asefa *et al*., 2011). Rice production in Ethiopia is predominantly constrained by biotic stress like termite, blast, brown spot diseases, and weeds; abiotic stress such as cold, drought and salinity. Moreover, shortage of adapted varieties to different agro-ecologies and lack of recommended crop management practices for different rice ecosystem (MoARD, 2010; NRRDSE, 2010; Lakew *et al*., 2014). Lack of awareness on its utilization, inadequate technology promotion and seed supply, skilled work force, erratic rainfall, flood and rice seed shattering were observed (Meron, 2016).

Knowledge on association of crop trait for yield with other related traits is essential to the breeder for making improvement in complex quantitative traits such as yield and for which trait direct selection is not much effective. Hence, association analysis is important to determine the direction of selection and number of traits to be considered in improving grain yield (Idris *et al*., 2012). Path coefficient analysis is a standardized partial regression coefficient and as such measures the direct and indirect effect for one variable upon another and permits the separation of the correlation coefficient into components of direct and indirect effect (Dewey and Lu, 1959). Since yield is a complex trait, indirect selection through correlated traits is less complex and easier measurable traits would be an advisable strategy to increase the yield. Efficiency of indirect selection depends on the magnitude of correlations between yield and target yield component traits (Bhatti *et al*., 2005). Breeding strategy in rice mainly depends upon the degree of associated traits as well as its magnitude and nature of variation (Zahid *et al*., 2006).

Rice breeders are interested in developing cultivars with improved yield and other desirable agronomic traits. Plant breeders have used path coeffiecent analysis to assist in identifying traits that are useful as selection criteria to improve yield (Dewey and Lu, 1959; Milligan *et al*., 1990). However, information about trait association between yield and related traits in introduced lowland rice improvement program is not yet well studied. Therefore, in view of this gap, the present study was carried out to evaluate the association between yield and related traits with the objective of estimating the extent of association between pairs of traits at genotypic and phenotypic levels and thereby comparing the direct and indirect effects of the traits.

Materials and Methods

The study areas

The experiment was conducted in 2015/16 cropping season at Pawe Agricultural Research Center and Fogera National Rice Research and Training Center. The locations are situated in northwestern part of Ethiopia in Benishangual Gumuz and Amhara Regional States, respectively.

Fogera National Research and training Center is located 607km from Addis Ababa. Particularly, the experimental site is located at 11^{0}58'N latitude, 37^{0}41'E longitude and at elevation of 1810m. Based on ten year's average metheorogical data ,the annual rainfall, mean annual minimum and maximum temperature are 1300mm ,11.5^{0}C, respectively. The soil type is black (*Vertisol*) with average pH of 5.90.

Pawe Agricultural Research Center is located 578km away from Addis Ababa. The experimental site is found at 13° 19' N latitude, 37° 24' E longitude and at an elevation of 1200m above sea level. The major soil type of the study site is well drained *Nitisol* with the pH value ranging from 5.3 to 5.5. The annual rainfall, mean annual minimum and maximum temperatures are 1587mm, 16.3°C and 32.6°C, respectively.

Experimental materials, design and trial management

The present study contained thirty six rice genotypes including two checks (Ediget and X-jigna). All rice genotypes were obtained from Fogera National Rice Research and Training Center. The experiment was laid out in a 6x6 simple lattice design at each location. The plot size was six rows of 5m length with 0.2m row spacing giving a total areas of 6m^2. Spacing of 1.0m and 0.30m were used between blocks and plots, respectively. For data collection, the middle four rows were used for determination of yield and yield component traits. The genotypes were planted by manual drilling at a rate of 36g per plot in 2015/16 cropping season at two locations. Recommended fertilizer of Urea and DAP at the rate of 64kg N/ha and 46 kg P_2O_5 /ha was applied to each experimental plot. P_2O_5 was applied all at planting time while N was applied in three splits (1/3 at planting, 1/3 at tillering and the remaining 1/3 at panicle initiation). Weeding was done by hand two to three times starting from 25 to 30 days after sowing depending on infestation level. All other important agronomic practices were applied as per the recommendation for rice production in the two locations during the growing season.

Data collected

Data were recorded on fourteen quantitative traits at the right growth stage according to the rice descriptors (IRRI, 2002). Days to 50% heading, fertile tillers per plant, plant height (cm), Panicle length (cm) culm length (cm), flag leaf length (cm), number of filled grains per panicle, number of unfilled grains per panicle, number of total spikelets per panicle, days to 85% maturity, biomass yield (g) grain yield (g) thousand grains weight(g) and harvest index (%) were collected.

Data analysis

Path analysis, phenotypic and genotypic correlations data was subjected to analysis by using SAS 9.2 (SAS, 2008) and GENRES Statistical Software (1994).

Correlation coefficient analysis

Genotypic coefficient of correlation (r_g) and phenotypic coefficient of correlation (r_p) were computed as per Robinson *et al*. (1955).

$$r_g = \frac{Covg\ (X.Y)}{\sqrt{Var\ gX}.\sqrt{Var\ gY}}$$

Where, Covg (XY) is genotypic covariance between characters X and Y
Var gX is genotypic variance of character X
Var gY is genotypic variance of character Y.

$$r_p = \frac{Covp\ (X.Y)}{\sqrt{VarpX}.\sqrt{VarpY}}$$

Where, Covp(XY) is phenotypic covariance between characters X and Y
Var pX is phenotypic variance of character X
Var pY is phenotypic variance of character Y.

Estimates of genotypic and phenotypic correlation coefficients were compared against r-values given in Fisher and Yates (1963) table at g-2 degrees of freedom, at the probability levels of 0.05 and 0.01 to test their significance, where g is the number of genotypes. To test the significance of correlation coefficients, the following formula was adopted (Sharma, 1998):

$$tna = \frac{r}{ser}, \quad sre = \sqrt{\frac{1 - r^2}{n - 2}}$$

Where, r is correlation coefficient; n is number of characters. To test the significance of correlation coefficient, the calculated t-value can be compared with tabulated t-value at (n-2) degree of freedom at 5% and 1% levels of probability (Snedecor and Cochran, 1981).

Path coefficient analysis

The measure of direct and indirect effects of each trait on grain yield was estimated using a standardized partial regression coefficient known as path coefficient analysis , as suggested by Dewey and Lu (1959). Therefore, correlation coefficient of different characters with grain yield was partitioned direct and indirect effects adopting the following formula:

$$riy = r1ip2 + \cdots r1ipi \ldots + rnipn$$

Where, riy=is correlation of i^{th} character with grain yield; r1ip2 is indirect effect of i^{th} character on grain yield through first character; rni is correlation between nth character and i^{th} character is the number of independent variables; pi is direct effect of i^{th} character on grain yield; pn is direct effects of character on yield.

The direct effects of different characters on grain yield were obtained by solving the following equations:

$$[riy] = [Pi]\,[rij]; \text{ and } [Pi] - 1\,[r1iPi]$$

Where, (Pi) is matrix of direct effect
(rij) is matrix of correlation coefficients among all the n^{th} component characters (riy) is matrix of correlation of all component characters with grain yield
(r1iPi) is indirect effect of i^{th} character on grain yield through first character.

The contribution of the remaining unknown factors was measured as the residual factor R, which was calculated as given in Dewey and Lu (1959).

$$R = \sqrt{(1 - \sum rik.pkj)}$$

The analysis was based on all yield contributed traits influencing yield. The estimated values were compared with table values of the correlation coefficient to test the significance of the correlation coefficient prescribed by Fisher and Yates (1967).

Results and discussion

Analysis of variance

The analysis of variance revealed that there were significant differences ($P < 0.01$) among thirty-six genotypes for most of the characters studied at two locations. However, number of filled spikelets per panicle, fertile tillers per plant, number of total spikelets per panicle and harvest index were non-significant at Pawe location while number of unfilled spikelets per panicle ($p < 0.05$) was significant at Fogera location.

However, unfilled spikelets per panicle and thousand grains weight was non-significant at both locations.

Table 1. Mean square values from analysis of variance, and coefficient of variation (CV) for 14 traits of 36 rice genotypes evaluated at Pawe and Fogera during the 2015/2016 main cropping season

Sources of variation	Location	Rep	Genotype	Location X Genotype	Intra block error	CV (%)
DF	1	25	35	35	10	2.82
DH	2240.44**	16^{ns}	149.69**	13.003*	5.73^{ns}	
DM	3.67^{ns}	150.06^{ns}	199.89**	112.82**	28.51^{ns}	5.7
PH	17897.98**	64.80*	706.98**	140.71**	30.74*	4.71
PL	282.24**	0.04^{ns}	6.77**	2.34**	2.15*	5.52
CL	10760.61**	33.64^{ns}	670.62**	126.47**	30.95*	5.6
FLL	1622.75**	0.51^{ns}	32.95**	23.59**	8.84^{ns}	10.37
FSPP	16409.61**	294.69*	173.58**	110.67**	58.29^{ns}	6.48
USPP	0.56*	1.89*	0.25*	0.11^{ns}	0.09^{ns}	22.32
FTP	189.98**	38.65**	3.46**	2.83**	4.66**	15.99
NTSPP	11481.12**	377.00*	183.82**	125.48**	71.32^{ns}	6.61
TGW	201.24**	25.33^{ns}	17.85*	12.54^{ns}	2.50^{ns}	11.66
BY	44.11**	15.41*	7.55**	2.01*	1.64^{ns}	11.28
PY	524929.20^{ns}	118043.80^{ns}	3264619.3**	1490636.3*	936552.1^{ns}	13.96
HI	0.04**	0.024**	0.005**	0.0034*	0.002*	12.97

CV = Coefficient of Variation and DF= Degree of Freedom ""= Significant at 5% probability level and "**"= Highly significant at 1% probability level and NS= Non- Significant. BY= Biomass Yield, DH= Days to Heading, CL= Culm Length, DM= Days to Maturity, FSPP = Filled Spikelets per panicle, FLL= Flag Leaf Length, FTP= Fertile Tiller per plant, PY= Paddy Yield kg/ha , HI= harvest Index , NTSPP= Number of Total Spikelets Per Panicle, PH= Plant Height, PL= Panicle Length, TGW= Thousand Grain Weight, UGY= Unfilled spikelets per panicle.*

Character association

Phenotypic (rp) and genotypic (rg) correlation estimates between the various characters are presented (Table 2). A close values of genotypic and phenotypic correlations were observed between some trait combinations, such as days to heading with plant height, culm length with biomass yield, panicle length with flag leaf length, culm length with filled grains per panicle, biomass yield with harvest index and plant height with panicle length which might be due to reduction in environmental variance to minor proportions as reported by Dewey and Lu (1959). Yield exhibited positive and highly significant ($p<0.01$) genotypic correlation with days to heading (rg=0.678**), days to maturity (r_g=0.803**), filled grains per panicle (r_g=0.523**), fertile tillers per plant (r_g=0.702**), harvest index (r_g=0.668**), total spikelets per panicle (r_g=0.501**) and biomass yield per plot (r_g = 0.730**), respectively which shows that improving these traits may result in the improvement of yield as the results of positive and strong correlation (Table 2). Similarly, Iftekharuddaula *et al*. (2002) reported the positive correlation of grain yield with panicle length and harvest index. Moreover, days to heading (r_g= 0.532**), days to maturity (rg=0.471**), fertile tillers per plant (r_g=0.314*), total spikelets per panicle (r_p=0.382*), biomass yield (r_p=0.654**) and harvest index (r_p=0.430**) showed positive and significant correlation with yield at phenotypic level. Similar findings were reported by Nandan *et al*. (2010) for days to heading and Karim *et al*. (2014) who observed positive association between harvest index and yield. Indris *et al*. (2013) and Kishore *et al*. (2015) reported positive correlation of filled grains per panicle with yield. Laza *et al*. (2004) reported similarly for total spikelets per panicle with yield. Corresponding findings was noticed by Naseem *et al*. (2014) for days to maturity and total spikelets per panicle. Similarly, Fentie *et al*. (2014) confirmed positive correlation of biomass yield with grain yield.

Phenotypic correlation between the traits

Correlations between yield components and other quantitative traits help in understanding the association between the characters. Days to heading exhibited positive and significant ($p<0.01$) phenotypic association with days to maturity (r_p=0.747**), panicle length (r_p=0.356*), filled grains per panicle (r_p=0.457**), biomass yield (r_p=0.648**) and total grains per panicle (r_p=0.427**). Days to maturity showed significant correlation at ($p<0.01$) with biomass yield (r_p=0.565**) .

Plant height showed positive and significant correlation with culm length (r_p=0.995**), flag leaf length (r_p=0.687**), panicle length (r_p=0.403*), above ground biomass yield (r_p=0.337*) and thousand grains weight (r_p=0.464**) and negative and significant correlation with harvest index (r_p=-0.566**). The finding is in conformity with Ghosal *et al. (*2010) and Kishore *et al. (*2015) for panicle length. Moreover, panicle length showed significant and positive association with culm length (r_p=0.333*), flag leaf length (r_p=0.539**), filled grains per panicle (r_p=0.426**), total grains per panicle (r_p=0.387*) and biomass yield (r_p=0.539**).

Culm length had significant and positive association with the traits such as flag leaf length (r_p=0.656**) and 1000 grain weight (r_p=0.482**) whereas it had negatively associated with harvest index (r_p=-0.559**). Flag leaf length manifested positive and significant association with 1000 grains weight (r_p=0.368*) and had negative association with harvest index (r_p=-0.520**). Number of filled grain per panicle showed a positive strong to moderate correlation with number of total grain per panicle (r_p=0.951**) and biomass yield (r_p=0.466**), respectively. However, in contrary to the observation of Karim *et al*. (2014) who reported highly significant negative correlation between 1000 grains weight and number of filled grain per panicle. According to Adams and Grafius (1971) the negative correlations arise primarily from competition for a common possibility, such as nutrient supply. If one component gets advantage over the other, a negative correlation may arise. The genetic reasons for this type of negative association may be linkage or pleiotropy. Number of total grain per panicle revealed positive correlation with biomass yield (r_p=0.418*).

Table 2. Estimates of genotypic (r_g) above diagonal and phenotypic (r_p) correlation coefficients below diagonal for fourteen traits of thirty six genotypes studied at two locations during 2015/16 main cropping season.

Trait	DH	DM	PH	PL	CL	FLL	FGP	UGP	FTP	TGP	BY	TSW	HI	GY
DH	1	0.930**	-0.098	0.509**	-0.138	0.195	0.614**	0.396*	0.281	0.588**	0.731**	-0.305	-0.083	0.678**
DM	0.747**	1	-0.075	0.446**	-0.116	0.186	0.459**	0.154	-0.001	0.431**	0.756**	-0.099	0.067	0.803**
PH	-0.089	-0.063	1	0.450**	0.997**	0.783**	0.076	-0.402*	-0.311	0.053	0.337*	0.680**	-0.702**	-0.145^{ns}
PL	0.356*	0.277	0.403*	1	0.369*	0.511**	0.503**	0.500**	0.292	0.524**	0.729**	-0.061	-0.439**	0.415*
CL	-0.127	-0.095	0.995**	0.333*	1	0.756**	0.043	-0.453**	-0.362*	0.019	0.300	0.685**	-0.695**	-0.178^{ns}
FLL	0.115	0.104	0.687**	0.539**	0.656**	1	0.319	-0.029	-0.347*	0.309	0.411*	0.497**	-0.667**	-0.046^{ns}
FGP	0.457**	0.296	0.104	0.426**	0.068	0.235	1	0.659**	0.005	1.000**	0.580**	-0.237	-0.084	0.523**
UGP	0.149	0.112	-0.181	0.218	-0.212	0.007	0.283	1	1.000**	0.600**	0.373*	-0.27	0.352*	0.615**
FTP	0.177	0.13	-0.131	0.106	-0.155	-0.185	0.222	0.151	1	-0.042	0.378*	-0.434**	0.633**	0.702**
TGP	0.427**	0.278	0.092	0.387*	0.063	0.153	0.951**	0.334*	0.288	1	0.531**	-0.151	-0.04	0.501**
BY	0.648**	0.565**	0.337*	0.539**	0.292	0.32	0.466**	0.251	0.252	0.418*	1	0.035	-0.356*	0.730**
TSW	-0.209	-0.031	0.464**	0.084	0.482**	0.368*	-0.122	-0.187	-0.034	-0.095	-0.013	1	-0.456**	-0.298^{ns}
HI	-0.058	-0.057	-0.566**	-0.281	-0.559**	-0.520**	-0.003	0.077	0.095	0.001	-0.332*	-0.231	1	0.381*
GY	0.532**	0.471**	-0.091^{ns}	0.278^{ns}	-0.125^{ns}	-0.082^{ns}	0.417^{ns}	0.246^{ns}	0.314*	0.382*	0.654**	-0.184^{ns}	0.430**	1

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Genotypic correlation coefficient

Some of traits genotypic correlation coefficients were higher than their corresponding phenotypic correlation coefficient values (Table 2). Similar findings were reported by Zahid *et al*. (2006) and Prasad *et al*. (2001). The yield component traits revealed various trends of association between themselves. For instance, days to heading (0.930**) followed by biomass yield (r_g=0.731**), filled grains per panicle (r_g=0.614**), total grains per panicle (r_g=0.588**), panicle length (r_g=0.509**) and unfilled grains per panicle (r_g=0.396*) showed significant and positive correlation ($p<0.01$) with days to maturity. Moreover, days to maturity manifested significant and positive correlation ($p<0.01$) with panicle length (r_g=0.446**), filled grains per panicle (r_g=0.459**), total grains per panicle (r_g=0.431**) and biomass yield (r_g=0.756**).

Plant height had significant and positive genotypic correlation with traits such as panicle length (r_g=0.450**), culm length (rg=0.997**), flag leaf length (r_g=0.783**) and biomass yield (r_g=0.337*) however it had negative and significant association with unfilled grains per panicle (r_g=-0.402*) and harvest index (r_g=-0.702**). Likewise, Iftekhalruddaaula *et al*. (2001) reported highily significant and positive correlation of plant height with panicle length and negative correlation for harvest index. Similarly, Ghosal *et al. (*2010); Babu *et al. (*2012) and Kishore *et al*. (2015) reported positive correlation of plant height with panicle length. Panicle length was positively and significantly associated with culm length (r_g=0.369*), flag leaf length (r_g=0.511**), filled grain per panicle (r_g=0.503**), thousand grains weight (r_g=0.405*), unfilled grain per panicle (r_g=0.500**), total grain per panicle (r_g=0.524**) and biomass yield (r_g=0.729**). Harvest index had negative and significant association with panicle length (rg=-0.439**) culm length (-0.695**), flag leaf length (-0.667**), biomass yield (-0.356*) and thousand grains weight (-0.456**) while positive significant association with unfilled grains per panicle (0.352*). In contrast, Kishore *et al*. (2015) reported non-significant association with filled grain per panicle and thousand grains weight.

Filled grains per panicle had strong positive correlation with the total grains per panicle (1.000**) followed by unfilled grain per panicle (0.659**) and biomass yield (0.580**) .Unfilled grains per panicle showed positive correlation at genotypic level with total grains per panicle (0.600**), biomass yield (0.373*) and harvest index (0.352*). Fertile tillers per plant showed significant positive association with biomass yield (0.378*) and harvest index (0.633**) while it showed significant and negative correlation with thousand grains weight (-0.434**). Similarly, Rokonuzzaman *et al*. (2008) reported significant negative correlation for thousand grains weight. Total grains per panicle was showed significant association with biomass yield (0.531**). On contrary, Iftekhalruddaaula *et al*. (2001) observed significantly negative association with harvest index and thousand grains weight. Biomass yield manifested negative and significant association with harvest index (-0.356*). Culm length revealed positive and significant association with flag leaf length (0.756**) and thousand grains weight (0.685**) whereas it had negative and significant association with unfilled grain per panicle (-0.453**), fertile tillers per plant (-0.362*) and harvest index (-0.695**). Similarly, flag leaf length exhibited positive and significant correlation with thousand grains weight (0.497**) and biomass yield (0.411*). However, harvest index (-0.667**) and fertile tillers per plant (-0.347*) showed significant and negative correlation.

Path Coefficient Analysis

Grain yield is being complex outcomes of various traits were considered to be the dependent trait. In the current study, thirteen traits were selected as casual variables to evaluate the contribution of these individual traits for yield (Table 3).

Direct effect of different traits on yield

A perusal result of genotypic path analysis revealed that biomass yield (1.052) followed by harvest index (0.722), total grains per panicle (0.643) and plant height (0.459) had highest direct effect on yield with significant and positive genotypic correlation across locations, which indicates the correlation that explains the true association with yield and direct selection through these traits will be effective. Hence, selection of genotypes with more total grain per panicle, harvest index, biomass yield and plant height on which an emphasis should be given during simultaneous selection to prove effectively in increasing yield potential (Table 3). These traits have been identified as major direct contributors towards yield by Srek and Beper (2002) and Pratap *et al*. (2012) for biomass yield and harvest index for rice, respectively. Khare *et al. (*2014) reported similarly the highest positive direct effect of the total grains per panicle on yield in earlier study. Sravan *et al*. (2012) reported a maximum direct effect of biological yield on yield followed by harvest index, total grains per panicle in upland rice. Mulugeta (2015) reported biomass yield and plant height as the major contributors to yield and had direct effect on yield in upland rice. Karim *et al*. (2014) and Kishore *et al*. (2015) reported that plant height had high direct positive effect on yield.On the other hand, days to heading (-0.020), days to maturity (-0.068), panicle length (-0.062), culm length (-0.580), unfilled grains per panicle (-0.257), filled grains per panicle (-0.503) and thousand grains weight (-0.049) had negative direct loading on yield except on culm length, panicle length, and thousand grains weight but showed positive and significant genotypic correlation with yield. The negative direct effect indicates that the direct selection through these traits would not prove to be useful for the improvement of yield of rice. Similar results reported earlier by Mulugeta *et al*. (2012) for days to maturity and Kiani and Nematzadeh (2012) also noticed negative direct effect of panicle length on yield. In the contrary, Kiani and Nematzadeh (2012) reported the positive direct effect of filled grains per panicle on yield of rice.

Indirect effect of various traits on yield

The highest and positive genotypic indirect effect on yield showed by days to maturity through biomass yield (0.796), days to heading via biomass yield (0.769), panicle length through biomass yield (0.767), filled grains per panicle through total grains per panicle (0.648) , filled grains per panicle by way of biomass yield (0.611), total grains per panicle by way biomass yield (0.559), fertile tillers per panicle through harvest index (0.457) and culm length via plant height (0.457). In contrast, Karim *et al*. (2014) reported negative indirect effect of panicle length on yield. The perusal of path analysis result indicated that plant height exhibited high negative indirect effect on yield through culm length (-0.578) and harvest index (-0.506), total grains per panicle through total grains per panicle (-0.507) and culm length via harvest index (-0.502). The indirect effect of days to heading through culm length (0.080), flag leaf length (0.030), fertile tillers per plant (0.037) total grains per panicle (0.378), biomass yield (0.769) and thousand grains weight (0.015) counter balanced the negative direct effect days to heading on yield (-0.020) and reduced the correlation coefficient to +0.678.

Correspondingly, the indirect effect of days to maturity through culm length (0.067), flag leaf length (0.029), fertile tillers per plant (0.0001) total grains per panicle (0.277), biomass yield per plot (0.796), thousand grains weight (0.005) and harvest index (0.049) counter balanced the negative direct effect of days to maturity on yield (-0.068) and reduced the correlation coefficients to +0.803. The indirect effect of panicle length through plant height (0.206), flag leaf length (0.079), fertile tillers per plant (0.038), total grains per panicle (0.337), biomass yield (0.767) and thousand grains weight (0.003) counter balanced the negative direct effect of panicle length on grain yield (-0.062) and reduced the correlation coefficient +0.415. The negative direct effect of culm length on yield per hectare (-0.580) was counter balanced mainly by its positive indirect effects through plant height (0.457) and reduced its genotypic correlation to -0.178. Similarly, the indirect effect of filled grains per panicle mainly counter balanced through total grains per panicle (0.648) and biomass yield (0.611) reduced its genotypic correlation to +0.523. The residual effect was (0.118) showed the traits which are included in the genotypic path analysis explained 88.2% of the total variation on yield that was contributed by thirteen traits studied. The residual 11.8% showed that there are some more traits that were not included in the present study but could contribute to yield. Most likely biomass yield, harvest index, total grains per panicle and plant height has the highest direct effect on yield with significant and positive genotypic association. This indicates that the correlation revealed the true association and direct selection through these traits will be effective.

Table 3. Estimates of direct (bold diagonal and underlined) and indirect effect (off diagonal) at genotypic level of 13 traits on grain yield in 36 rice genotypes tested at Pawe and Fogera in 2015/16 cropping season.

Traits	DH	DM	PH	PL	CL	FLL	FGPP	UGPP	FTP	NTGPP	BY	TSW	HI	R_G
DH	**-0.02**	-0.063	-0.045	-0.032	0.08	0.03	-0.309	-0.102	0.037	0.378	0.769	0.015	-0.06	0.678
DM	-0.019	**-0.068**	-0.034	-0.028	0.067	0.029	-0.231	-0.04	0.000	0.277	0.796	0.005	0.049	0.803
PH	0.002	0.005	**0.459**	-0.028	-0.578	0.122	-0.038	0.104	-0.041	0.034	0.355	-0.033	-0.506	-0.145
PL	-0.01	-0.03	0.206	**-0.062**	-0.214	0.079	-0.253	-0.129	0.038	0.337	0.767	0.003	-0.317	0.415
CL	0.003	0.008	0.457	-0.023	**-0.58**	0.117	-0.022	0.117	-0.047	0.012	0.315	-0.034	-0.502	-0.178
FLL	-0.004	-0.013	0.359	-0.032	-0.438	**0.155**	-0.161	0.007	-0.045	0.199	0.432	-0.024	-0.482	-0.046
FGPP	-0.012	-0.031	0.035	-0.031	-0.025	0.05	**-0.503**	-0.169	0.001	0.648	0.611	0.012	-0.06	0.523
UGPP	-0.008	-0.01	-0.185	-0.031	0.263	-0.005	-0.331	**-0.257**	0.134	0.386	0.393	0.013	0.254	0.615
FTP	-0.006	0	-0.142	-0.018	0.21	-0.054	-0.003	-0.264	**0.131**	-0.027	0.397	0.021	0.457	0.702
NTGPP	-0.012	-0.029	0.024	-0.033	-0.011	0.048	-0.507	-0.154	-0.005	**0.643**	0.559	0.007	-0.029	0.501
BY	-0.015	-0.051	0.155	-0.045	-0.174	0.064	-0.292	-0.096	0.049	0.342	**1.052**	-0.002	-0.257	0.73
TGW	0.006	0.007	0.312	0.004	-0.397	0.077	0.119	0.069	-0.057	-0.097	0.037	**-0.049**	-0.329	-0.298
HI	0.002	-0.005	-0.322	0.027	0.403	-0.104	0.042	-0.091	0.083	-0.026	-0.374	0.022	**0.722**	0.381

Residual Effect=0.118

BY= Bimass Yield , DH= Days to heading, CL= Culm Length, DM=Days to Maturity, FGPP =Filled Grains per panicle, FLL=Flag leaf length, FTP= Fertile tillers per plant, HI= Harvest Index, NTGPP= Number of total grains per panicle, PH= Plant height, Pl= Panicle length, TGW=Thousand Grains Weight, UGPP=Unfilled grains per panicle and RG= Genotypic Correlation

Conclusion

Yield exhibited positive and highly significant (P <0.01) genotypic correlation with traits like days to heading, days to maturity, filled grains per panicle, fertile tillers per panicle, harvest index, total grain per panicle and biomass yield, respectively. This indicates the importance of these traits for yield improvement in rice. Thus, the indirect selection for higher yield based on these characters would be reliable. Path coefficient analysis revealed that biomass yield, harvest index, and number of total grains per panicle had the highest direct effect on grain yield with significant and positive genotypic association, which indicates the correlation explains the true association with yield and direct selection through those traits will be effective. Thus, selection of genotypes with more harvest index, biomass yield, plant height and total grains per panicle are important to develop high yielder varieties and an emphasis be given for these traits in future breeding efforts. Biomass yield, harvest index, and number of total spikelets per panicle showing positive and significant correlation and positive direct effect. Hence, these will be a useful traits for indirect selection to increase rice grain yield.

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Rice-based Cropping System

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Introduction

Rice is among the main crops in Fogera, Dera and Libokemkem Districts of South Gondar Zone of Amhara Region. Despite long history of Agriculture in Ethiopia in general and in Amhara region in particular, rice cultivation in South Gondar Zone, however has a history of no longer than 35 years. Areas covered under rice in Fogera had been used for communal grazing lands, which were characterized by serious water logging in the rainy season. These areas were not suitable for any other crop production except grass pea and chickpea, which were grown using residual moisture after the rainy period elapsed and once standing water in a plot drains down and soil starts to dry up. These areas are now used for low land rice cultivation, whereas upland rice production is also practiced in areas where water drains easily. This paper presents the prevailing cropping systems in Fogera plain and some of the research findings in the rice based cropping system.

Experiences and challenges

Since the start of rice cultivation in 1990's, the same land has been used for rice growing year after year particularly in the rainfed lowland ecosystem. In a few areas, grass pea is a relay cropped, while in other areas vegetable production, mostly onion and tomato, using irrigation is a common practice after rice harvesting. So far rice cultivation in the dry season using irrigation has not yet been started.

Monoculture and its consequences of repeated cultivation of rice year after year on the same land would lead to high risk of production and marketing. Observation made so far indicated buildup of disease and insect pests of rice, vegetables, and grass pea compelling farmers to spray repeatedly fungicide and insecticide, which is not friendly to the environment. Reduction in productivity and quality is the ultimate drawback of repeated cultivation. For instance, buildup of disease and insect has led to the extent of causing tremendous rice yield losses and abandoning pepper production in various areas in those districts. Similarly, bulb rotting is observed and becoming a serious threat to onion and garlic production.

Despite the preference by farmers for various merits of rice variety, x-jigna, serious disease attack is observed on this variety to the extent of producing, in certain areas, no grain at all. Furthermore, farmers in Fogera, Dera and Libokemkem Districts, which are the main rice growing areas reiterated that the response of rice crops to the same quantity of synthetic fertilizer is becoming poor from year to year further entailing that a unit of plot is requiring more and more fertilizer over years to give the same quantity of produce. It is therefore critical to try to devise strategies to alleviate this risk of production. Otherwise, serious reduction in quality and productivity would be reflected in a short term while the effect to abandoning production at all may follow in a longer period. In effect, sustainability of production and profitability of rice and other associated crops will be serious challenges of the production system, thereby compelling growers to look for other alternative crops and farming sysstems.

Different reports revealed that, cropping sequences in a particular location may be influenced by agro-ecological conditions; such as rainfall, topography, soil type, fertility status, disease, and pests. In addition to this, cropping sequences is possibly prejudiced by socioeconomic and environmental conditions. In Iran, wheat seed yield was increased up to 37% in wheat-wheat-wheat-rape seed-wheat cropping sequence as compared with wheat monoculture cropping (Ahmad ZF, 2013). According to Deep et al (2018), rice based cropping system is a major cropping system practiced in India, which include the rotation of crops involving rice, pulses, oil seeds, cotton, sugarcane, green manures, vegetables, etc. Rice based cropping systems may include lowland and upland crops. So far, most people have been focusing on individual crops disregarding the fact that each crop is only a component of a cropping system.

The continuous sequential rice-wheat cropping has observed problem of stagnation of the rice-wheat productivity in Pakistan (Deep et al, 2018). It was further reported that stagnation in yield of rice and wheat is mainly due to uninterrupted sequential rice-wheat cropping which is the main cause of prevailing soil fertility deterioration, increased pressure of weed, disease and insect pest problems, and consequently leading to yield losses.

Evidences from some long-term experiments show that the problems of stagnating yields and even yield declines are occurring in the rice-wheat system of South Asia (Regmi et al., 2002; Duxbury et al., 2000). Total factor productivity is declining and farmers have to apply more fertilizer to obtain the same yields (Hobbs and Morris, 1996; Murgai et al., 2001). Practicing research-based cropping pattern (crop combinations) is essential to ensure the sustainability of the production system.

Cropping system in the rice based production of Fogera plain

Relay intercropping or relay cropping is a practice of planting a second crop into an existing rice crop when it has flowered but before harvesting. The seed of succeeding crops like grass pea, lentil, and linseed is sown broadcast in maturing rice crop. There is thus a minimum temporal overlap of two or more crops. This helps to save time; restore soil fertility and improve productivity. It is common mainly in the lowland rice culture. The relay crop should be fairly tolerant of shade and trampling.

An experiment on effects of rice-grass pea relay intercropping on productivity and soil nutrient status for sustainable rice production in Fogera plain was carried out and the result indicated that grass pea relay cropping at dough stage with 2:1 ratio (rice: grass pea) gave the highest grain as well as straw yield, 3.6 and 7.2 t/ha respectively (Table 1).

Table 1. Total final yields (t/ha) of continuous rice-rice monocropping and rice-grass pea relay intercropping when averaged over two years (2016/17-2017/18)

Treatment	Grain yield	Straw yield
Continuous sole rice	3.4	5.3
rice grass pea relay cropping at milk stage	3.2	5.5
rice grass pea relay cropping at dough stage	3.1	5.5
rice grass pea relay cropping near maturity	3.3	6
rice grass pea relay cropping at milk stage	3.3	5.8
rice grass pea relay cropping at dough stage	3.6	7.2
rice grass pea relay cropping near maturity	3.2	5.2
Broadcast planted rice, grass pea relay cropping at milk stage	3.4	6.3
Broadcast planted rice, grass pea relay cropping at dough stage	3.4	5.7
Broadcast planted rice, grass pea relay cropping near maturity	3.5	6
Sole grass pea	3.5	6.6

In the rice based cropping system of the Fogera plain, the double cropping of vegetable crops using irrigation in the dry season is a common practice. An experiment was conducted on intercropping of onion with other crops following rice harvesting. Onion production in the dry season by intercropping with different crops is more advantageous than sole cropping (Tables 2 and 3). This would further improve soil fertility, minimize, or avoid pathogens thereby contributing to improved rice based onion productivity and quality. Except for intercropping onion with fenugreek which was found inefficient than sole cropping, intercropping onion with other crops, i.e., lentil, black cumin, dill, linseed, rapeseed and kale) considered in this study is more advantageous than sole cropping. For dry season onion production, the type and choice of appropriate companion crop from among several tested in relay intercropping with onion, was dependent on productivity and profitability, market demand, sustainability and scale of production.

Table 2. Total marketable yield (t/ha), harvesting dates of different crops in relay intercropping trials planted with onion as a main component crop at Fogera in 2017/18 dry season

Crop	Yield of onion	% non marketable yield	Yield of second crop	Harvesting date
Lentil	19.434	7.34	1.251	2nd April 2018
Rape seed	16.824	12.23	13.539	14 Feb - 19 March 2018
Fenugreek	16.121	10.84	0.488	10 April 2018
Linseed	15.804	13.88	0.730	19 April 2018
Kale	23.335	6.30	6.952	27 Feb – 19 March 2018
Dill	18.122	12.44	0.829	25 April 2018
Black cumin	23.446	7.39	0.420	23 April 2018

Sole onion	36.124		0.754	12 April 2018

Table 3. LER from onion intercropping in the dry season

Crop	2016/17	2017/18
Lentil	0.98	1.40
Rape seed	1.49	1.37
Fenugreek	0.85	0.81
Linseed	0.91	1.11
Kale	1.22	1.34
Dill	1.62	1.06
Black cumin	1.14	1.07
Sole onion	1.00	1.00

Another experiment on rice intercropping with other vegetable crops was carried out at Fogera for two dry seasons using irrigation from December 2016 until April 2018 (Dessie et al, 2018). Observation at Fogera center showed that intercropping tomatoes with upland rice in the rainy season was fruitful. Obtaining early income from the sale of tomatoes is possible in this practice. Meanwhile, the vegetative performance of the rice crop was also excellent. In case of rice is intercropped with crops, such as rapeseed or kale, early harvest from the companion crop is possible. When Lentil and fenugreek were intercropped, they took longer time to mature than a crop, like rapeseed, but they were harvested even earlier than the main onion crop. Crops maturing before its companion crops could help to lessen the competition between the two crops- creating favorable companionship with good LER value. In contrast, Black cumin, linseed, and dill were found to be late maturing crops, and harvested after onion harvesting is over.

Lessons from Other countries on Rice-based cropping for integrated farming system

Based on market demand and sustainability of the system, the following combinations of rice-based cropping systems are practiced in different parts of the world.

Crop rotation or sequential cropping

It refers to growing two or more crops one after the other in the same piece of land. Crops are grown as either preceding or succeeding to the rice crop. It is advantageous that the succeeding crop belongs to a family different from that of the previous crop. The period of crop rotation may last for two to three years or longer. Farm income could be significantly increased by alternating lowland rice with high-value crops like garlic, onion, pepper and other vegetables. In addition to increased crop yield and profit, advantages of crop rotation over monoculture, the continuous growing of a single crop include better control of weed by intending to break the lifecycle and suppress the growth of weeds. Some pests and causal organisms of plant diseases are host specific and are better controlled by crop rotation. Furthermore, it helps to improve soil fertility, soil structure, and organic matter content of the soil.Diversification of crops in a rice-based system, particularly with the use of vegetable crops, improves overall farm income, reduces the degree of deterioration of fertility, increases the uses of residual moisture and cropping intensity, and improves daily cash flows. Such multiple cropping systems also help reduce insect populations. It is also helpful to minimize or avoid risks of production and marketing with an overall goal of ensuring profitability and sustainability of production.

Mixed varietal cropping of rice

It is a common practice constituting different proportions of both early and late rice variety, such as a mix of rice variety of contrasting maturity group. Mixing of rice variety, such as at a certain ratio, might help to avoid total crop loss in the event of flood. However, performing agricultural operation like harvesting is difficult.

Intercropping rice with other crops

Intercropping is the growing of two or more crops together in proximity on the same land. Two or more crops are managed at the same time on the same plot of land. It is a common practice under upland conditions in many countries to grow rice intercropped with legumes, sesame maize, finger millet and other minor millets.

Conclusion

Multifaceted problems are being observed in the existing cropping system at and around Fogera in South Gonder zone. It is therefore critical to develop effective rice based cropping pattern that would help sustain the production system. The cropping system/ pattern should contribute towards avoiding/ minimizing environmental degradation / pollution, controlling / reducing pest build up, ameliorating soil fertility and improve the structure of the soil and ultimately raising productivity and profitability. Concerted effort on identifying suitable companion crops for rice based cropping system should therefore be a priority task.

Way forward

Effective cropping pattern should be developed and followed, since cropping pattern is a basic part of any sustainable cropping plan. It is an effective, low cost and widely used cultural practice to prevent or reduce the buildup of populations of soil-borne plant pathogens, weeds and insect pests, and to ameliorate soil fertility and to avoid /or reduce risks of production and marketing. It should however be supported by detailed study of alternative cropping systems and effects on environmental variables. It is critical to quantify economic and environmental advantages such as crop yield, water use, soil erosion, nutrient leaching, green house gas emissions of varied cropping systems practiced across a varied environment like weather, soils, topography. It is therefore critical to

- identify suitable crops for most profitable and sustainable cropping system (inter, mixed, relay and sequential cropping);
- intensify crops in rice-based production systems by increasing the number of crops grown on the same land each year following the main rice crop by using shorter season varieties, improving on-farm water and soil fertility management; for example, water harvesting practices, minimum tillage, supplementary irrigation),and introducing rotation crops; and
- boost yields by improving the efficiency of water and nutrient use.

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Research on Rice Cultural Practices in Ethiopia

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Introduction

Rain-fed rice is cultivated in Amhara, Tigray, Oromia, South Nation Nationality and people Region (SNNPR), Gambella and Benshangule Gumuze Regions (MoARD, 2010). The Amhara region takes the lion's share of producing the crop and accounted for 74-81% of the area coverage and 78-85% of the production in the years 2016-2018 (CSA 2016, CSA 2017 and 2018).

Production of rice depends on several factors: climate, physical conditions of the soil, soil fertility, water management, sowing date, cultivar, seed rate, weed control, and fertilization (Jing *et al*., 2008). Improvement of rice production can be achieved through different agronomic and management practices like plant spacing and fertilizer use that these factors can increase yield of rice and sustaining the production of the crop. Special attention should be given for increasing yield by applying nutrient retention practice in the soil, use of optimum rate of nitrogen fertilizer and other nutrients; proper seed rate, effective row and plant spacing, and high yielding varieties and/or hybrid varieties.

Crop management

Seed rate and spacing

An experiment was conducted at Werer Agricultural Research Center (WARC) in 2016 cropping season under irrigation (Tamiru, 2018). The highest grain yield (5327 kg/ ha) was obtained from 20 x 20 cm inter and intra row spacing and 3 seedlings per hill and the lowest grain yield (2957 kg/ ha) was obtained from 20 x 15 cm inter and intra row spacing and 2 seedlings per hill (Table 1). Use of 20 x 20 cm spacing improved grain yield of rice by 44.5% over 20 x 15 cm spacing. The higher the number of tillers, especially fertile tillers, the more will be the yield. Roshan M, (2011), reported that the highest grain yield was obtained from plant spacing of 20 x 20 cm along with 3 seedlings per hill. Therefore, it can be concluded that spacing 20 x 20 cm with 3 seedlings per hill appears as the best combination to obtain maximum grain yield of NERICA-4 under transplanted system of cultivation.

Table 1. Grain yield of rice as affected by interaction effect of inter and intra row spacing and number of seedlings per hill at Werer

	Number of seedlings per hill		
Inter and intra row space	Two seedling	Three seedling	Four seedling
20*10	2970[fg]	2993[fg]	3074[efg]
20*15	2957[g]	3315[defg]	3166[efg]
20/20	3505[de]	5327[a]	4033[c]
30*10	3209[defg]	4001[c]	3382[defg]
30*15	3100[efg]	4111[c]	3168[efg]
30*20	3427[def]	4830[b]	3653[cd]

*LSD (0.05) Spacing*Seedling per hill=4601: CV (%)=7.8 LSD Least Significance difference at 5% level: CV Coefficient of Variation. Means with in Columns and Rows followed by the same letters are not significantly difference at 5% level of significance*

An experiment conducted in 2009 (2001 E.C) production season at Tahtay Koraro Wereda in Northern Ethiopia indicated that among direct seeding and transplanting planting techniques of rice crop, transplanting produced higher overall mean grain yield than direct sowing. The highest mean grain yield was recorded from the variety NERICA-3 (46.6q/ha), followed by X-jegna (44.8 q/ha) and Kokit and NERICA-4 (44.7 q/ha) each under transplanting conditions (Table 2). From this experiment, it can be concluded that transplanting of rice seedlings enhances the performance of rice varieties through producing strong and fertile tillers, vigor plants and good stand of crops.

Table 2: Days to heading, days to maturity and grain yield (q/ha) of rice under different planting methods at Tahtay Koraro

Variety	Days to heading		Days to maturity		Grain yield	
	D	T	D	T	D	T
AD-048	102	127	130	148.3	38.3	38.3
Kokit	101.3	125	126.7	150	37.4	44.7
N3	99	120	115	145	33.2	46.6
N4	99	118.67	115	145	31.3	44.7
Tigabe	101.7	128.33	128.3	150	41.2	43.0
X-jegena	116	130	135	155	43.9	44.8
Cv (%)	5.9	3.5	7.1	2.4	42.28	20.68

CV coefficient of variation; 1Qt = 100kg, days to heading and maturity of the crops include age of seedlings on nursery. D=Direct seeding, T=Transplanted

An experiment was conducted in 2005 and 2006 cropping seasons in Fogera plain to determine seeding rate of rice under different fertilizer rates. The two-year combined analysis showed that grain yields significantly responded only to seed and fertilizer rates but not to their interaction (Tables 3). The highest seed rate of 140 kg/ha and the highest fertilizer rate of 115-23 N-P_2O_5 kg/ha gave the highest grain yield. Considering the economic profitability, it is concluded that 140 kg/ha seed rate and a fertilizer application of 69-23 N-P_2O_5 kg/ha are recommended for rice production in Fogera plain.

Table 3. Two-year combined effect of variety, seed and fertilizer rate on rice grain yield (kg/ha) of rice

Seed rate(kg/ha)	X-Jigna			Gumara		
	$N\text{-}P_2O_5$ (kg/ha)			$N\text{-}P_2O_5$ (kg/ha)		
	46-0	69-23	115-23	46-0	69-23	115-23
80	3709.9	3792.9	4204.4	3868.2	4586.6	4950.9
100	3898.3	4282.0	4379.8	3982.3	4530.9	4936.9
120	3942.4	4142.4	4555.3	4194.2	4560.0	5087.8
140	4285.9	4259.1	5375.6	4770.4	4722.7	5436.2

A field experiment on sowing method and seed rate was conducted in Wolliso District of Oromia Region on three different rice varieties. Higher grain yield/ha was produced by Gumera than Superica-1 and X-Jigna. The seeding rate of 100 kg/ha, gave higher grain yield than 75 and 125 kg/ha (Table 4). The results showed that significant differences in grain yield and most of parameters of rice were observed due to variety and seeding rates. Gumara yielded maximum yield at seeding rate of 100 kg/ha. Hence, it is recommended that Gumara variety should be planted at a seeding rate of 100 kg/ha with either broadcasting or row planting method in Woliso area.

Table 4. Effect of variety, sowing method and seeding rate effects on grain, straw and total biomass yield (kg/ha)

Variety	Grain
X -Jigna	18.23
Gumara	3264
Superica-1	2200
$LSD_{0.05}$	265.7
Sowing method	
Broad cast	2329
Row planting	2529
$LSD_{0.05}$	NS
Seeding rate (kg/ha)	
75	2279
100	2785
125	2224
$LSD_{0.05}$	265.7
C.V%	16.07

NS- Not Significant

Effects of row spacing and nitrogen fertilizer levels on yield and yield components of upland rice varities were evaluated at Pawe, North western Ethiopiain 2017 (Zewdineh, 2017). The highest grain yield (6462.56 kg/ ha) was observed from NERICA-4 at the row spacing of 20 cm and 96 kg N/ ha and the lowest grain yield (1933.57 kg N/ ha observed from variety Pawe-1 at 30 cm row spacing and 0 kg N per hactare (Table 5). For both of the varieties, row spacing of 20 cm with maximum N level (96 kg/ ha) gave the maximum grain yield.

Table.5: Interaction effects of variety, row spacing, and nitrogen level on grain yield (kg/ha)

Varity	Nitrogen (kg/ ha)	Row spacing (cm)		
		20	25	30
NERICA-4	0	2705	2841.63[Kl]	3476.26[m]
	32	4733.0[cd]	3473.63[ij]	3912.97[ghij]
	64	5041.9[be]	4541.43[edef]	4641.40[cde]
	96	6462.56[a]	5565.60[b]	5441.10[b]
Pawe-1	0	2527.13[lM]	2759.37[Kl]	1933.57[m]
	32	3618.57[hij]	3330.50[jk]	2741[kl]
	64	4433.90[defg]	3666.00[hij]	4001[fghi]
	96	4791.17[ed]	4122.23[efgh]	3594.50[hij]
LSD(0.05)			599.32	
CV(%)			9.28	

Means in the columns and rows followed by the same letter(s) are not significantly at 5% level of significance, LSD (0.05) =Least significant difference at 5%; and CV (%) =coefficient of variation.

Achievements on rice planting methods

Transplanting and direct seeding (Abeysiriwardena *et al*., 2005) are the two methods of rice plant establishment. Broadcasting is the major method of rice planting being used in Fogera plain. However, transplanting is the major means of rice planting used in other parts of the world (Morris, 1980; Patel and Charugamba, 1981). A rice transplanting experiment was conducted for two years (2005-2006) in Fogera plain (Tilahun *et al* 2013[a]). The comparison of transplanting with the control (dry sowing) showed that there was significant difference for most of the yield components including the grain yield. X-Jigna gave an average grain yield of 3493 kg/ ha during transplanting while 2347 kg/ ha by dry sowing. Similarly, Gumara gave an average grain yield of 4304 kg/ha when transplanted but it gave 2616 kg/ ha when dry sown. (Table 6).From this experiment it is recommended that rice seedlings should be transplanted at 4 leaf stage age with a spacing of 25 cm x 20 cm and 3 seedlings per hill. The observed increase in rice grain yield due to transplanting is in line with (Ehsanullah *et al*., 2000). The report of Patel and Charugamba (1981) indicated that transplanted rice is capable of yielding 30% more than broadcasted rice.

Table 6 Two years combined effect of seedling age, spacing, and number of plants per hill on grain yield (kg/ha) of transplanted rice

Plants per Hill	X-Jgna				Gumara			
	25cmx20cm		25 cmx 25 cm		25cmx 20cm		25cmx25cm	
	4 Leaf stage	2 Leaf stage	4 Leaf stage	2 Leaf stage	4 Leaf stage	2 Leaf stage	4 Leaf stage	2 Leaf stage
2	3839^{e-1}	3673^{GHI}	3921^{D-1}	3478^{I}	4511^{A-D}	4241^{A-G}	4241^{A-G}	4030^{C-I}
3	4181^{B-H}	3998^{D-1}	3829^{F-1}	3635^{HI}	4716^{A}	4654^{ABC}	4677^{AB}	4629^{ABC}
Mean	4010^{c-1}	3835^{E-1}	3875^{E-1}	3556^{I}	4613^{ABC}	4448^{A-E}	4459^{A-E}	4330^{A-F}

Achievements on pre-planting seed treatment

An experiment on seed treatment was conducted in Fogera plain for two consecutive seasons (2005-2006). The two years ANOVA indicated that the interaction of variety and incubation period caused significant difference in number of tillers, number of fertile panicles and number of infertile panicles (Tilahun *et al*., 2007). Days to emergence and days to maturity significantly varied between pre-germinated and dry sown seeds. The use of pre-germinated seeds makes X-Jigna and Gumara to emerge 4.8 and 5.8 days, respectively, earlier than their dry sowing. Based on the results of this experiment, 48 hours seed soaking and a one-day seed incubation is recommended both for X-Jigna and Gumara varieties.

A study was conducted on effects of hydro-priming and seed pre-germination in Fogera plain, in the 2010 and 2011 cropping seasons (Tilahun *et al.*, 2013[b]). The highest grain yields were recorded when pre-germinated seeds were planted at farmers' sowing time followed by planting seeds soaked for 24 hrs and dried for 24 hrs at farmers' planting time (Table 7). Planting pre-germinated seeds at farmers' sowing time resulted in the yield advantage of 1.73 t/ha over planting dry seeds at similar sowing time. The results of the study revealed that, planting hydro-primed rice seed by 24 hours seed soaking and re-drying it for 24 hours and planting at the farmers sowing time resulted in the highest grain yield of the crop. Therefore, these two treatments are equally useful in enhancing the grain yield of the crop in the study area.

Table 7. Effect of seed treatment and sowing time on grain yield (t/ ha) of rice at Fogera in the 2010 and 2011 main cropping season

Seed treatment	Sowing time relative to farmer's time	
	1 weeks before farmers sowing time	2 weeks before
Dye seed (control)	2.37^{J}	2.56^{HU}
Pre-germinated	4.08^{BCD}	4.69^{A}
12hrs soaking+24drying	3.58^{FG}	4.22^{BC}
18hrs soaking + 24drying	3.49^{G}	4.24^{BC}
24hrs soaking+24drying	3.72^{D-G}	4.44^{AB}
12hrs soaking +24drying+	3.76^{D-G}	4.05^{B-F}
18hrs soaking +24 drying +	3.98^{CF}	4.00^{B-F}
24 hrs soaking+24hrs drying+	3.62^{EFG}	4.15^{BCD}
CV (%)	15.63	

Achievements on post-planting rice crop management

An experiment was conducted in 2009 and 2010 in Fogera plain, North Western Ethiopia to determine the effects of water management on rice production. The Combined analysis on effects of irrigating pre-germinated seeds and drain flood regimes in grain yield indicated that the IPJS treatment had the highest grain yield (6.36 t/ha) and the DS had the lowest grain yield (4.67 t/ha) and the difference was significant (Table 8). The findings of the research result showed that reducing water input and increase aeration of the soil increase rice productivity. Therefore, irrigating pre-germinated seeds just after sowing + drain flood regimes within 3 days interval is preferably recommended in Fogera Plain areas and other similar rice growing environments.

Table 8. Combined interaction effects of irrigating pre-germinated seeds and drain flood regimes on grain yield t/ha (In 2009 and 2010)

Pre germinating seed	CF	D3	D5	D7	Mean

DS	3.72i	15.52e	5.00f	4.45g	4.67d
IPSJ	5.09f	7.95a	6.56c	582d	6.36a
IPS1	4.28hg	6.98b	5.78d	4.26f	5.33b
IPS2	4.05h	6.013d	5.18f	4.23hg	4.858c
Mean	4.29d	6.67a	5.63b		4.69c
$LSD_{0.95}$	0.2673				
CV	4.35				

Means followed by the same letter within a column are not significantly different with LSD at 5% level. DS, Dry seeds; IPSJ, Irrigating pre-germinated seeds just after sowing; IPS1,Irrigating pre-germinated seeds just after one day; IPS2, Irrigating pre-germinated seeds just after two days and CF, Continuous flooding; D3, Drain within3days interval; D5, Dain within5days interval; D7, Drain within 7days interval.

The experiment on the effects of mechanical rotary weeders on rice production conducted in 2011 and 2012 in Fogera plain, showed that puddling and weeding once using rotary weeder had the highest grain yield (6.64 t/ha) and W0 and P0 had the lowest grain yield (3.23 t/ha) (Tesfaye, 2014). Higher grain yields of 103.4%, 92.7% were recorded over (control) due the combined effects of P1 and W1; P2 and W1 treatments, respectively (Table 9). From this results, it may be decisively recommended that puddling after 10 and 15 days flooding combined with three times weeding by rotary weeder with little hand weeding supplement, two times weeding by rotary weeder with little hand weeding supplement; pre-flooding combined with three times weeding by rotary weeder with little hand weeding supplement plays a vital role in increasing rice yield.

Table 9 Combined effect on rotary weeder and puddling on yield and yield parameters of rice

Treatment		Filled grain % per panicle	Number of grains per panicle	Straw yield (t/ha)	Grain yield (t/ha)	Weed dry biomass (g/m^2)
Puddling	Rotary weeder					
Po	Wo	0.70f	81.33e	5.32d	3.23c	51.31a
Po	W1	0.85ba	97.5de	5.52cd	4.93b	33.57dc
Po	W2	0.78d	80.33e	5.32d	3.56c	35.85c
Mean		0.78b	86.39e	5.38b	3.91c	40.24b
P1	Wo	0.74e	118.00b	6.32cb	5.18b	18.20e
P1	W1	0.87a	133.33a	8.52a	6.64a	9.20f
P1	W2	0.83bc	125.67ba	7.11b	6.22a	11.15f
Mean		0.81a	125.67a	7.32a	6.01a	12.85c
P2	Wo	0.76d	91.83de	5.17d	3.64c	42.0lb
P2	W1	0087a	124.50ba	6.20c	6.37a	30.31d
P2	W2	0.82c	111.83bc	5.62d	5.10b	35.72c
Mean		0.82c	109.39b	5.66b	5.04b	35.06b
$LSD^{0.05}$		.0025	15.225	0.85	0.76	11.37
Cv		2.78	12.197	11.98	4.27	11.37

An experiment on time and frequency of weeding was conducted in 2008/9 on farmers' fields in Metema woreda (Kokit and Afitit Kebeles). Rice yield has significantly responded to the timing and frequency of weeding. Hand weeding at 20, 35 and 50 days after emergence showed the highest significant yield (3530 kg/ ha) next to the weed free check (3640 kg/ha) (Table 10). The lowest yield was recorded in the unweeded check (140 kg/ ha). Weed population was significantly lower with hand weeding at 20, 35, and 50 days after emergence next to the weed free check (Table 11). Highest weed population was recorded in the unweeded plot and the lowest was recorded at hand weeding at 20, 35 and 50 days after emergence next to the weed free check. It was found that weeding rice at 20, 35 and 50 DAE had increased both productivity and profitability in Metema. Therefore, this weeding time and frequency is recommended for rice production in Metema area.

Table 10. Effect of time and frequency of weeding on the yield of upland rice at Metema (across locations) in 2008/9

Treatment	Yield (kg/ ha)	Yield loss (%)
No weeding (HW1)	140[d]	96.1
Weed free (HW2)	3640[a]	0.0
Hand weeding at 20 DAE (HW3)	1420[c]	60.9
Hand weeding at 35 DAE(HW4)	2010[bc]	44.8
Hand weeding at 50 DAE(HW5)	1490[c]	59.1
Hand weeding at 20,35 DAE(HW6)	2630[b]	27.7
Hand weeding at 20, 35, 50 DAE(HW7)	3530[a]	3.0
Grand mean	2130	-
CV (%)	18.83	-

Table 11. Effect of time and frequency of weeding on the weed population of direct seeded upland rice in Metema

Treatment	Weed count/m^2			
	1st weeding	2nd weeding	3rd weeding	Average
No weeding (HW1)	135[a]	218[a]	279[ab]	161[a]
Weed free (HW2)	62[c]	41[b]	9[d]	30[c]
Hand weeding at 20 DAE (HW3)	91[b]	213[a]	284[a]	150[b]
Hand weeding at 35 DAE (HW4)	155[a]	58[b]	188[c]	103[b]
Hand weeding at 50 DAE (HW5)	141[a]	220[a]	70[d]	111[b]
Hand weeding at 20,35 DAE (HW6)	80[b]	91[b]	217[bc]	100[b]
Hand weeding at 20, 35, 50 DAE (HW7)	70[bc]	49[b]	12[d]	35[c]
Grand mean	105	127	151	99
CV (%)	13.25	25.18	24.03	16.81

Conclusion and future direction

Improvement of rice production can be achieved through different agronomic and management practices like plant spacing and fertilizer use that these factors can increase yield of rice and sustaining the production of the crop. Some rice management technologies have been developed so far in different parts of the country. More emphasis should be given for generating rice crop management technologies with respect to planting methods, proper seed rate, effective row and plant spacing, water management, and irrigation agronomy considering untargeted areas and newly developed rice varieties.

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Response of Rice to Fertilizer in Ethiopia

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Introduction

The average rice productivity in Ethiopia is estimated at 2.8 t/ha (CSA, 2018), which is much lower than the World's average of 4.4 t/ha (FAO, 2012). Weeds, pests, soil nutrient deficiencies and terminal moisture stress are the are among major causes of low rice productivity in Ethiopia (MoARD, 2010; Gebey *et al*., 2012). Poor soil fertility is among the major factors limiting rice production in Ethiopia. Appropriate fertilizer application is an important management practice to improve soil fertility and production of rice (Maneesh *et al*. 2018). Productivity increments were observed in various experiments conducted on soil nutrient management for rice production in Ethiopia.

An inadequate amount fertilizer and improper application technique are one of the factors responsible for low yield of rice (Aamer *et al*., 2000). Availability of plant nutrients, particularly nitrogen at various plant growth stages is of crucial importance in rice production. Recommendations on different period of nitrogen fertilizer application were given for various production systems. Dobermann and Fairhurst (2000) indicated that the number and timing of splits fertilizer applications are affected by the total amount of nitrogen fertilizer to be applied based on the desired yield level.

To achieve potential rice yield, modern cultivars of rice require different types of nutrients. Among all nutrients, nitrogen (N) is the most essential for plant development, growth and grain quality. Because of the significance of nitrogen as a major nutrient for rice crop to attain high grain yield, it is crucial to determine the ideal amount and timing of N application for each rice cultivars (Fazli *et al*., 2019).

Even though the inorganic fertilizers could resulte in higher crop yield, over reliance on them often associated with declined soil properties and degraded soils and in turn decreased yield in subsequent period (ShaRada *et al*., 2018). Traditionally, Diammonium phosphate and urea (supplying nitrogen and phosphorus) were the major fertilizers used by farmers in Ethiopia, creating nutrient imbalances in soils (Birhan *et al*. 2017). Therefore, to make the soil well supplied with all the plant nutrients in the readily available form and to maintain good soil health, it is necessary to use organic manures in conjunction with inorganic fertilizers to obtain optimum yields. The integrated use of NP and FYM gave higher yields than application of either NP or FYM alone for many crops production (Birhan *et al*. 2017).

Different experiments were conducted to tackle rice soil fertility constraints. The major focuses of the experiments include inorganic fertilizers application rates, application times and their integration with organic fertilizers (Tilahun *et al*., 2007; Alemayehu *et al*., 2013; Kiros *et al*., 2013; Tilahun *et al*., 2013; Alem Redda and Fetien Abay, 2015; Bekele *et al*., 2016; Alem *et al*., 2018; Dereje *et al*., 2017; Mitiku *et al*., 2017). The results of the experiments are summarized in this review paper.

Physico-chemical soil properties of rice agronomy experimental sites

According to Landon, available soil P level of less than 10 ppm is rated as low, 11-31 ppm as medium and greater than 18 ppm is rated as high. Thus, most trial location had very low to medium available P. Following the rating of total N of >1% as very high, 0.5 to 1% high, 0.2 to 0.5% medium, 0.1 to 0.2% low and <0.1% as very low N status; all the experimental soils qualify for low total N. Similarly, the organic carbon (OC) content of the soil was also low in accordance with Landon, who categorized OC content as very low (<2%), low (2- 4%), medium (4-10%), high (10-20%) (Table 1).

Table 1. Some soil chemical characteristics of sample taken before planting of rice

Location	Reference	Soil chemical characteristics			
		Available P (Olsen)	Total N %	Organic Matter %	P^H
Fogera	Tilahun *et al*., 2007	12.639 (Moderate)	0.16 (Low)	3.20 (Low)	5.48
Metema		3.482 (extremely Low)	0.12 (Low)	2.40 (Low)	6.105
Maitsebri	Alem *et al*., 2018	3.8 (very low)	0.09 (Very low)	2.12 (Low)	6.3
Kamashi/ Assosa	Bekele *et al*., 2016	9.8 (Low)	0.17 (Medium)	3.72 (Low)	5.46
Bambasi/Pawe		3.2 (extremely Low)	0.13 (Low)	4.346 (Medium)	5.25
Tepi—Kuja	Mitiku *et al*., 2017	5.9 (very low)	0.06 (Very low)	2.13 (Low)	5.66
Tepi---Gojeb		6.3 (very low)	0.09 (Very low)	2.98 (Low)	6.31

Inorganic fertilizer management

Nitrogen and Phosphorous

A fertilizer rate trial was conducted on rainfed lowland rice from 2002 to 2004 cropping seasons at Fogera (Tilahun et al., 2007). The results of the experiment indicated that the interaction effect of nitrogen and phosphorous, the 115-46 N-P_2O_5 kg/ha application gave the highest grain yield, 4076.4 kg/ha, with a yield advantage of 1325.9 kg/ha over the unfertilized (0-0 N-P_2O_5 kg/ha) level at Fogera (Table 2). However; the economic analysis done following the partial budget analysis of CIMMYT. (1988) for Fogera indicated that it was the 69-23 N-P_2O^5 kg/ha rate that was found the first profitable rate followed by 46-46 N-P_2O_5 kg/ha and 46-0 N-P_2O_5 kg/ha fertilizer (Table 3). Thus, 69-23 N-P_2O_5 is the best recommended fertilizer rate for rice production in Fogera plain. In cases where farmers face economic difficulty, money shortage at the time of planting, the 46-46 N-P_2O_5 could be used as a second alternative.

An experimental conducted on upland rice at Assosa indicated that significant grain yields were obtained with the applications of N and P, but not their interaction (Bekele *et al*., 2016). The highest grain yield was obtained from plot that received maximum nitrogen and phosphorous rates (Table 4). Another field experiment carried out on upland rice at Bambasi District of Assosa Zone, revealed that most of yield and yield components of rice were significantly ($P<0.05$) affected by the main effect of N and P. The highest grain yield (3244 kg/ ha) was recorded from 92 kg N/ ha combined with 46 kg P_2O_5 /ha and the lowest grain yield (1415.6 kg/ ha) was recorded from the control treatment (Table 5). Partial budget analysis also indicated that the highest net return (28548 birr/ ha) was obtained from the application of 92 kg N/ ha combined with 46 kg P_2O_5/ ha fertilizer rate (Table 6). Thus, from the result of this study, it can be concluded that the application of 92 kg N/ ha combined with 46 kg P_2O_5/ ha was found superior both agronomically and economically for rice NERICA-4 variety under main cropping season in the study area.

An experiment was conducted in 2014 and 2015 in Tigray, Ethiopia, on upland rice with the objectives of determining the economically optimum rates of N and P (Alem *et al*., 2018). The interaction effects of N and P were significant ($P \leq 0.05$) for grain and straw yields (Table 7). The combination of 138 kg N/ha and 46 kg P_2O_5/ha resulted in grain yield of 5723 kg/ha and the control; i.e. no N with no P resulted in the lowest grain yield (1601 kg/ha). On the other hand, highest straw yield of 12246 kg/ha was observed at the treatment combinations of 138 kg N /ha and 69 kg/ha of P_2O_5 and the lowest biomass yield (4528 kg/ha) was observed on the control treatment. Unlike that of the agronomic yield, the economic analysis of the combined result over two years and two locations revealed that net return of 22208.63 birr/ha was obtained for the plot that received 69 kg N/ha and 23 kg P_2O_5/ha which gave 11185.12 birr more than the net returns obtained from the control, 11023.51 birr (Table 8). Therefore, farmers in Tselemti District and similar areas should use the most economically feasible fertilizer rate with highest value of marginal rate of return i.e. 69 kg N/ha with 23 kg P_2O_5/ha. The experiment conducted on upland rice at Metema showed that the highest grain yield was obtained with the application of 60/20 N/P_2O_5 (3355kg/ha) followed by 60/40 and 80/20 N/P_2O_5 which gave 3198 and 2920 kg/ha, respectively (Table 9). Treatment 60/20 N/P_2O_5 had a yield advantage of 2009 kg/ha over the control treatment (Tilahun *et al*., 2007). However, according to partial budget analysis application of 60/20 N/P_2O_5 was economically profitable and is the first recommendation for

Metema area while application of 60/0 N/P_2O_5 could be the second option to be recommended (Table 10).

Table 2. Effect of Nitrogen and Phosphorous on the grain yield (kg/ha) of rice for lowland rice production system around Fogera

Nitrogen (kg/ha)	Phosphorous (kg/ha)			
	0	23	46	Mean
0	2750.5	2925.5	3325.7	3000.5
46	3466.8	3524.1	3790.6	3593.8
69	3595.0	3922.4	3851.2	3789.5
92	3912.6	3694.7	3746.1	3784.5
115	3750.2	3938.2	4076.4	3921.6
Mean	3495.0	3601.0	3758.0	
	N	P_2O_5	N x P_2O_5	
$LSD_{5\%}$	345.5	NS	598.5	
CV%	27.18			

Table 3. Economic analysis of rice fertilizer rate determination for lowland production system around Fogera

Dominance analysis				MRR analysis				
N-P_2O_5 (kg/ha)	TVC	NB.		N-P_2O_5 (kg/ha)	TVC	NB	MRR(%)	Rank
0-0	0.0	5224		0-0	0	5224		
0-23	187	5351		0-23	187	5351	67.5	
46-0	338	6352		46-0	338	6352	663.2	
0-46	374	6026	D	69-0	507	6384	19.2	
46-23	459	6255	D	46-46	580	6721	463.2	**3rd**
69-0	507	6384		69-23	628	6806	175.0	**2nd**
46-46	580	6721		92-0	676	6855	102.6	**1st**
69-23	628	6806						
92-0	676	6855						
69-46	749	6583	D					
92-23	797	6363	D					
115-0	845	6504	D					
92-46	918	6189	D					
115-23	966	6602	D					
115-46	1087	6694	D					

**TVC=Total Variable Cost (Birr/ha); **NB= Net Benefit (Birr/ha)*

Table 4. Yield and yield components of rice as influenced phosphorus and nitrogen rates, at Assosa

Source of variation	Grain yield (kg/ha)
Phosphorous (P)	
0	4205.9^{C}
10	4886.4^{BC}
20	5197.5^{AB}
30	5660.6 ^{A}
LSD	694.85***
Nitrogen (N)	
0	3867.0^{B}
46	5124.9 ^{A}
92	5265.7^{A}
138	5692.8 ^{A}
LSD	694.85***
CV%	24.14

Table 5 Interaction effect of nitrogen and phosphorus rate application on straw and grain yields of upland rice (NERICA - 4) in Bambasi District

N (kg/ha)	P_2O_5 (kg/ha)	Straw yield (kg/ ha)	Grain yield (kg/ ha)
0	0	6333.5^{b}	1415.6^{f}
0	23	7926.0^{b}	1861.3^{de}
0	46	8259.5^{ab}	2117.3^{cde}
0	69	9518.5^{ab}	2160.7^{bcde}
46	0	10111.0^{ab}	2245.6^{bcd}
46	23	10537.0^{ab}	2312.0^{bc}
46	46	8000.0^{b}	2231.9^{bcd}
46	69	7389.0^{b}	2130.4^{cde}
92	0	11203.5^{ab}	1790.0^{ef}
92	23	7463.0^{b}	2151.1^{bcde}
92	46	15524.0^{a}	3244.0^{a}
92	69	8092.0^{ab}	2503^{bc}
138	0	11944.5^{ab}	2521.8^{b}
138	23	12944.5^{ab}	2443.7^{bc}
138	46	12240.5ab	2125.7^{cde}
138	69	12074^{ab}	2357.0^{bc}
LSD (5%)		4098.6	214.21
CV (%)		24.6	15.77

Table.6 Partial budget analysis of N and P fertilizer application rates on rice in Bambasi District

Treatment Combination (kg N-P_2O_5 / ha)	Total variable cost (Birr)	Net benefit (Birr)	Marginal Rate of return (%)
0-0	5075	10832.2	-
0-23	6012.5	14702.2	412.8
0-46	6950	16235.5D	-
0-69	7887.5	16318.1D	-
46-0	6560	18705.9	225.2
46-23	6742.5	19334	344.2
46-46	7425	16662.1D	-
46-69	8107.5	14760.6D	-
92-0	7045	14666.8D	-
92-23	7727.5	15363.9D	-
92-46	8410	28548	552.6
92-69	9092.5	17480.7D	-
138-0	9015	19653.5D	-
138-23	9697.5	18768.1D	-
138-46	10380	14871.6D	-
138-69	10614.5	16635.5D	-

Table 7 Effect of N and P fertilizer sources on grain and biomass yields of upland rice in Tselemti District, N.W Tigray (combined over locations and years)

N (kg/ha)	P_2O_5 (kg/ha)	GY (kg/ha)	Straw (kg/ha)
0	0	1601.19^{i}	4528^{ghi}
0	23	1734.28^{hi}	4582.23^{gh}
0	46	2080.58^{ghi}	7786.47^{fgh}
0	69	2124.10^{ghi}	8333.24^{bcde}
23	0	2717.64^{fghi}	8987.88^{bc}
23	23	3161.63^{efgh}	4527.61^{cdefg}
23	46	3082.91^{efgh}	6966.78^{cdefg}
23	69	3104.21^{efgh}	7550.85^{cdefg}
46	0	3393.11^{defg}	9004.33^{bcde}
46	23	3463.96^{defg}	10533.80^{bcd}
46	46	4042.20^{cdef}	5024.60^{cde}
46	69	4254.24^{bcde}	6773.94^{bcd}
69	0	3906.54^{cdef}	8699.70^{bcd}
69	23	4671.20^{abcd}	9147.16^{bcd}
69	46	4532.48^{abcde}	11927.33^{bc}
69	69	3975.54^{cdef}	5237.79^{cde}
138	0	4231.06^{bcde}	7167.94^{bcd}
138	23	5095.94^{abc}	8861.98^{bc}
138	46	5723.26^{a}	8457.12^{bcd}
138	69	5653.82^{ab}	12246.3^{a}
SEM		525.3	945
CV (%)		24	28
LSD (<0.05%)		1467.27	2640

Table 8 Partial budget analysis for the combined two cropping season (2 years and 2 locations) in Maitsebri 2014 and 2015

N (kg/ha)	P_2O_5 (kg/ha)	Gross return (Birr)	TVC (Birr/ha)	Net return (Birr/ha)	DA	MRR (%)	Rank
0	0	11023.51	0	11023.51	-	-	
23	0	16651.9	663.5	15988.4	*	748	
0	46	10404.78	827.25	9577.53	D		
0	23	20665.78	1327	19338.78	*	1953	3
69	0	19035.25	1490.75	17544.5	D		
69	23	12863.13	1654.5	22208.63	*	2848	1
46	0	23309.78	1990.5	21319.28	D		
46	23	20792.67	2154.25	18638.42	D		
46	46	18546.48	2318	16228.48	D		
138	0	13214.88	2481.75	10733.13	D		
23	46	24949.14	2817.75	20131.39	*	2797	2
23	69	24178.21	2981.5	21196.71	D		
69	69	18940.22	3145.25	15794.97	D		
69	46	26645.88	3645	23000.88	*	1441	
138	23	25221.55	3808.75	21412.8	D		
23	23	25217.37	3981	21236.37	D		
138	46	23703.66	4472.25	19231.41	D		
0	69	30149.26	4808.25	25341.01	*	1818	
46	69	33934.74	5635.5	28299.24	*	357	
138	69	33877.75	6462.75	27415	D		

Key: PBA = Partial Budget Analysis; DA= Dominance Analysis; D= Dominated; TVC= Total Variable Cost. Note: Price of fertilizer and unpolished rice is as of 2014/15; Source: CIMMYT (1988).

Table 9 Effect of combined N and P fertilizer rates on upland rice grain yield in Metema

P_2O_5 (kg/ha)	N (kg/ha)				
	0	20	40	60	80
0	1181^{g}	2489^{cd}	2437^{d}	2904^{bc}	2559^{cd}
20	1575^{efg}	1789^{e}	1658^{ef}	3355^{a}	2920^{abc}
40	1346^{fg}	1887^{e}	1745^{ef}	3198^{ab}	2383^{d}
CV (%)	18.58				

Numbers followed by different letters indicate significance difference at 5% level of significance

Table 10 Economic analysis of fertilizer application on upland rice inMetema

N/P_2O_5	Yield (kg/ha)	GFB (Birr/ha)	Fertilizer cost (Birr/ha)	Labor cost (Birr/man day)	TVC (Birr/ha)	Net benefit (Birr/ha)	Dom. analysis	MRR (%)	Rank
(0,0)	1346	2788	0	0	0	2788			
(20,0)	1658	4473	120	1.63	121	4352		1389	
(0,20)	1575	4025	152	1.63	154	3871	D		
(20,20)	1789	5180	218	2.53	221	4960		711	
(40,0)	1745	4943	239	3.26	243	4700	D		
(0,40)	1181	1897	304	3.26	308	1590	D		
(40,20)	2489	8961	345	4.25	349	8612		2951	
(60,0)	2559	9339	359	4.89	364	8975		2585	2nd
(20,40)	1887	5710	424	4.89	429	5281	D		
(40,40)	2437	8680	450	5.25	455	8225	D		
(60,20)	3350	13610	464	5.88	470	13140		4011	1st
(80,0)	2383	8388	478	6.52	485	7903	D		
(60,40)	3198	12789	569	6.88	576	12213	D		
(80,20)	2920	11288	584	7.52	591	10697	D		
(80,40)	2904	11202	689	8.51	698	10504	D		

** *GFB=Gross field benefits, TVC =Total cost that vary*

Nitrogen and sulphur fertilizers rate determination

The nitrogen and sulphur fertilizers experiment on irrigated rice at Afar Region (Kiros *et al*., 2013) indicated that application of S improved the grain and straw yield on average by 0.5 and 1.3 Mg/ ha, compared to similar N rates without S (Table 11). The combined application of N with S increased on average the grain and straw yield by 0.82 and 2.27 Mg/ ha, respectively, compared to the control (N0S0). The highest grain yield (4.0 t/ha) was obtained when N4 (105 kg/ ha) was combined with S2 (40 kg/ ha) (Table 11). The above findings on the effect of N fertilization on yield and yield components of upland rice variety are similar with the findings reported on the same crop by Walker et al. (2008) and Shiferaw et al. (2012). Ample N supply enhances the assimilation of ammonia, increasing both the protein content and leaf growth of crop plants, resulting with an increase in net photosynthesis (Marschner, 2012). Growth and yield response to the application of S has been reported for many crops (Stabursvik and Heide, 1974; Zhao et al., 1999; Habtegebrial and Singh, 2006), where, an insufficient S supply can affect yield and quality of crops, caused by the S requirement for protein and enzyme synthesis (Zhao et al., 1999). Sulphur is also reported to enhance the photosynthetic assimilation of N in crop plants (Anderson, 1990; Ahmad and Abdin, 2000).

Table 11 Response of grain and straw yields of rice to N and S for the 2010 crop season

N (kg/ ha)	Grain yield (t/ha)			Straw yield (t/ha)		
	S (kg/ ha)			S (kg/ ha)		
	0	20	40	0	20	40
0	1.81	1.87	1.96	5.30	6.19	6.33
36	2.02	2.19	2.33	6.29	6.45	6.77
59	2.32	2.49	2.65	6.60	7.76	8.02
82	2.51	2.95	3.30	7.60	8.63	8.74
105	2.84	3.33	4.00	8.44	9.24	8.86
LSD	0.11			0.22		
CV(%)	21.1			35.6		

Time of nitrogen fertilizer application for lowland rice production system

An experiment consisting of two fertilizer rates (69/23 and 46/46 kg N/P_2O_5 per hactare) and five nitrogen (N) application times (half at planting + half at tillering (control), half at planting + half at panicle initiation, one-third at planting + two-third at tillering, one-third at planting + two-third at panicle initiation and one-third at planting + one-third at tillering +one-third at panicle initiation) was conducted on the Vertisols of Fogera plain during the 2006 and 2007 cropping seasons (Alemayehu *et al*., 2013). Results showed significant difference in grain yield in response to the time of nitrogen fertilizer application. The highest mean grain yield (4409 kg/ ha) was recorded when nitrogen fertilizer was applied at one-third at planting and two-third at the tillering stage of the crop. Hence, application of nitrogen fertilizer one-third at planting and two-third at tillering stage of rice, disregard of the fertilizer rate, is recommended for rice production in the Fogera plain (Table 12).

Table 12 Effect of nitrogen fertilizer rate and nitrogen application time on the grain yield of rice in the Vertisols of Fogera plain, combined over sites

Time of N application	Fertilizer rates (kg/ha)		
	46-46 N-/P_2O_5	69-23 N-/P_2O_5	Mean
Half at planting and half at tillering (control)	4001	3944	3972^{b}
Half at planting and half at panicle initiation	3899	3635	3767^{b}
One-third at planting and two-third at tillering	4357	4462	4409^{a}
One-third at planting and two-third at panicle initiation	3961	4215	4088^{ab}
One-third at planting, one-third at tillering and one-third at panicle initiation	4120	3425	3772^{b}
Mean	4067	3936	

Numbers followed by different letters on the same column indicate significant differences at 5% level of significance using Duncan's multiple range test.

Integrated application of Inorganic and organic fertilizers

In 2011/12, an experiment was conducted in Maitsebri, to evaluate the effect of integrated application of inorganic fertilizers and farmyard manure on yield and yield components of upland rice (Alem *et al*., 2015). The results indicate that the highest straw yield 5 t/ha was obtained when 9 t/ha FYM is combined with 75kg/ha DAP + 75 kg/ha urea while the lowest straw yield (30.64 q/ha) was obtained in the control treatment (Table 13). Highest mean grain yield of 44.4 q/ha was also found from the combined application of fertilizers at the higher rates (Table 13).

Table 13 Straw and gain yield of upland rice as influenced by the integrated nutrient management, in Maitsebri

FYM (t/ha)	IF (kg/ha)	Straw yield (q/ha)	Grain yield (q/ha)
0	0	30.64	24.27f
0	75kg/ha DAP + 75kg/ha Urea	43.94	38.11b
0	50kg/ha DAP + 50kg/ha Urea	36.8	34.6bcd
0	25kg/ha DAP + 25kg/ha Urea	34.26	29.25e
6	0	33.3	33.4cde
6	75kg/ha DAP + 75kg/ha Urea	43.8	38.74b
6	50kg/ha DAP + 50kg/ha Urea	42.7	37.11bc
6	25kg/ha DAP + 25kg/ha Urea	36.0	31.97de
9	0	36.5	36.66bc
9	75kg/ha DAP + 75kg/ha Urea	49.9	44.40a
9	50kg/ha DAP + 50kg/ha Urea	41.2	37.01bc
9	25kg/ha DAP + 25kg/ha Urea	43.8	35.8bcd
CV (%)		9.53	7.15
LSD(0.05)		6.362	4.251
SEM(±)		14.111	6.307

Another study conducted on integrated nutrient management of NP fertilizers with farmyard manure (FYM) at Gojeb in Kaffa Zone and at Kuja in Benchi Maji Zone showed that the highest grain yields of 4.05 t/ha and 5.06 t/ha in Kuja and Gojeb, respectively, were obtained from the application of 5 t FYM /ha combined with 75% recommended inorganic NP followed by the application of 5 t/ ha FYM with 50% recommended rate of inorganic NP (Table 13). The application of 5 t/ ha FYM in combination with 75% inorganic NP has increased grain yield by 73.51% and 13.51% at Kuja and by 77.96% and 17.76% at Gojeb over the control and the application of 100% recommended rate of NP fertilizers, respectively (Table 14). The increase in yield of rice due to the integration of 5 t FYM/ ha with 75% inorganic fertilizers over 100% of inorganic NP might be due to the addition of both macro and micro nutrients from the FYM, which indicates that even full rate of blanket inorganic NP was not adequate for rice production both at Kuja and Gojeb. The economic analysis revealed that the highest net returns of Birr 67521.8/ ha at Kuja and 78311.34 at Gojeb were obtained with the application of 5 t FYM

/ha + 75% inorganic NP (Tables 15 and 16). Thus, from the economic point of view, 5 t FYM /ha + 75% of inorganic NP were more profitable than the other treatments both at Kuja and Gojeb since the highest income were from these treatments as compared with the other treatments (Mitiku and Getachew, 2017).

Table 14 Grain yield of rice as influenced by integrated nutrient management in Kuja and Gojeb

Treatment	Grain yeld (kg/ha)	
	Kuja	Gojeb
2.5 t FYM+25% RDF	3577.3[c]	3737.7[c]
2.5 t FYM+50% RDF	3635.3[c]	4200.2[bc]
2.5 t FYM+75% RDF	3684.3[bc]	4455.1[abc]
5 t FYM+25% RDF	3924.3[a]	4685.2[ab]
5 t FYM+50% RDF	4018.0[a]	4878.5[ab]
5 t FYM+75% RDF	4050.0[a]	5064.2[a]
7.5 t FYM+25% RDF	3911.0[a]	4944.0[ab]
7.5 t FYM+50% RDF	3904.0[a]	5000.4[a]
7.5 t FYM+75% RDF	3886.3[ab]	5003.2[a]
100% RDF	3502.7[c]	4164.7[bc]
Control	1072.7[d]	1116.1[d]
LSD (5 %)	213.83	796.36
CV (%)	13.54	10.94

Table 15 Results of partial budget analysis of integrated nutrient management on rice in Kuja

Treatment	Total cost (birr/ha)	Net return (birr/ha)
2.5 t FYM+25% RDF	3005.8	59775.82
2.5 t FYM+50% RDF	3149.4	60650.12
2.5 t FYM+75% RDF	3271.9	61387.57
5 t FYM+25% RDF	3322.3	65549.17
5 t FYM+50% RDF	3531.4	66984.5
5 t FYM+75% RDF	3555.7	**67521.8**
7.5 t FYM+25% RDF	3822.8	64815.25
7.5 t FYM+50% RDF	3999.8	64515.4
7.5 t FYM+75% RDF	4056.5	64148.07
100% RDF	3028.6	58443.79
Control	1201.8	17624.09

Table 16 Results of partial budget analysis of integrated nutrient management on rice in Gojeb

Treatment	Total cost (Birr/ha)	Net return (Birr/ha)
2.5 t FYM+25% RDF	2844.6	57706.14
2.5 t FYM+50% RDF	2977.6	65065.64
2.5 t FYM+75% RDF	3052.9	69119.72
5 t FYM+25% RDF	3362.6	72537.64
5 t FYM+50% RDF	3436.1	75595.60
5 t FYM+75% RDF	3728.7	78311.34
7.5 t FYM+25% RDF	3825.4	76267.40
7.5 t FYM+50% RDF	3899.2	77107.28
7.5 t FYM+75% RDF	3906.6	77145.24
100% RDF	2906.4	64561.74
Control	1307.4	16773.42

From an experiment carried out in Fogera plain, during the main cropping seasons of 2010 and 2011; it was observed that the highest grain yield was attained at the combined application of the highest rates of all three fertilizers i.e., 15 t/ha manure with 100 kg P_2O_5 /ha and 120 kg N/ ha (Table 17). Results of the economic analysis showed that the maximum net benefit (23751 birr/ha) with an acceptable MRR was obtained from the combined application of 7.5 t FYM / ha, 120 kg N / ha and 100 kg P_2O_5 /ha (Table 18). This combination has resulted in a net benefit advantage of birr 7415/ ha over the control treatment (0-0 N-P_2O_5 kg/ ha) (Tilahun *et al*., 2013).

Table 17 The interaction effect of integrated FYM, N and P application on aboveground biomass and grain yields of rice in Fogera in 2010 and 2011

FYM (t/ ha)	Nitrogen (kg/ ha)	Phosphorus (kg P_2O_5 /ha)			Phosphorus (kg P_2O_5/		
		0	50	100	0	50	100
		Aboveground biomass yield (t/ha)			Grain yield (t/ha)		
0	0	9.7^{hi}	9.5^{i}	11.2^{e-i}	2.2	2.29^{j}	2.32^{j}
	60	10.5^{ghi}	10.5^{ghi}	12.5^{c-g}	2.3	2.44^{ij}	2.51^{ij}
	120	12.0^{c-g}	13.5^{bcd}	12.7^{c-g}	2.4	2.57^{ij}	3.67^{de}
7.5	0	10.8^{f-i}	10.5^{ghi}	9.5^{i}	2.3	3.10^{fgh}	3.42^{efg}
	60	11.5^{d-i}	11.7^{c-i}	11.9^{c-h}	2.9	3.48^{ef}	4.26^{cd}
	120	11.8^{c-h}	13.3^{b-e}	13.8^{b-e}	3.1	3.76^{de}	4.42^{c}
15	0	10.8^{f-i}	11.0^{f-i}	10.5^{ghi}	2.9	3.44^{ef}	3.43^{ef}
	60	12.5^{c-g}	12.8^{b-f}	15.0^{ab}	3.2	4.21^{cd}	4.93^{b}
	120	11.0^{f-i}	13.0^{b-f}	15.8^{a}	3.4	3.87^{de}	5.01^{a}
	CV (%)	19.70			12.68		

Means followed by the same letters within each growth parameter are not significantly different at P=0.05.

Table 18 Economic analysis for integrated use of FYM, N and P in rain-fed lowland rice grown in Fogera plain in 2010 and 2011

FYM (t/ ha)	N (kg/ ha)	P_2O_5 (kg/ ha)	TVC (Birr/ ha)	NB (Birr/ ha)	MRR (%)
0	0	0	0	16336	-
0	120	100	4368	21864	126.6
7.5	120	100	6528	23751	87.3
15	60	100	9993	25121	39.6

TVC = Total variable cost, NB = Net benefit, MRR = Marginal rate of return.

Conclusion

Different fertilizer experiments had been conducted on rice in different parts of the country. The experiments are mainly focusing on artificial fertilizers specifically on nitrogen and phosphorous nutrients. There are also few experiments conducted on the integrated application of farmyard manure and chemical fertilizers. Though the Ethiopian agriculture development is introducing other nutrients coming in the artificial fertilizers like sulfur, boron, and zinc containing fertilizers, the research has so far not focused on them. Thus, nutrient management research should give attention for the other nutrients other than N and P. It should also give more emphasis on the integrated nutrient management research.

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Rice Weed Species and Weed Management in Ethiopia

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Introduction

Weeds are the principal limiting biological factor in global rice production, with losses that vary from country to country, depending on the cultivation system, predominant weed communities and weed control methods employed by the farmers (Labrada, 2003). Worldwide, it is estimated that weeds cause on average 9% of rice crop losses (Rodenburg and Johnson, 2009). In Colombia, losses of 30 to 73% have been reported (Cobb and Reade, 2010). Appropriate control methods in rice crops are essential to minimize the negative effect of weeds (Fuentes, 2010). Use of herbicides has become the most used weed control method worldwide, on a large number of species. However, there are many concerns related to excessive use of herbicides. Although it does solve the problem of manual labor in many countries, incorrect use causes problems such as resistance in weeds, changes in weed populations, less availability of new broad-spectrum herbicides (Singh, 2012).

This paper reviews the the past research outputs on rice weed species and weed managemnt which had focused on applicability, efficacy of several of weed management option, importance or composition of weed species, and future prospective of weed management for the effective and sustainable management of rice weeds in smallholder farmers in Ethiopia.

Weed composition and diversity

Weed survey in Assosa Zone on upland rice fields revealed the species composition, prevalence and dominance and distributions of weeds in the fields. Twenty-one weed species belonging to 10 families were identified. The most dominant weed family based on number of weeds per area was Poacea (grass) family with five (5) species composition. The majority (66.7%) of the weed species were broad-leaved weeds. The most frequent and distributed weeds were *Ageranthum conizoid*, *Cyprus rotundus*, *Commelina subulata*, *Digitaria abisynica*, *Elusin indica*, *Leucas martinicensis*, *and Galensoga parviflora*. The dominant weeds in 2012 in the rice community were *Ageranthum conizoides* accounted 54.59% of the species followed by *Cyperus rotondus*, *Spergula arvensis* and *Commelina subulata* while in 2013 *Polygonum nepalense* (20%) followed by *Ageranthum conizoides*, *Cyperus rotondus*, *Commelina subulata* and *Leucas martinicensis* (Table 1). It is recommended that the weed control and management research strategy should target the dominant and frequent weed species that were from Poacea and Asteracea Family of weeds in both cropping seasons and weed flora composition.

Based on dominance, frequency and number of weed species, the most abundant weed families among the 12 weed families of Tepi area were from poaceae, asteraceae, commelinaceae and cyperaceae. The weed species identified in the rice research field of Tepi were 21 which were 11 from broad leaved weeds, 6 from grassy weeds and 4 sedges (Table 1). The result revealed the four dominant and highly competent weeds, at the earlier growth stage of rice, such as *Cyperus assimilis, Setaria pumila, Phalaris paradoxa and Xanthium spinosum* (Tilahun and Kifle, 2015). These weed species were also reported to be major weeds at Kafa and Bench-maji (Getachew *et al*., 2017).

Thirty-six weed species were collected and identified from South Gondar Zone in both years of 2016 and 2017 main cropping seasons of rice field (Table 2). From these 28 weed species in 2016 from surveyed 138 rice field and 31 weed species in 2017 from 144 surveyed rice fields were found dominant. In upland rice field totally 19 species, lowland 15 species and both from upland and lowland 2 species from rice field ecosystems were identified. These weed species belong in 16 weed families. The large majority of these, 18 were broad leave (herbaceous) weed species, 13 grasses, and 5 sedges. The five major families, based on the number of taxa were: Poaceae (10), Asteraceae (6), Cyperaceae (5), accounted for 58% of the total weed flora. The most economic important weed species were also prioritized depending on weed frequency (F), abundance (A) and dominance (D) of the weed species. The most frequent, abundant and dominant weeds were *Tagetes minuta, Conyza Canadensis (L.), Oryza barthii, Cyperus Difformus (Ghion), Echinochloa colona (L.), Panicum maximum, Cyperus iria (Bhoin), Commelina diffusa (L.), Koeleria macrantha, Ischaemum rugosum and Ludwigia octovalvis (Jacq.)* in 2017. In 2016 also *Ischaemum rugosu, Tagetes minuta, Koeleria macrantha, Oryza barthii, Alysicarpus monilifer, Echinochloa crusgalli, Cyanotis axillaris, Cyperus iri, Ludwigia octovalvis, Ludwigia octovalvi, Ageratum conyzoides (L.), Cyperus Difformus, Conyza Canadensis, Scirpus jancoides, Ammannia prieureana* again in terms of frequency, abundances and dominance of weed species in rice field were quantified. It was recommended that the weed control and management research strategy should target the dominant and frequent weed species in both rice field of ecosystem and weed flora composition (FNRRTC, 2017)

Table 1: Weed species composition from upland rice field in Benishangul Gumuz (2012 and 2013) and Tepi and Bench Maji (2014-16)

Species	Family	Life cycle	Location	Weed type
Agerathum conizoid (L.)	Asteraceae		K	H
Amaranthus caudatus (L.)	Amaranthaceae	A	T	H
Amaranthus hybridus (L.)	Amaranthacceae	A	K, B	H
Amaranthus hybridus (L.)	Amaranthaceae	A	K,B	H
Amaranthus spinosus (L.)	Amaranthaceae	A	T, K	H
Argemone mexicana (L.)	Papaveraceae	A	K,B	H
Avena fatua (L.)	Poaceae	A	K	H
Bidens pilosa (L.)	Asteraceae	A	K	H
Celosia argentea (L.)	Amaranthaceae	A	K	H
Cleome monophylla (L.)	Cpparaceae	A	K	H
Commelina benghalensis (L.)	Commelinaceae	P, A	K,T	H
Commelina latifolia Hochst. ex A.Rich.	Commelinaceae	A/B	K, T	H
Commelina subulata Roth	Commelinaceae	A	K	H
Corchorus olitorius (L.)	Malvaceae	B	T, B	H
Crassocephalem rubens (Jack.) S. Moor	Asteraceae	A	K	H
Cynodon nlemfuensis Vanderyst	Poaceae	P	T, B	G,S
Cynoglossum lanceolatum Forsk	Boraginaceae	B,P	K	H
Cyperus assimilis Steud.	Cyperaceae	P	T,K,B	S
Cyperus difformis (L.)	Cyperaceae	P	T	S
Cyperus esculantus (L.)	Cyperaceae	P	T,K,B	S
Cyprus rotundus (L.)	Cyperaceae	P	T, K, B	S
Datura stramonium (L.)	Solanaceae	A	K, B	H
Digitaria abyssinica (A. Rich) Stampf	Poaceae	P	K,T, B	G
Digitaria ternate (A. Rich) Stampf	Poaceae	A	K, B	G
Eleusine indica (L.) Gaerttn	Poaceae	A	K	G
Eriochloa fatmensis	Poaceae	A	T	H
Eriocloa fatmensis	Poaceae	P	K,B	G
Galensoga parviflora Cav.	Asteraceae	A	K	H
Hygrophila auriculata T. Anders	Acanthaceae	A,B	K,B, T	H
Launaea cornuta (Hochst. ex Oliv. & Hiern.) C. Jeffrey	Asteraceae	P?	T, B	H
Leucas martinicensis (Jacq.) Ait. f.	Lamiaceae	A	K	H
Nicandra physalodes (L.) Gaertner	Solanaceae	A	T, B	H
Oxygonum sinuatum (Meisn.) Dammer	Polygonaceae	A	T, B	H
Parthenium hysterophorus (L.)	Asteraceae	A	K,B	H
Pennisetum clandestinum Hochst. ex. Chiov.	Poaceae	P	T,B	G, S
Phalaris paradoxa L.	Poaceae	A	T, K,B	G
Plantago lanceolata L.	Plantaginaceae	P	K	H
Polygonum nepalense Meisner	Polygonaceae	A	K	H
Setaria pumila	Poaceae	A	T,K,B	G
Seteria verticillata (L.) Beauv.	Poaceae	A	K,B	G
Sonchus asper (L.) Hill	Asteraceae	A/B	T, K,B	H
Spergula arvensis (L.)	Caryophyllaceae	A	K, B	H
Xanthium spinosum (L.)	Asteraceae	A	K,B, T	H

**A=Annual; P=Perenneal; S= Sedge; H=Herbaceous; G=Grass; K=Kamash; T=Tepi, B=bench-maji*

Table 2: Weed species composition and diversity in South Gondar Zone (2016 and 2017)

Scientific name	Family	Life cycle	weed type	Ecology	Characters	Reproduction
Achyranthes aspera (L.)	Amaranthaceae	A	H	U	d	rs
Ageratum conyzoides (L.)	Compositae	A	H	U	d	rs
Alysicarpus monilifer	Fabaceae	A	G	U	m	rs
Amaranthus spinosus (L.)	Amaranthaceae	A	H	U	d	rs
Ammannia prieureana	Lythraceae	A	H	U	d	rs
Andrographis paniculata Wall.	Acanthaceae	A	H	U	d	rs
Commelina benghalensis (L.)	Commelinaceae	A	H	L	d	rv/rs
Commelina diffusa (L.)	Pontederiaceae	A, P	H	L	m	rv/rs
Conyza Canadensis (L.)	Asteraceae	A	H	U	d	rs
Cyanotis axillaris	Commelinaceae	A	G	U	d	rs/rv
Cynodon dactylon (L.)	Poaceae (Graminae)	A	G	L	m	rs
Cyperus Difformus (Ghion)	Cyperaceae	A	S	L	m	rv/rs
Cyperus esculentus	Cyperaceae	A	S	L	m	rv/rs
Cyperus iria (Bhoin))	Cyperaceae	A	S	U, L	m	rs
Cyperus rotundus	Cyperaceae	A, P	S	L	m	rs/rv
Dactyloctenium aegypticum (L.)	Poaceae	A	G	L	m	rs
Digitaria ciliaris	Poaceae (Graminae)	A	G	U	m	rs
Digitaria setigera	Poaceae (graminae)	A	G	U	m	rs
Echinochloa colona (L.)	Poaceae (graminae)	A	G	L	m	rs
Echinochloa crusgalli	Poaceae (graminae)	A	G	L	m	rs
Ipomoea cairica	Convolvulaceae	P	H	L	d	rs/rv
Ischaemum rugosum	Poaceae (Graminae)	A	G	L	m	rs
Koeleria macrantha	Poaceae	A	G	L	m	rs
Ludwigia octovalvis (Jacq.)	Onagraceae	A	H	U	d	rs
Medicago sativa	Papilionaceae	A, P	H	U	d	rs
Oryza barthii	Poaceae	A	G	L	m	rs
Panicum maximum	Gramineae	A	G	U	m	rs
Parthenium hysterophorus L.	Asteraceae	A	H	U	d	rs
Paspalum distichum L.	Poaceae	P	G	L	m	rv/rs
Plantago lanceolata L	Plantaginaceae	P	H	U	d	rs
Rhamphicarpa fistulosa (Hochst.)	Broomrape	A	H	U	d	rs
scirpus jancoides	Cyperaceae	A	S	L	m	rv/rs
Sonchus asper (L.) Hill	Asteraceae	A	H	U	d	rs
Tagetes minuta	Asteraceae	A	H	U	d	rs
Xanthium spinosumL	Asteraceae	A	H	U, L	d	rs
Xantium strumarium	Asteraceae	A	H	U	d	rs

**A=Annual; P=Perenneal; S= Sedge; H=Herbaceous; G=Grass; d=Dicot; m=monocot; U=upland; L= lowland; rs=reproduce by seed; rv =reproduce by vegetative*

Yield loss

In a weeding frequency trial at Pawe Research Center indicated that weeding three times (15, 30, 45- 60 days after emergence (DAE)) has been recommended to minimize losses caused by weeds. In the experiment, whenrice weeds are left unweeded, resulted in weed losses ranged between 45% and 87% with average yield loss of 67% of Pawe-1 rice variety (Table 3). Similarly, 68 % loss was reported at Kaffa and bench Maji research plots (Getachew et al., 2017). When it is weeded only once at 30 DAE resulted in average yield loss of 20 % (Gezahegn *et* *al*., 2009). Another study, Yield losses of 22 % was recorded when rice weeds were left unweeded until 30 DAE. Similarly, yield losses of 8.4 to 22.7 q/ha; i.e., 39 to 106 % and 8.5 to 32.2 q/ha; i.e., 27 to 102 % yield loss in Superica-1 and Nerica-4 varieties, respectively, were reported when crop was left unweeded at the early stage of the crop development (Tilahun and Kifle, 2015). The experiment result showed that the importance and critical time for weeding at the early stage of crop development. One time weeding at early stage (at 15 days after rice emergence) reported to cause loss of 20 %, while weeding once at 30 days after emergence resulted to double the yield losses to 39 % (Gezahegn *et al*., 2009).

Table 3: Mean grain yield, percentage yield loss, estimated person-days and estimated labor cost (Birr) for various time and weeding frequencies in year 2004 & 2005 at Pawe.

Treat	Grain yield (kg/ha)	Yield loss (kg/ha)	% Yield loss	Estimated man days ha^{-1}	Estimated abor cost
Weedy	681	1388.1	67.1	0.0	0.0
Wedding 15 DAE	1262	808.0	39.0	23.0	103.7
Weeding 30 DAE	1656	413.7	20.0	53.9	242.5
Weeding 15&30 DAE	1977	92.2	4.46	62.8	282.6
Weeding 15,30 &45DAE	2188	-118.8	-5.7	103.0	463.5
Weeding 15 & 45 DAE	2029	40.8	2.0	74.7	336.3
Weeding 30 & 45 DAE	1878	191.6	9.3	95.2	428.4
Weeding 15,30&60 DAE	1934	135.2	6.5	125.6	565.0
Weeding 15,45&60 DAE	2155	-85.3	-4.1	132.7	597.0
Weed free	2070	0.0	0.0	169.4	762.4
CV (5%)	1783				
Mean	492.4				
LSD	28				

Weeds on upland rice resulted in yield loss through affecting yield components such as number of tillers per plant, panicle length, and thousand seed weight (TSW). The highest thousand seed weight of 42.8g was recorded in weed free treatment while the lowest TSW of 32.0g was recorded in weedy treatment. Weeds accounted to 25.2 % TSW loss. Similarly, number of tillers per plant (14.6) and panicle length per plant (24.7) were highest in weed free treatments. In contrary the lowest score of 9.3 tiller number per plant and 9.8 panicle length per plant were recorded in weedy plots. In this case, weeds accounted to cause 36.6% reductions in tiller number per plant and 60.3% reduction in panicle length (Getachew Mekonnen et al., 2017). Thousand seed weight, tiller number per plant, and panicle length per plant increased with the increase in the duration of weed free periods and decrease with the duration of weedy periods (Getachew Mekonnen et al., 2017).

Critical weeding time

The critical crop weed competition period was between 30 and 70 days after crop emergence (DAE) at Bench maji; and between 28 and 47 DAE at Gojeb in Kaffa Zone (Getachew Mekonnen et al., 2017).

In weed frequency trial, at Pawe indicated that no appreciable yield gain was obtained when weeding was made after 45 days of rice emergence. So, the critical weed crop competition period in rice was determined to be between the periods of 15 and 45 days since rice emergence (Gezahegn Girma et al., 2009).

With increasing duration of weed interference, weed dry weight, and the number of days of rice plant required to reach physiological maturity were increased whereas number of tillers per plant, panicle length, thousand seed weight, grain yield, aboveground biomass, and harvest index of the rice crop were reduced (Getachew Mekonnen et al., 2017).

Hand weeding frequency studies

An experiment to see the effect of different weeeding time on rice yield and yield components was conducted at Kaffa.The treatments tesed were three weeding times (such as 15-20+30-35+45-50 days after emergence (DAE), 20-25 +35-40 +50- 55 DAE, 30-35+45-50+60-65 DAE and farmers practice (weeding at 20-25 DAE once) as control was done (Table 4). The yield and yield components were significantly affected ($P<0.001$) by the weeding time. The maximum grain yield of 44.18 and 63.82 q/ha was obtained from weeding made at 15-20+30-35+45-50 DAE while the minimum yield of 21.36 and 31.63 q/ha obtained from weeding at 30-35+45-50+60-65 DAE on Superica-1 and Nerica-4 rice varieties, respectively (Table 3). Moreover, maximum 1000-grain weight, straw yield, and tillers number of rice were recorded upon weeding at 15-20+30-35+45-50 DAE. Early weeding of 15-25 DAE was found to increase grain yield and yield components of upland rice and recommended for upland rice production in Kafa and similar agro ecologies (Tilahun and Kifle, 2015). Therefore, early weeding has significant contribution in order to increase upland rice yield and yield components and it was important to prevent yield losses in yield and production costs and important to maintain good grain quality (Tilahun and Kifle, 2015).

Another experiment in Pawe Research Center on Pawe-1 variety evaluated different hand weeding frequencies to determine weeding time, and it recommended that three times hand weeding that is 15, 30 and 45 - 60 DAE were advised to farmers due to its reasonable yield and lower estimates of man-days and cost of production (Gezahegn *et al*., 2009).

Table: 4 Effect of weeding time on yield and yield components of 'Superica and Nerica-4' Rice variety in Kaffa, SW Ethiopia in 2009/10

NB: T1 =weeding 15-20 DAE, 30-35 DAE, 45-50 DAE; T2 = weeding 20-25 DAE, 35-40 DAE, 50-55 DAE; T3 = weeding 30-35 DAE, 45-50 DAE, 60-65 DAE; T4 = farmers practice(control) 20-25 DAE; LSD=least
significant difference; CV=coefficient of variation; S-1=Superica-1, N-4=Nerica-4

Treat	Tiller no.		Plant height (cm)		Panicle length (cm)		Culm length (cm)		Straw yield (kg/ m^2)		Yield (q/ha)		TSW (g)	
	S-1	N-4	S-1	N-4	S-1	N-4	S-1	N-4	S-1	N-4	S-1	N-4	S-1	N-4
T1	8.7	10.2	109.3	100.3	18.5	39.8	90.8	60.5	1.7	1.5	44.1	63.8	44.1	63.8
T2	7.7	6.2	97.3	89.4	18.2	18.6	78.9	70.8	1.2	1.2	29.8	40.1	29.7	40.2
T3	6.3	6.8	94.7	89.4	17.9	18.2	76.8	71.2	0.6	0.8	21.4	31.6	21.4	31.6
T4	6.4	7.4	92.0	90.3	17.0	19.0	75.0	71.3	0.8	1.0	29.9	48.2	29.9	48.2
Mean	7.3	7.7	98.3	92.4	17.9	23.9	90.8	68.5	1.13	1.13	31.3	46.0	37.1	37.3
LSD	3.2	1.9	14.7	11.5	2.7	36.9	78.9	37.7	1.35	0.54	20.6	20.2	1.7	2.0
CV	21.9	12.6	7.5	6.2	7.6	27.2	76.8	27.6	19.8	23.9	32.9	22.0	2.3	2.7

(Source: Tilahun Mola and Kifle Belachew, 2015)

Results of the weeding frequency in upland rice was combined a mean analysis in 2016 and 2017 main cropping season in Fogera and Dera Woreda of South Gondar Zone were summarized in Table 5. The grain yield (kg/ha), plant height (cm), panicle length (cm), number of spikelets per panicle and harvest index were showed statically significant differences between the frequency of weeding treatments (FNRRTC, 2017). The highest yield (6464.2 kg/ha) were obtained from four times of weeding (22, 48, 67, and 85 DAE). The trend of harvested grain yield (kg/ha) were increased from one time to four time of weeding significantly over check (Table 5).

Table 5: Effect of weed frequency on Agronomic, yield and yield component of upland rice in 2016 and 2017 in Fogera and Dera

Weeding time	PH	PL	NSPP	TGW	GY	DTM
Weed check	61.8	14.6	7.4	30.2	2188.5	130.7
One time (22 DAE)	66.8	15.6	8.4	28.7	4300.3	133.0
Two time (22 & 71 DAE)	67.7	16.5	9.3	28.6	4721.4	133.0
Three time (22, 48 & 71 DAE)	68.3	16.5	8.7	30.5	5565.7	132.0
Four Time (22, 48, 67, & 85 DAE)	71.5	17.7	9.1	31.1	6464.2	133.7
Weed free	72.2	17.2	10.0	30.2	6479.0	132.3
LSD	3.5	0.8	1.2	1.8	986.3	3.6
CV	4.2	4.2	11.6	5.0	16.6	1.5
Means	68.0	16.3	8.8	29.9	4953.2	132.4
P-value	<.0001	<.0001	0.007	0.05	<.0001	0.5475

** PH=Plant Height, PL=Panicle Length, NSPP=Number of Spikelet per Panicle, TGW=Thousands Grain Weight, GY= Grain yield, DTM=Days to Maturity*

Chemical weed control

Among weed management methods, chemical weed management is the best and cost-effective under large-scale rice production. However, the number of herbicides registered for rice and their availability in the market is very limited in Ethiopia. To alleviate the problem of availability and register a herbicide, pre-verification trial of a post emergence herbicide, KeeperTM 414 EC (Cyhalofop-butyl 184.3g ai/l+Fluroxypyr-meptyl 230.73g ai/l) has been under trial since 2017 and it will be registered after verification trial in 2018.

The herbicide is designed to the control of broadleaf and annual grass weeds in rice crop. Pre-verification study of the herbicide, Keeper^{TM} 414 EC, at three rates and hand weeding and weed free check as controls was conducted at two location around Pawe area during 2017 on NERICA 4 rice variety (Table 6). The yield obtained from the plot treated with keeper at the rate of 2 l/ha, 1 l/ha, and 1.5 l/ha are 4064.37kg/ha, 4040.73kg/ha and 4013.95kg/ha, respectively. In addition, they were statistically non-significant with that of the plot treated with hand weeding (4602.55kg/ha) which resulted in the highest yield. In the experiment, it was also clearly shown that weeds significantly affected yield of rice by at least 2.7fold. Weeds expressed their effect through reducing yield components of rice such as the number of effective tillers per plant and thousand seed weight, and yield (Table 6).

Table 6: Mean separation of combined weed biomass and grain yield of rice in Pawe in 2017

Treatment	NTM	PH	FWV	DWV	FWH	DWH	TSW	AdjGY (kg/ha)
Keeper™ 414EC 2l/ha	6.55	90.9	140.8[bc]	65.287[bc]	467.5[ba]	261.37[a]	27.375[a]	4064.37[a]
Keeper™ 414EC 1l/ha	6.2	93.7	83.45[c]	41.73[c]	378.87[b]	187[a]	27.25[a]	4040.73[a]
Keeper™ 414EC 1.5l/ha	6.1	92	148.72[bc]	69.45[bc]	347.22[b]	207.5[a]	27.5[a]	4013.95[a]
Hand weeding (2*)	6.25	91.55	195.1[ba]	97.812[ba]	65.87[c]	31.87[b]	27.5[a]	4602.55[a]
Weedy check	5.65	94.55	235.75[a]	114.52[a]	655.12[a]	242.37[a]	25.5[b]	1504.70[b]
Mean	6.15	92.54	160.77	77.76	382.92	186.04	27.025	3645.26
CV (%)	18.3	4.56	30.95	29.47	46.39	34.28	3.18	23.25
LSD	1.73	6.5	76.67	35.31	273.7	98.269	1.32	1305.8
P-Value (0.05%)	0.84	0.72	0.0102	0.0059	0.007	0.0021	0.028	0.001

** Values with the same letter are not significantly different.*

***NTM-Number of tillering at maturity, PH-Plant height, FWAV-fresh weight at vegetative stage, DWAV-dry weight at vegetative stage, FWAH-fresh weight at harvesting, DWAH-dry weight at harvesting and AdjGY-adjustable grain yield kilogram per hectare.*

Table 7. Weed species control effectiveness of a herbicide, keeper ™ 414 EC at Pawe

Weed species	Keeper ™ 414 EC 2 l/ha	Keeper ™ 414 EC 1 l/ha	Keeper ™ 414 EC 1.5 l/ha	Hand weeding	Weedy check
Commelina benghalensis L	++	++	+	+++	-
Eleusine indica	++	+++	+++	+++	-
Portulaca oleracea	+++	+++	+++	+++	-
Leucas martinicensis	++	++	++	++	-
Chromolaena odorata	±	+++	+++	±	-
Cyperus spp	+	+	+	+	-
Digitaria tarnata	++	+++	+++	+++	-
Amaranthus hybridus	+	+++	+++	+++	-
Hyptis suaveolens	+++	+++	+++	+++	-
Artracxan prionodes	++	++	+++	+	-
Bidens plosa	+++	+++	+++	+++	-
Commelina subulat	+++	+++	+++	+++	-
Sida rhombifolia	+++	+++	+++	+++	-
Aeschynomene americana	+++	++	+++	+++	-

** (-)-not effective, (±)- very low, (+)- low, (++)-moderate, (+++)-high*

The pre-verification result, also showed the effectiveness of Keeper TM 414 EC at three rates on important broad and grass weeds in Pawe area (Table 7). Keeper was also effective in controlling many dominant grasses weed species like *Cynodon dactylon*, *Digitaria tarnata* and *Eleusine indica*. Effective broadleaf and grass weed management in rice was obtained by Keeper TM 414 EC at the rate of 1.5 l/ha and its effectiveness could not increase as the rate increased beyond 1.5 l l/ha. Though the highest weed management was observed at the medium rate of Keeper TM 414 EC ;i.e. 1.5 l/ha), the lower rate; i.e.. 1l/ha was also effective, economical and environmentally safe as there was no significant difference in grain yield. Therefore, application of Keeper TM 414 EC at the rate 1 l/ha is effective in rice field, where both broad leaf and grass weed species are dominant. However, it should be supplemented by hand weeding in rice field where *Cyperus* spp. is dominant. Other studies on pre and post emergence herbicide evaluation at Pawe in 2016 and 2017 showed that, there were no effective herbicides like Keeper ™ 414 EC to control rice weeds.

In addition to the above results, farmers in Metekel Zone of Benshangul Gumz Region has experience in using chemical herbicides. In the Zone, 60 % of the area is black soil and it is determined to be very suitable for production of rice. Most farmers in the zone are producing upland rice. They have developed their own weed management practice. That is, burning of the residue in the off-season; applying of glyphosate before first plowing at the first shower of the rainy season to remove first flush of weeds, then they plow two times and sow the rice seeds, and then after 25 to 35 days after emergence of rice, selective herbicide (2,4-D) is applied to control broad leaf weeds. Then they use one-time supported hand weeding. This weed management practice is well practiced among the farmers in Metekel zone. The two herbicides, glyphosate and 2,4-D with different trade names, are popular and used very well by farmers in the zone. In addition, mixing of 1 to 2 ratios of 2,4-D to glyphosate is applied, at the first flash of weeds before sowing to synergize their effect and increase their effectiveness, and it is practiced by some farmers. The major concern in their weed management practice in the area is poor utilization of personal protectives while they are applying herbicides.

Integrated weed management

Heavy infestation of weeds is one of the major constraints for the successful cultivation of rice. No single weed control method can combat the multitude of weed problems in a given area and so it is necessary to use a combination of physical, chemical and cultural management techniques to achieve higher benefits in rice cultivation.

Different weeding management option were evaluated in 2016 and 2017 main cropping season at south Gondar zone (Fogera and Libokemekem woreda) on-farm of upland rice (Table 7). The rotary weeder with one-time supplimentary hand weeding (4719.1kg/ha), herbicide spraying and one-time hand weeding (4636.6 kg/ha) and two-time hand weeding alone (4921.1kg/ha) gave highest yields over the other weeding methods and weedy check during (Table 8). Manual weeding practice solitary by hand is inefficient method for weed control due to needs of intensive labor, time consuming and is not practical for large areas. Therefore, in the present study one-time herbicide application for first time weeding (30 DAE) and integrating with one-time hand weeding at flowering stage (60 DAE) is effective control measure. Rotary weeder (machine) for first time weeding (30 DAE) with one-time hand weeding at flowering stage was recommended to manage weed efficiently or as alternative management for any rice producer farm scale or type.

Table 8: Effect of weeding methods on combined mean of Agronomic, yield and yield component of upland rice

Treatment	PH	PL	NSPP	TGW	GY
Weed Check	67.4	16.5	8.0	28.8	2471.2
Hand weeding (30 DAE)	67.9	16.7	9.0	30.5	4040.5
Hand weeding (30, 60 DAE)	69.1	17.2	9.1	30.3	4921.1
Machine weeding (30 DAE)	70.9	16.2	8.7	28.8	3554.4
Machine weeding (30, 60 DAE)	66.7	16.5	9.0	29.5	3634.3
Chemical weeding (30 DAE)	65.1	16.3	8.4	28.5	2687.4
Chemical weeding (30, 60 DAE)	62.6	16.0	8.6	29.8	2905.7
Machine + Hand weeding (30 + 60 DAE)	67.2	16.8	9.0	31.3	4719.1
Chemical + Hand weeding (30+ 60 DAE)	68.2	17.1	9.5	31.5	4636.6
Machine + Chemical (30 DAE)	65.0	15.5	8.1	29.4	3130.2
LSD	4.3	NS	NS	NS	487.4
CV	5.5	6.2	8.4	7.5	11.4
Significance level	*	NS	NS	NS	***

** PH=Plant Height, PL=Panicle Length, NSPP=Number of Spikelet per Panicle, TGW=Thousands Grain Weight, GY= Grain yield*

Economics of rice weed management

In critical weeding trial, the cost benefit study using partial budget analysis indicated that the highest gross benefit of 78308 and net benefit of 64615 Birr/ha was obtained in weed free for 70 days treatment followed by weed free for 60 DAE with gross benefit of 71181 Birr /ha and net benefit of Birr/ ha (Getachew Mekonnen et al., 2017). In general, gross benefit increased with the increasing duration of the weed-free period (IDWFP) and decreased with the increasing duration of the weedy period (IDWP) (Getachew Mekonnen et al., 2017).

A research at Fogera pain revealed that the highest net benefit of 33563 Birr per hectare was obtained from application of puddling after 10 and 15 days of flooding and three times hand weeding, followed by application of puddling after 10 and 15 days of flooding and two times hand weeding while the farmers practice of three times hand weeding and with no puddling gave lowest net benefit of 13718 Birr per hectare. No puddling and two times hand weeding gave the least mean net return (15507.5 Birr) (Tesfaye, 2016).

On weeding frequency and time study, three-times weeding at 15,30 and 15 is recommnded at Pawe based on the man-days ha^{-1} (hours of labor/ ha) and cost of production. It was estimated that man-days per hectare of 103.7 and estimated cost of Birr 463.5 per hectare is needed for the weeding practice in 2005 (Gezahegn *et al*., 2009).

Conclusion

Proper weed management promises food security through enhanced productivity and profitability, while safeguarding the natural resource base. Successful identification and alleviation of weed threat is one approach to enhance yield and bridge yield gaps. Rice weed management studies or investigation in Ethiopia are at the infant stage as rice cultivation was started before few decades. The weed flora of rice and different weed management option studies from rice production potentials areas like South Gondar, Assosa, Pawe, and Bonga were reviewed in this paper to show recommendation of rice weed management, to inform the gaps and indicate the way of intervention to rice weed management in Ethiopia. Rice weed survey to identify the weed species of economic importantance,their distribution and abundances were conducted recently at all important and representative locations of rice production to both for upland and lowland rice ecosystems. The step by step of rice weed research (yield loss, critical weed periods, weed frequency, herbicide evaluation and integration to two and more weed management options and economic of rice weed management) were investigated to solve the rice yield gaps in the country. The weed species diversity and composition were varied from location to location due to different climatic factors, type of soil, cropping system, tillage type, and rice ecosystem. The un-similarities in weed species compositions were targeted to influence the weed management methods to apply directly and/or indirectly for rice production areas in Ethiopia.

More research is needed towards the manipulation of non-chemical means (improved tillage methods, weedier machine, row direct seed planter, seedling transplanting and other improved farm machinery) to the optimization and integration of these methods with chemical weed control methods. Studies also devoted to assessing the impact of herbicide usage on species richness, diversity, and abundance of resistant/tolerant weed species. Focused research is needed to unravel mechanisms conducive to the success of alien invasive weeds and identify vulnerabilities, to inform monitoring, early detection and warning systems, assist development of regional and national databases, strengthen quarantine and management systems, assess ecological and economic impacts, and improve public awareness. In order to harness the benefits of weed science for sustainable crop production, capacity building of researchers and extension personnel is needed. Networking and collaboration among researchers and institutions are critical.

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Rice Diseases and Insect Pests in Ethiopia

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Introduction

Globally the importance of rice increasing wich have shown an increasing trend on both productivity. However, diases and insect pest are still causing serious challenge to achive the genetic potential of the crop. Extnsive estimation of grain yield and quality lose caused by rice diseases and insect pests have not been reported. However, depending on the pathogen inoculum density, and agressiveness, environmental conditions, cultivar susceptibility, and interaction with other cultural practices yield lose raning for trace to total crop failure were reported (Savary et al., 2000; Song and Goodman, 2001). Stusies aborad on rice showed that more than 70 diseases caused by fungi, bacteria, viruses or nematodes (Manandhar *et al.*, 19980.These has made estimation of the effect of the different pathogen of yield and quality traits more challenging and resource demanding.

In Ethiopia rice is considered as one of the food security crop. As the country is investing huge amount of foreign currency there is a huge interest to expand total production to satify the gowing local demand. The current production and productivity of rice is lower due to several factors including poor system to access low level of access to improved crop production tehnologies and lack of pest and disease controlling options are the most important constraints (NRDSE, 2009). Although the effect of pathogens on grain yield and quality traits not properly estimated, it is belived insect pests and diseases have signficant contribution for the lower rice productivity. Therefore, to achieve the country's development plan and insure the food security and producing high quality grain development of integrated pest and diseas management options for sustainable rice production in Ethiopia is a top prority (EIAR/ FRG II, 2011).

This paper aimed to present review on status, challenges and opportunities on rice diseases and insect pests and their management; and point out future directions or issues that needs future attention in rice research and development endeavors for sustainable rice production in Ethiopia.

Research on rice diseases and insect pests

Rice is a recently introduced crops in the Ethiopian agriculture and the cultivation started in the early 1970's (EIAR/ FRG II, 2012; Gebeyhu *et al*. 2012). Research and extension were also started late 1990s mainly focussing on varietal development and technology promotion. Hence, information on dieases and insect epidemiology effect and management options are scanty. Study have indicated that rice blast diseases (*Pyricularia oryzae)* in Ethiopia has been observed in Amhara Region, since 1985 and also in SNNPR (Mebratu *et al.*, 2015). However, this does not mean that there were no other diseases, insect pests as well as rice blast in the country before. A number of pests including blast, brown spot, sheath rot, RYMV, stem borer, staked-eyed fly, termite, leaf hopper and leaf folder were considered as the mjor one (MoARD, 2010). This, thefore, suggested that rice diseases and insect pests possible coevolved since the introduction and cultivation of rice. As rice predominatly grown in swampy area of the country where other crops npt able to grow well, rice mono cropping is commonly practiced, which ight have contributed for the buld up of pest pressure.

Research Achievements

Survey and identification of rice diseases and insect pests

Survey conducted in 2013 in Fogera district reported rice yellow mottle virus (Rakotomalala et al. 2014). The vairus belongs to serotype 4, whihx has been found and reported in east Africa and in Madagascar. However, information is lacking regarding the severity and coverage thvirus in the study areas, which might need further research to design effective controlling options. .

In addition survety was conducted in 2015 in the major rice growing ares of Ethiopia in the Amhara, Benishangul Gumuz, Tigray, and SNNPR regional states. crop. The survey rsulted summurozed in Table 1 presented the occuracne of leaf and panilcle blast (Pyricularia oryzae) in both three regions. While brown spot (Cochliobolus miyabeanus) and sheat blight (Rhizoctonia solani) were observed in the three of the surveyed regions except SNNPR. In this survey four of the pathogens Sheath brown rot, Rice yellow motile virus, Udbatta disease and Downy mildew were only reported in the Amhara regional state. Among the disease identified in rice crop in Ethiopia, four diseases (leaf blast, panicle blast, brown spot and bacterial blight) were found in Amhara, Benishangul Gumuz, and Tigray. However, their severity was not similar in across the regions. This could be related to the different agro-ecologies or environmental conditions across regions. The highest disease severity was observed in the Amhara region and panicle blast was found more severe followed by brown spote (Figure 1)

In Benishangul Gumuz, the survey was conducted in 2015 in Pawe areas twice at vegetative and reporoductive stages (August and September) in the growth period of the crop. According to the result, among the identified diseases, the highest prevalence, incidence, and severity rate of were 80.08, 75 and 5.2%, respectively, whih was obtained by leaf blast at vegetative growth stage. . However, at heading stage, it was   panicle blast, which showed the highest severity percentage of 10.3% (Table 2).

Table 1. Rice diseases in different parts of Ethiopia

Diseases		Surveyed regional states and woredas			
Common name	Scientific name	Amhara (Dera, Fogera, Libokemkem woredas)	Benishangul Gumuz (Pawe woreda)	Tigray (Tselemt woreda)	SNNPR (Guraferda, Gimbo, Yeki woredas)
Leaf blast	*Pyricularia oryzae*	√	√	√	√
Node blast		√	x	√	√
Neck blast		√	x	√	√
Panicle blast		√	√	√	√
Brown spot	*Cochliobolus miyabeanus*	√	√	√	NI
Sheath blight	*Rhizoctonia solani*	√	√	√	NI
Bacterial panicle blight	*Burkholderia gluma*	√	√	x	NI
Sheath spot	*Rhizoctonia oryzae*	x	√	x	NI
Bacterial leaf strike	*Xanthomonas oryzae* pv. *oryzicola*	x	√	x	NI
Sheath rot	*Sarocladium oryzae*	√	x	√	NI
Grain spotting or Pecky rice	Various fungi	x	x	√	NI
Leaf scald	Microdochium oryzae	x	x	√	NI
Crown rot or foot rot	Erwinia chrysanthemi	x	x	√	NI
Head blight	Various fungi	x	x	√	NI
Sheath brown rot	*Pseudomonas fuscovaginae*	√	x	x	NI
Bacterial leaf blight	*Xanthomonas oryzae* pv. *oryzae*	√	x	√	NI
Rice yellow motile virus	Rice yellow motile virus	√	x	x	NI
Udbatta disease	*Balansia oryzae-sativa*	√	x	x	NI
Downy mildew	*Sclerophthora macrospora*	√	x	x	NI

N.B: √ = present, x = not present, NI = no information
Source (Wasihun and Flagote, 2016; Mebratu et al., 2015)

Table 2. Prevalence, incidence and severity of rice diseases at vegetative and heading stage of the crop in Pawe, Ethiopia in 2015

Disease		Growth stages					
Common name	Scientific name	Vegetative			Heading		
		P%	DI%	DS%	P %	DI%	DS%
Panicle blast	*Pyricularia oryzae*	15.51	11.15	1.10	100	100	10.30
Leaf blast	*Pyricularia oryzae*	80.08	75.00	5.20	100	96	7.21
Brown spot	*Cochliobolus miyabeanus*	32.43	46.15	1.40	47.83	74	1.90
Sheath blight	*Rhizoctonia solani*	56.75	69.23	2.70	62.16	42.3	2.90
Bacterial panicle blight	*Burkholderia gluma*	9.67	13.46	0.90	21.20	32.3	4.20
Sheath spot	*Rhizoctonia oryzae*	21.62	25.00	1.60	16.21	28.84	1.71
Bacterial leaf strike	*Xanthomonas oryzae* pv.*oryzicola*	32.64	21.15	0.80	35.13	46.15	1.10

NB. P% = prevalence, DI%= disease incidence, DS%= disease severity; Source: (Wasihun and Flagote, 2016).

Survey was conducted in Fogera, Libokemkem and Dera Woredas of the Amhara region in the 2016 and 2017 cropping seasons. In both seasons, despite the prevalence of some diseases across all surveyed areas, the type of diseases and their intensity varies from location to location and from year to year. This indicates that, regardless of the presence of the pathogen in the area, the preconditions for a specific disease development (virulent pathogen, susceptible host, and suitable environmental conditions) might not be consistent across locations and seasons. Among the identified rice diseases leaf blast, panicle blast, brown spot, sheath blight, sheath rot, kernel smut and rice yellow mottle virus were found across locations and seasons. Of the identified diseases, sheath rot has the highest incidence and severity followed by panicle blast and brown spot (Table 3).

Table 3. Prevalence, incidence and severity of rice diseases in South Gonder Zone

Disease	2016			2017		
	Prevalence %	Incidence %	Severity %	Prevalence %	Incidence %	Severity %
Leaf Blast	15.2	45.76	2.68	-	-	-
Node blast	-	-	-	10.4	2.9	22.2
Neck blast	-	-	-	20.2	12.4	55.9
Panicle blast	30.4	33	2.3	54.8	9.6	61.6
Brown spot	4.3	31	1.8	33.3	31.8	27.0
Sheath Blight	60.9	33.4	1.8	18.8	13.1	14.8
Sheath rot	69.6	47	3	100.0	43.3	44.0
Sheath brown rot	-	-	-	85.4	32.7	26.7
Bacterial panicle blight	2.2	75	5	8.3	7.2	11.1
Bacterial leaf blight	-	-	-	14.6	20.8	17.9
Kernel Smut	10.9	31.5	2.5	14.6	6.5	100.0
RYMV	4.3	42.8	3.7	8.3	47.2	90.1
Downy Mildew	2.2	20.6	1	-	-	-

Source: FNRRTC survey 2016 and 2017

In Tigray the survey was conducted during 2014 and 2017 cropping seasons at Tselemti distict which is the major rice growing area in the region. . During the survey, different diseases were identified. Of which, brown spot andleaf blast were found in both seasons, while panicle blast and sheath rot had high prevalence, incidence and severity (100, 25.23 and 11.29%, respectively) (Table 4).

Table 4. Prevalence, incidence, and severity of rice diseases in Tigray Region

Disease	2014			2017		
	Prevalence (%)	Incidence %	Severit y %	Prevalence (%)	Incidence %	Severity %
Brown leaf spot	64.71	23.41	9.96	89.58	13.61	4.14
Bacterial leaf blight	47.06	14.05	6.68	-	-	-
Leaf blast	23.53	5.94	4.51	91.67	7.64	5.64
Node blast	-	-	-	2.08	1.19	2.5
Neck blast	-	-	-	83.33	7.19	7.07
Panicle blast	-	-	-	100	14.44	9.64
Grain spotting or Pecky rice	11.76	1.32	2.68	-	-	-
Leaf scald	17.65	4.92	2.83	-	-	-
Crown rot or foot rot	11.76	3.21	8.11	-	-	-
Head blight	5.88	0.59	2.65	-	-	-
Sheath rot	-	-	-	97.92	25.23	11.29

Source: Shire-Maitsebri ARC survey 2014 and 2017

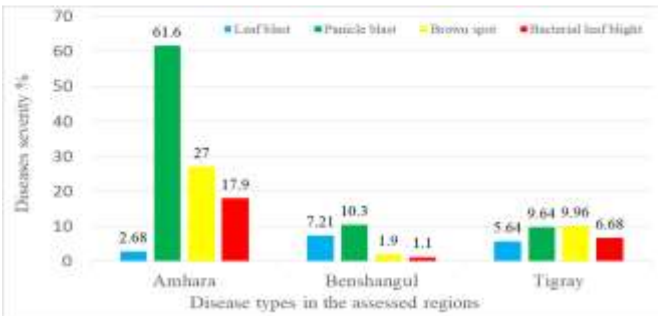

Figure 1. Severity of the common diseases across different regions

In SNNP a survey was conduct on rice blast disease in three districts and six localities during 2013 cropping season (Table 5). According to surveyed result, there was overall average rice blast prevalence of 100%, incidence of 65.68% and severity of 47.15% Mebratu et al. 2015). Moreover, the researchers identified six Pyricularia oryzae isolates from their collected 90 samples during the survey and characterized (Table 6).

Survey was also conducted on rice insect pests' in the Amhara and Tigray regional states, and hence the major rice insect pests of the areas were identified. The survey results are presented in Table 7. Stalked eyed fly, leafhopper, stinkbug, rice leaf folder, and stalk borer were common in both Amhara and Tigray. However, their prevalence was not similar across the regions (Figur 2).

Table 5. Prevalence, *incidence,* and severity of rice blast disease in SNNPR

Survey areas			No. of fields inspected	Infected fields	Prevalence %	Incidence %	Severity %
Zone	District	Localities					
Bench Maji	Guraferda	Otuwa	15	15	100	85.69	55.70
		Berji	15	15	100	75.50	55.40
		Kuja	15	15	100	96.80	48.44
Sheka	Yeki	alamo	15	15	100	54.61	42.07
Kafa	Gimbo	Choba	15	15	100	66.50	47.70
		Argoba	15	15	100	42.01	33.62
Total			90	90			
Mean			15	15	100	65.68	47.15

Source: Mebratu et al. (2015)

Table 6. Characteristics of *Pyricularia oryzae* isolates identified in SNNPR

Isolate	MCD (mm) 10 DAI at different media	MCD (mm) at different temperature	MCL (µm)	MCW (µm)	Septation of conidia	DMW (mg) at different PH
Po 12	67.50	25.424	23.50	6.56	1-septate & 2 celled	108.11
Po 28	68.87	24.663	19.96	7.86	2-septate & 3 celle	102.69
Po 41	65.65	28.139	21.66	6.03	1-septate & 2 celled	102.05
Po 55	62.7	26.617	24.73	5.96	2-septate & 3 celled	101.20
Po 72	66.55	25.284	18.93	7.59	2-septate & 3 celled	102.20
Po 85	67.62	25.281	18.60	6.04	2-septate & 3 celled	112.90

N.B: *MCD = mycelia colony diameter, DAI = days after inoculation, MCL = mycelia colony length, MCW = mycelia colony width, DMW = dry mycelia weight*
Source: Mebratu et al. (2015)

Table 7. Type and prevalence of rice insect pests in Amhara and Tigray regions

Insect		Insect prevalence by region	
Common name	Scientific name	Amhara (Dera, Fogera, Libokemkem woredas)	Tigray (Tselemt woreda)
Rice bug	*Leptocorisa oratorius*	39.6	0
Stalked eyed fly	*Diopsis thoracica*	68.75	70.6
Plant hopper/leaf hopper	*Nephotettix* spp.	72.9	35.3
Stink bug	*Asparvia armigera*	16.6	52.9
Rice trips	*Stenochaetothrips biformis*	8.3	0
Stalk borer	*Chilo polychrysus*	4.2	41.2
Cricket	*Gryllotalpa orientalis* Burweister	10.4	0
Whorl maggot	*Hydrellia philippina* Ferino	54.2	0
Leaf worm	*Leucania convecta*	45.75	0
Rice leaf folder	*Stenochaetothrips biformis*	35.4	65.7
Rice aphid	*Aphis craccivora*	10.4	0
Africa Rice Gall Midge	*Oreolia oryzivora*	0	47.1
Termite	*Macrotermes subhyalinus* Rambur	0	23.5

Source: FNRRTC and Shire-Maitsebri ARC survey

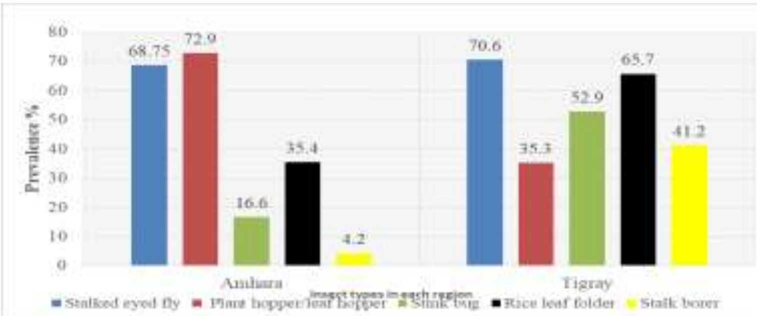

Figure 2. prevalence of the five common insect pests across the two regions

Screening of rice genotypes against rice diseases

There are several control strategies that may be undertaken for management of rice diseases and insect pest; these may include chemical control, nutrition management, cultural practices, and use of resistant varieties. The use of resistant varieties would offer a better management compared to other control strategies, as it is inexpensive and eco-friendly strategy to the environment (Agrios, 1997; Mabrouk and Belhadj, 2012). However, in areas or conditions whenever there is no resistant variety against the diseases or insect pests, and when it is economically feasible, using of other management options regardless of their limitation is important. There have been efforts to screen rice geneotypes for comically important diseases. The study which was done using 12 upland release varieties revealed that the Nerica varieties were resistant to blast disases while the improved varieties Getachew and Tana were susceptible to blast disease (Table 8). In addition, the study that was done on disease management reported that hot water treatment at 60oC for 10 minutes was effective as compared to the control rice sheath rot disease.

Table 8. Prevalence, incidence, and severity of blast disease on rice cultivars in southwestern Ethiopia

Cultivar	Prevalence (%)	Incidence (%)	Severity (%)
Kokit	100	24.6	3.33
Hidasie	100	91	78.34
Suparica-1	100	83.3	73.4
Nerica-3	100	20.7	2.6
Nerica-4	100	23	2.6
Andassa	100	87.6	60.2
Tana	100	92.2	75.4
Getachew	100	94.6	80.2
fofi3737	100	74	47.03
fofi3730	100	81.6	54.2
Guraferda local	100	96.7	86.3
Nerica 12	100	18.9	2.2
Mean	100	65.68	47.15

Source; Mebratu et al. (2015)

Managing termites on upland rice

Termites are very serious pests in several parts of Ethiopia, particularly in the dry areas of the country. For example, termites are a common problem of rice production in Metema, Pawe, Assosa, and Gambella area particularly in upland rice and affecting the plant at the later stage. Several termite control methods have been practiced in Ethiopia, including mound treatment using chemicals, queen removal, mound flooding and to some extent use of botanicals (Mulatu and Emana, 2015). Among the tested control methods against rice termites soil amendment with cow dung and applying of Clorotaria, Hanclopa, Fibronil, and Dursban chemicals reduce termite attack and increased grain yield.

Rice diseases and insect pests

Currently, Rice production and area coverage is increasing in eight regions of the country (Amhara, Tigray, Oromia, SNNPR, Afar, Benishangul Gumuz, Gambella and Somali). Meanwhile, the threat of disease and insect pests on rice production is also increasing which can cause significant yield reduction on rice production. The prevalence of RYMV is one of the threats for lowland rice in Fogera. Termite was common problem in Metema, Pawe, Assosa, and Gambella area particularly for upland

rice. . Stem borer and staked eyed fly were observed in lowland rice in Fogera and Pawe areas. The increasing pest and disease incidence in the major rice production areas is a signal to give emphasis to research and develop controlling options.
In view of the above-mentioned increasing rice diseases and insect pests' threats, efforts have been made to understand the incidence and severity of disease and insect pests and development of controlling options have been conducted. However, the more focus was give on screening rice genotypes against rice sheath rot and brown spot diseases. There were also efforts to screen fungicides against sheath rot and blast diseases and chemicals were verified for control of stalked eyed fly and leaf folder. The yield loss caused by brown spot was also studied.

Contrarily to the opportunities, limited knowledge and skill on the major pests is considered as one of the challenges to generate appropriate controlling options. The risk of introduction of ne pests and disease is increasing with introduction of seeds from abroad and the weak quarantine sytem in place. Moreover, because of the changing climate disease and insect pests' outbreak increasingly challenging rice production and productivity. In addition to the above-mentioned challenges, the unique nature of the rice crop which grow in swampy area and hence not suitable for crop rotation also play its own role. This is because; mono cropping encourages the overwintering and epidemic development of pests. Similarly, inappropriate field and nutrient management practices of farmers are also other challenges that create conducive microclimates for pests.

Future directions

- Due emphasis should be given to rice diseases and insect pests management options;
- The regulatory and quarantine system should be strengthened;
- Research facilities and infrastructures should be fulfilled and developed;
- Survey and identification of the major rice pests should be conducted;
- The observed diseases and insect pests should be positively identified;
- Race identification and pathogenicity test should be conducted;
- Controlling and mmanagement options should be designed to put the pest pressure under the economic threshold level; and
- Researchers, eextension workers and farmers should be trained to identify and control rice pests.

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Research on Pre-harvest Technologies for Rice Production in Ethiopia

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Introduction

Mechanization technologies in rice worldwide have been well developed and extensively used mostly in East Asia and India since the era of the famous green revolution to date (IRRI, 2006). Experience in Japan showed that timely field operations, increased rice acreages, yield, and production are possible through use of levelers, direct seeders, puddlers, and trans-planters. However, these technologies have not been tested and adapted to the local agro-ecological and social-economical situations of the farmers in Ethiopia.

In recognition to this, the National Rice Research and Development Strategy of Ethiopia indicated the need to promote batch production and participatory evaluation of recommended farm tools and implements for wider adaptation through field demonstration and training of farmers, development agents, and local manufacturers. It anticipated the manufacturing of efficient tillage implements (animal drawn moldboard plough, row planters, and weeders) by national and regional agricultural mechanization research centers and subsequent distribution to trained farmers. Once adequate demand is created for these technologies, the wider multiplication and marketing is expected to be made by private workshops (MoARD, 2010).

In this regard, as part of the implementation of the rice research and development strategy, the national research and extension system has been engaged to introduce and popularize pre-harvest technologies of rice. This paper presents the overview of rice pre-harvest practices, the research endeavors, introduced technologies, and the need for future research in address pre-harvest challenges in rice production in the country.

Pre-harvest practices

Land preparation

Farm power sources are categorized into human, animal, mechanical and a combination of them (FAO 2006). Since ancient times animal power has been the predominant power available for tillage and weeding to the Ethiopian farmers. In the northern Ethiopian highlands, smallholder agriculture is largely dominant and tillage takes place with a pair of oxen pulling the ard plough or Maresha (Simoons, 1958; Nyssen et al., 2000; Solomon et al., 2006) (Fig. 1), a tool similar to that of the eastern Mediterranean and large parts of the Arab world (Audebeau and Mosséri, 1916;

Varisco, 1982, 2004). Rice cultivation in Ethiopia is dominantly done by oxen ploughing using the local implement called "*Maresha*".

Figure.1 Oxen ploughing using *Maresha.*

Almost all of the land in rice cultivation is prepared by *Maresha*. Naturally, soil preparation is usually the first task in crop production, undertaken to achieve a variety of basic interrelated objectives such as seedbed preparation, weed control, soil and water conservation, soil compaction amelioration, etc. In traditional tillage, soil or land preparation to achieve a combination of these objectives usually involves tilling with a local *Maresha*, and constitutes the most significant characteristic of repeated ploughing up to 5 times

Curiously, no manually operated machine for land preparation is commonly available. *Maresha* is the most popular and most versatile tool used in Ethiopia where smallholder farmers account for close to 90 percent of the area under cultivation. *Maresha* is the tool used almost exclusively in land preparation of smallholder agriculture, for combined primary and secondary tillage, and for land-forming operations such as ridging, bedding, mounding, bunding, and ditching. The demonstration made on use of two-wheel tractor has shown the potential of wider use given farmers' interest to own.

Land leveling

Without land levelling, unevenness of fields leads to inefficient use of irrigation water and delays tillage, crop establishment and uneven maturing of crops, which in turn reduces the yield, grain quality and farm income. Hence, a precisely levelled field is a pre-requisite for an efficient surface irrigation system, seeding, trans planting, and harvesting operations. There is no attempt to develop or to adopt land-leveling technologies for rice cultivation.

Planting and transplanting

Broadcasting is the current planting practice which has an effect on yield and drudgery. Proper agronomic practices are very essential for crop production**.** According to some farmers in Fogera District, the South Koreans have demonstrated small self-propelled engine driven trans-planters. However, there is no yet an application of such trans-planters for rice in Ethiopia.

Weeding

Weeding is done manually especially with family labor involving mostly women. Human-powered rotary hoes and many designs of human-powered wheeled cultivators with different kinds of weeding shares (tines, hoes, etc.) are available but are suitable only for row crops in friable soils. Some examples of rotary hoes and wheeled cultivators are given in Figure 6. Naturally, use or ownership of these more sophisticated human-powered weeders is very much restricted, thereby severely limiting their impact on the activities of peasant or smallholder farmers of the tropical world.

Chemical application

The purpose of applying agricultural chemicals is to provide nutrients for plant growth and to control weeds, insects and other crop pests, and plant diseases. Chemical application in the rice farming is currently done with a manual backpack knapsack sprayer in Ethiopia. Pesticides are chemicals that can cause both short and long-term health problems with people (Miller and Bellinder, 2011). Many of the Class I (highly or extremely toxic) pesticides are still being used in developing countries (Friedrich, 1996). Since our farmers are not using safety protection devices while they use knapsack sprayers and hence will be exposed for long and short term health problems and it is essential to advice farmers and enforce chemical safety regulations for using knapsack sprayers in a farm.

Research undertakings

This part presents the research activities and achievements in pre-harvest technologies for rice cultivation focusing on technologies for land preparation, planting, and weeding. Research for land leveling and chemical application is not yet started even though rice farmers use traditional and/or imported equipment.

Improved tillage implements and demonstration of single axle tractors

Animal drawn mold board plough was developed by the Ethiopian Institute of Agricultural Research (EIAR). This implement resolves tillage repetition and incomplete ploughing. Its easiness to be compatible with the local wooden beam (*Mofer and Erfe*) makes it also the preferred technology by the farmers. However, this technology was not demonstrated as expected. However, the demonstration of the mold board plow in one of the major rice producing areas (Fogera, Libokemkem & Dera woredas) is underway by the Fogera Rice Research and Training Center. In addition, on farm evaluation and demonstration of single axle tractor at Fogera for land preparation has been made and the preliminary assessments indicate the interest of farmers to adapt these technologies. Figure 2 indicates the two demonstrated technologies for land preparation.

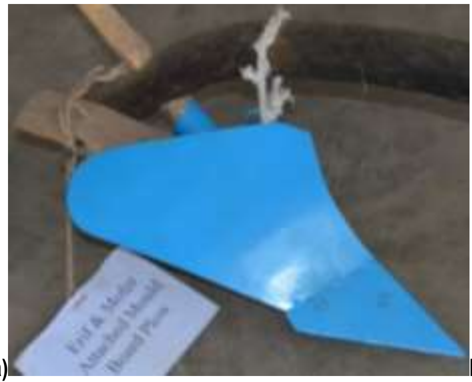
a)  b) 

Figure 2. a) *Erf* and *Mofer* attached oxen drawn moldboard plow b) On farm evaluation of single axle tractor at Fogera for land preparation.

Planting implement

Rice planting is mainly by broadcasting, which does not take time but cost a lot of seed. Farmers claim that lack of appropriate seeders and the time requirement for manual row planting are the reasons for adoption of planting using broadcasting method. The North Koreans made the first attempt in Ethiopian rice cultivation history in introducing self-propelled trans-planters together with rice agronomic practices at the end of 1970s.

A research conducted to compare implications of broadcasting, row planting and Mennonite Economic Development Associates (MEDA) in Fogera made transplanting in rice farming. The study compared yield difference between broadcasting, row planting and transplanting with a variety called X-Jigna (widely used local variety). The result shows 51.67 $q.ha^{-1}$ with broadcasting, 64.36 q/ha with raw planting and 64.93 q/ha with transplanting. The yield increases recorded with transplanting from row planting and broadcasting were 0.57 q/ha and 13.26 q/ha, respectively (Endelkachew, 2014). The results indicate the need to promote transplanting for increased yield.

A number of attempts by different research institutes and universities were made in the past two decades to develop appropriate row planter and trans-planter. For instance, Bahir Dar Mechanization Research Center conducted participatory evaluation of a IRRI seeder for paddy field and also tried to develop 5 row upland rice seeder (Fig.3 a & b). EIAR also modified the IRRI 8 row seeder into 4 row hand pushed seeder (Fig 3d). It was found that the efficiency of the IRRI seeders was four times higher than manual hand row seeding (Yonas L, 2014).

Figure 3. a) & b) Hand pulled 8 row IRRI seeder under testing by the Bahirdar Mechanization & Food Science Research c) 5 row upland rice seeder development by the then Bahirdar Mechanization and Food science Research d) IRRI modified seeder by EIAR. ***Photo sources***: a), b) & c) by Mr. Abu Tefera & d) by Mr.Yonas Lema (Yonas L,2014)

In 2016, EIAR has started a participatory evaluation of animal drawn four row seeder developed by Melkassa Agricultural Research Center and single axle attached seeders (2BFG and VMP models), imported from China and Bangladesh, respectively (Fig.4a). A research is underway to adopt the front pack tef seeder, developed by Melkassa Research Center, for upland rice seeder.

a)  b)  c)

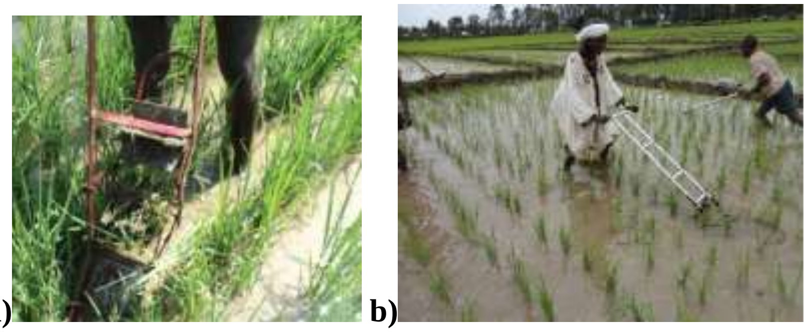
Figure 4. a) On station evaluation of 2BFG seeder b) 4 row oxen drawn upland seeder developed by EIAR c) Rice field seeded by the 2BFG seeder.

Bahir Dar University developed a manual 4 row trans-planter and conducted evaluation in 2017 (Fig 5). It was a promising technology, which requires rigorous testing and modifications for improved efficiency.

Figure.5 Four-row hand pushed manual trans-planter developed by Bahir Dar University.

Weeding implement

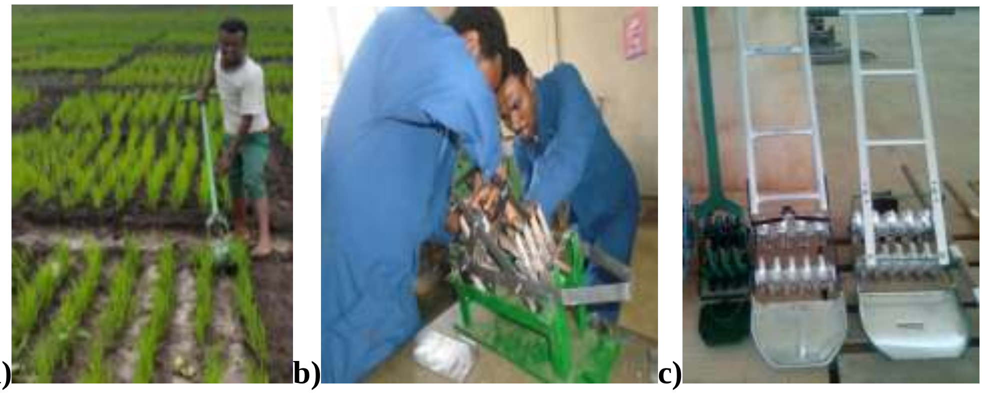
The establishment of Rural Technology Promotion Center in 1985 in Bahir Dar city was an eye opening in the development of rice mechanization technologies. The Center later converted to the Amhara Agricultural Mechanization Research Center under Amhara Regional Agricultural Research Institute (ARARI). The center had a mechanization research and technology multiplication unit a pre-harvest, technology, and farm power research section. Until it was handed over to the Amhara Metal Industry Corporation (METEC), the center was attempting to test and introduce lowland weeders in the rice growing areas (Fig.6 a & b).



a) b)

Figure 6. a & b Hand pushed low land weeder comparative test by the then Amhara Mechanization Research Center under ARARI (***Photo Source*** : Abu Tefera from Amhara METEC)

EIAR's Agricultural Engineering Research Process at Fogera NRRTC is currently undertaking research activities on adopting and modifying the paddy rotary weeder into upland weeder. Researchers were sent to Madagascar to study and fabricate a weeder that is adaptable to the Ethiopian context by EthioRice project. On-station and on-farm evaluations are underway.



a) b) c)

Figure 7. a) Hand pusher rotary weeder under testing at Fogera NRRTC, b) Construction of the rotary weeder by researchers in Madagascar c) Rotary weeder for paddy imported from Japan for demonstration.

Demonstrating and scaling up of pre-harvest technologies

EIAR and development partners had catalyzed the demonstration of various technologies that could maximize production and productivity of rice. The widely demonstrated pre-harvest technology is weeders that are accepted for wider use among the rice producers. For example, MEDA distributed 127 different types of rotary weeders (upland and low land) to farmers through a 70% prices mart subsidy (Endelkachew, 2014). EIAR, since the establishment of Fogera NRRTC in 2013, did not conduct rice mechanization research until 2016 and hence it has carried out limited scaling up and demonstration of pre-harvest technologies.

Conclusion

Different research institutions and universities in introducing and promotion of pre-harvest technologies have made a number of attempts even though the adoption was not adequate. Oxen drawn *Maresha* plough is used for rice cultivation since its introduction in Ethiopia. Farmers are still using *Maresha* plough and preserved in its pristine shapes and size they inherited it from their great ancestors of many centuries ago and using it for rice as it is for other crops. The overriding characteristics of the animal drawn implements are their relatively low energy demand, low labor productivity, low technology, low output and inherently high laboriousness and tedium. This implies the need for the national research to focus on introduction and scaling of appropriate pre-harvest mechanization technologies especially scaling of the use of single axle and small horsepower tractors for land levelling, puddling, seeding, transplanting, water lifting, weeding and chemical application rather than the animal drawn technologies. Large-scale demonstrations need to be conducted by research, development institutions.

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Post-harvest Processes and Advances to Introduce Loss-reducing Technologies for Rice

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Introduction

Grain post-harvest system is a series of processes beginning from harvesting to consuming, which include such operations as harvesting, threshing, cleaning, drying, storing, transporting and processing (He Yong and He Yong-sheng, 1996). Post-harvest losses present one of the main problems not only in rice but also in all grain production. According to estimates provided by the African Post-harvest Loss Information system (APHLIS), physical grain losses prior to processing can range from 10 to 20 %. In many developing countries, overall post-harvest losses of cereals and grain legumes of about 10 to 15 % are fairly common (Rembold *et al.*, 2011). Furthermore, a study by the International Rice Research Institute IRRI (2007) in the Philippines estimated that between 5 and 16 % of rice is lost in the post-harvest process, which includes harvesting, handling, threshing, and cleaning. During the post-harvest period, another 5 to 21 % disappears in drying, storage, milling and processing. Total estimated losses not counting later losses by retailers and consumers run from 10 to 37 % of all rice grown (De Padua, 1978, as cited in Chukwunta, 2014).

Quantitative post-harvest losses of rice in Sub Saharan Africa are estimated between 10 and 22% while qualitative losses could be as high as 50%. A recent assessment in Ghana also indicated that harvest and post-harvest activities account for nearly 20% of total grain loss while constituting 21% of total production cost. In general, post-harvest loss is more than losses of food and financial loss to farmers and translates into tremendous environmental waste as well (Chukwunta 2014). If 20 % of a harvest is lost, also wasted are the same proportion of land used to grow the food, the water used to irrigate it, along with the human labor, seed, fertilizer and other inputs. In Ethiopia, estimates of magnitude of post-harvest loss was found tremendous for different cereal grains that can go as high as 30 to 50 % (Dubale, 2018).

Improved grain post-harvest management encompasses a series of processes beginning from harvesting to consuming for delivering the crop with minimum loss, maximum efficiency and maximum return for all involved. Reducing post-harvest losses throughout the post-harvest chain can significantly increase rice producer's incomes from proper handling, storage and processing. It requires adapting and disseminating the appropriate skill, technology and knowledge particularly with regard to the level of post-harvest losses attributed to a combination of factors during post-production operations. This paper presents an overview of the main post-harvest operations traditionally used by rice farmers in Ethiopia and research achievements to introduce rice post-harvest technologies suited to the Ethiopian small and medium farmers.

Rice Post-harvest Practices

Harvest and post-harvest losses could greatly affect sustainable food security globally. In Ethiopia nearly all paddy production operations are done following the local knowledge, practice and traditional tools and implements used for other grain crops. However, this post-harvest practices lead to considerable losses in all the grain production including rice. Losses in rice can occur during any of the various post-harvest stages. Furthermore traditional practices are quite time consuming and monotonous.

Harvesting

Rice harvesting in all parts of the country is done mainly manually using serrated sickle at a rate of 200 to 240 man-hr/ha for cutting the standing crop and further 20 man-hr/ha for collection and piling (personal communication with farmers and field observation). It is a highly labor intensive and slow process. During peak harvesting season, farmers encounter labor shortages which results in delays in harvesting and subsequent large losses. Table 1 shows yield losses at different maturity time.

To obtain high quality as well as high grain yields, rice must be harvested at the proper stage of maturity. However, lack of mechanization is the major reason for delays in harvesting that causes significant losses. According to Toquero and Duff (1974), harvesting and its additional handling steps like manual harvesting, field drying, bundling and stacking in traditional systems could incur losses of from 2 to 7 percent and take 3 to 5 days for drying. Losses are greater when stack is left longer in the field, particularly where the grain moisture content is high. High moisture accumulations in the crop lying in the field may even lead to start mold growth in the field. APHLIS reported6.9% harvesting/drying losses of African rice found from Madagascar. This is rather high compared to several Asian countries combined, which is 4.0 % (Calverley, 1996).

Table 1. Grain losses at different harvesting times based on crop maturity

	Maturity date					
Harvesting time (*weeks*)	-1	0	+1	+2	+3	+4
Losses (%)	0.8	3.4	5.6	8.6	40.7	60.5

Source: Almera, 1997.

If it is not performed at adequate crop maturity and moisture content, a large amount of shattering losses occurs before or during the harvesting operations. Harvesting too late also incurs excessive breakage during milling due to a phenomenon known as fissuring, which is the development of cracks in the individual kernels. Correspondingly harvesting too early at high moisture content increases the drying cost, making it susceptible to mold growth and insect infestation, and resulting in a high amount of broken grains and low milling yields. The optimal stage to harvest a rice crop is when the grain moisture content is between 20-25% or when 80-85% of the grains are straw.

Threshing and cleaning

Threshing is the separation of the rice grain from the panicles but not removing the husk. After harvesting, if there is a large quantity of rice, threshing is accomplished using oxen in many parts of Ethiopia. The oxen trample on a layer of 15 to 20 cm thick harvested rice stalks spread on well-compacted and plastered hard surface, bare or covered with tarpaulin and the grains are swept and gathered. The grain output is 81 kg to 104 kg/hr (Dagninet *et al.*, 2015). Threshing of smaller quantity rice is done by beating bunches of panicles with sticks. Threshing should occur immediately after harvesting as the longer the harvested panicles remain in a stack, the higher the chance of discoloration or yellowing and shattering too. To reduce yield losses and save time, mechanical threshers are now being promoted by different government and non-government organizations in the country.

The cleaning process is performed after the threshing to separate whole grains from broken grains and other foreign materials, such as straw, stones, sand, chaff, and weed seed. Cleaning is a necessary process as clean paddy stores better and further processing such as milling is more efficient. Farmers use the simple traditional cleaning method by tossing into in the air to remove the light elements from the grain. This method could not separate the stones, soil and weed seeds mixed with paddy, making it inferior in quality. A large amount of grains are lost as spillage during this operation, and grain losses during winnowing can be as high as 4% of the total production (Sarkar *et al.*, 2013). Mechanical winnowers that incorporate a fan and several superimposed reciprocating sieves or screens are not in use in the country.

Drying

Grains are usually harvested at high moisture content (22-28%) to minimize the shattering losses in the field. However, the safe moisture content for long-term storage of most of the crops is considered below 13% (Baloch, 2010). Either the harvested crop is left in the field to dry before threshing or threshed paddy generally is sun-dried on hard surfaces or plastic sheet, the farmer determines the dryness required for storage on the basis of experience. Due to limited/lack of knowledge on the drying process a significant amount of rice breakage occurs during milling. Drying problem particularly in hot sunny days is to prevent excessive heating and hydric stress in the grain. On the other hand, high relative humidity (unfavorable weather)notably in southern part of the country often delays drying process causing degradation of grain, (Dash et al., 1997; Ahmed and Mazed, 1996) and took much handling time. Fissured grain results in significantly lower milling recoveries and any delay in drying makes grain to become darker in color. To maintain quality, grain should be dried and tampered a number of times or in stages during the drying process. This means drying the grain for a number of hours and allowing it to cool before drying it again. This process should be repeated a number of times until the grain reached 14% moisture content or less. When seeds are to be stored for a longer period, they should be dried to 12% or less and preferably stored in a sealed container.

Paddy rice storage

Storage plays a vital role in the food supply chain, and several studies reported that maximum losses happen during this operation (Majumder et al., 2016). All food grains commonlystoried by most Ethiopian farmers and assemblers in small towns at their home, mill houses or in small storage rooms using 100 kg plastic/polythene bags and are commonly used for the short duration storage. Some farmers store in indigenous storage bins made of locally available materials such as straw, grass, wood, bamboo, mud, etc.(Figure 1).

These storage methods expose the stored grains to different deterioration agents or conditions and to which appropriate management and monitoring of all the influencing factors hasn't been considered. Among all the biotic factors, pest infestation due to insects and rodents cause huge losses and is a real threat when paddy or milled rice is stored by these storage methods. As they are incapable to provide protection for long-term storage, grain is periodically fumigated to control insect infestation.

Figure 1 Bag storage method (left) (traditional storage bins (right)

Milling

The purposes of rice milling are to remove the husk and bran layers of paddy to provide cleaned and whole white rice kernels for human consumption. Traditionally, rice milling for domestic consumption in some rural areas is normally carried out within households by repeated pounding or taken to grinding mills where the hull is removed (dehulled) by coarse grinding. Then pounded/course grounded grain is winnowed to remove the husk from the brown rice using a winnowing basket. This results in breakages of rice kernels and incomplete removal of husks. Furthermore, though the traditional pounding method of processing rice is simple, but tedious and has very low outturn. The resulting de-hulled rice (brown rice) is further processed in to flour with local grain grinding mills (Halos-Kim 2014). The final product, flour is then used for the preparation of mainly *enjera* and other local foods and beverages. The by-product, hull, is used as a source of energy. Conversion to white rice under the rural settings was not possible.

Some rice-producing households also directly take their paddy rice to urban commercial rice processors who have small scale rice mills. The common milling machine types in use are the Chinese made single pass Engelberg and the double pass SB10 (Figure 2). Engleberg rice mill is a steel friction type mill and uses very high pressure to remove the hull and polish the grain. Rice processing with Engelberg removes hull and bran in one-step and milled or white rice is produced directly out of paddy. These mills are relatively cheap, easy to operate and maintain but notorious for breaking the paddy grain. Because of the high breakage, the total milled rice recovery is 53-55% and head rice recovery is in the order of 30% of the milled rice. Final white rice is ground into flour for making *enjera*. The by-product, bran often mixed with fine broken kernel particles and ground rice hull, could be sold to processors or might be taken back home for their own livestock, while the hull was left around the processing facilities. This type of rice mill was very popular in most rice-growing parts of the countries.

Figure. 2. Single pass Engelberg rice mill (left), double pass SB10 rice mill with rubber rollers for hulling(middle and right) commonly available in rice producing areas of Ethiopia

The SB10 rice mill on the other hand has separate hulling (husk removing) and polishing (bran removing) processes. Rubber rollers remove the husk and the brown rice is then polished with a steel friction whitener similar to the Engelberg. The milling performance of the compact rice mill is superior to the single pass Engelberg huller with milling recoveries normally above 60%. These mills have high hulling efficiency, reduced grain breakage but the disadvantage of this mills are high wear rate of rubber rollers, requires skilled operator, high maintenance cost, taking more time, and shorter service life than Engelberg rice mill.

Research achievements

Even though rice production trend is increasing in Ethiopia, post-harvest problems in terms of availability of and access to appropriate rice harvesting, threshing, and milling equipment and the lack of drying and modern storage facilities are the major constraints in Ethiopia. In the last two decades, different governmental and non-governmental organizations and private sector in Ethiopia including but not limited to Ethiopian Institute of Agricultural Research (EIAR), Amhara Regional Agricultural Institute (ARARI), Japan International Cooperation Agency (JICA), Sasakawa Africa Association (SAA)/Sasakawa Global 2000 (SG2000), Mennonite Economic Development Associates (MEDA) and Bahir Dar University have been involved and played different roles in assessing post-harvest losses and introducing technologies for loss reduction. As a result, several types of small scale post-harvest equipment like rice harvesters, grain threshers, storage facilities and rice milling equipment/technologies were acquired both from abroad and different sources in the country. In recent years, these technologies were evaluated in the field and recommended for use with continued promotion.

Evaluation of motorized rice/wheat harvesters

Rice is a labor-intensive crop especially for weeding and harvesting requires too much labor. Mechanical harvesting of rice by combine harvester in Ethiopia was first introduced in large-scale farm at Tana Beles project, Pawe before two decades back. However in small scale major rice growing areas like Fogera or somewhere else in the country, there is no experience of harvesting rice by combine harvester on rental bases as has been used for wheat in Arsi and Bale area. This could be due to fear of rice residue losses due to incorporation of livestock in their farming systems, availability of home labor, field condition (small size, wet soil moisture condition during harvesting time) or lack of attention from the service providers side.

Currently,labor is becoming scarce and costly due to migration to urban areas. The big harvesting machines like combine harvester is not accessible to these farmers due to small and fragmented lands, production area may not be attractive for hiring service providers. Considering the advantage of small and mid-level harvesting machines, a walking behind vertical reaper and brush cutter harvesters (Figure 3) were entered in the Ethiopian market by private enterprises and NGOs. Thus, Melkassa Agricultural Research Center acquired these technologies and evaluated on wheat (Kakaba and

Digelu varieties) at Kulumsa and Ginir Woredas and on rice (x-Jigna variety) at Fogera area.

Figure 3 Tested motorized rice harvester: reaper (left) and bush cutter (right)

The result indicated that walking behind harvester (reaper) has shown excellent performances for harvesting both crops with a labor time requirement of 7.6 hr/ha and 6.3 hr/ha for wheat and rice respectively. Harvesting loss of wheat with the same machine were 3.5% and 6.9 % for crop moisture contents of 14% at Ginir and 6.1% at Kulumsa respectively. Similarly there was 7.1% rice loss harvested at 17% moisture content with reaper at Fogera. On the other hand, the bush cutter on average performed at a rate of 29hr/ha with crop loss of 3.3 and 6.9% at Ginir and Kulumsa. Rice harvesting with bush cutter resulted a field capacity of 23hr/ha with 7.1% crop loss at Fogera. However, the bush cutter occasionally encountered clogging of the rotating discs in the presence of weeds and immature or not dried plants. Besides, the operator feels fatigue while operating the bush cutter i.e. holding the implement closer to the ground and swiping it to the right and left to cut the standing crop caused higher drudgery (Yonas, 2018). Therefore, the reaper harvester is a good choice in terms technical performance, and could help to address the problem of delayed harvesting due to home labor shortage or can make harvesting faster and easier thereby reduce losses.

Mechanical threshers

Performance evaluation of engine driven threshers

In recent years, three types of engine driven threshers, two imported and one locally made, were tested using Edget and NERICA-4 rice varieties at Fogera Rice Research and Training Center. The locally made thresher was a malti-crop thresher manufactured by Selam Technical and Vocational Training Center (SELAM) (named as SELAM thresher) while the other two rice threshers were imported by JICA from Indonesia (named as Indonesians thresher) and from China (named as Chinese thresher). The results of the main thresher performance parameters were presented in Table 2. Threshing capacity in both varieties were highest for Indonesians followed by

Chinese thresher. Conversely, the test performance parameters indicate highest in terms cleaning and threshing efficiency with lowest threshing loss for Chinese thresher followed by Indonesian for both verities.

Table 2. Main operating performances three rice threshers

Parameter	Variety EDIGET			Variety NERICA -4		
	Indonesia	China	Selam	Indonesia	China	Selam
Moisture content of crop	9.5	9.5	9.5	13.87	13.87	13.87
Threshing capacity (kg/hr.	606.06	500	416.67	632.9	606.06	588.23
Threshing efficiency (%)	98.2	99.5	97.3	98.5	99.75	96.5
Cleaning efficiency (%)	85.34	99.21	70	86.48	97.33	74.32
Total loss (%)	1.05	0.71	3.15	0.845	0.465	3.985

Adaptation of pedal operated rice thresher

In order to alleviate problems of small-scale resource on rice threshing, a hold-on pedal operated rice thresherwas adapted at the Bahir Dar Agricultural Mechanization and Food Science Research Center (Figure 4).

This pedal thresher consists of an open rotating drum with wire loops. The drum strips the grains from the panicles when fed by hand. It is simple to operate with leg muscle does not consume fuel and easily detach paddy rice. It can also be operated by women and can be used in hilly or terraced areas because of its portability. This rice thresher is operated by 2 persons, weight 35 Kg-40 Kg, and had 110-120 Kg/hr. threshing capacity (Table 3) with a very good shelling efficiency and no broken seeds.

Figure 4. Tested thresher types: SELAM (top left), Chinese thresher (top right), Indonesians thresher (bottom left) and pedal thresher (bottom right)

Table 3. Average threshing capacity (kg/hr.)

Thresher	Mean capacity (kg/hr.)	SE
Traditional	92.04	4.19
Modified pedal	119.6	2.12
Pedal	127.5	5.65

Source:Dagninet et al., 2016

Participatory evaluation of hermetic storage technologies

Provision of good storage enhances the shelf life of the produce as well as reduces losses. This situation was observed with the use of two hermetic storage technologies, namely household metal silo and Purdue Improved Cowpea Storage (PICS) bag (Fig. 4). On an on-farm participatory trial carried out at 9 districts selected from the four major regions of Ethiopia (Gedeb Asassa, Fedis, Adami-Tulu, Debre-Elias, Debub Achefer, Loka-Abaya, Sorro, Offla and Alamata), both metal silo and PICS bag storage technologies reduced stored grain losses to a minimum for a storage period of six months (Bisrat et al., 2018). The technology is now extensively promoted to a number of farmers throughout the country by Monistry of Agriculture (MOA), EIAR, FAO, SG 2000 and private suppliers.

Metal silo storage facility is a 300 to 1000 kg capacity cylindrical structure, made from galvanized iron sheet of 0.5mm thickness (Figure 5). It is aluminum painted for additional protection of the sheet against corrosion and to improve silo's appearance. It lasts more than 15 years with minimum maintenance. The technology is a valuable structure highly recommended by FAO for small and medium scale farmers in developing countries. It was introduced as a part of the Swiss Cooperation for Development in Central America, and its effectiveness for safe storage of all grain crops has been proven in several countries since the 1980s.

PICS bags were identified as a potentially impactful intervention in terms of reducing post-harvest loss from pests and moisture. They have 50 or 100 kg holding capacity and are suitable for hermetic storage of dry grains. PICS bags are made up of three nested plastic bags; the inner two hermetically seal when closed properly. The outer bag resembles more commonly available storage bags with tightly woven plastic strips. PICS bag storage technology is well accepted as has proved successful wherever it has been tried but rodents are a big challenge to farmers who do not follow instructions on how to use and store. Generally metal silo and PICS bags storage methods offer economic impact by facilitating storage and sale later in the season when grain prices are higher.

Figure 6. Metal silo (left); and PICS bag (Right) heretic storages

Rice Milling (Local and Global Experience)

Milling quality of a given rice variety is defined as the ability of the grain to withstand hulling and polishing forces without breakage. Rice kernel breakage during the milling process is affected by different parameters such as paddy harvesting conditions, paddy drying, physical properties of paddy kernels, environmental conditions, and type and quality of milling system components. Milling yields are highly dependent on the milling method, skills of the operator, and crop conditions before the milling process. Milling of paddy containing foreign materials results in a high amount of cracked and broken kernels and can damage machines. Furthermore, inadequately maintained milling machines result in a high amount of broken kernels and low milling yields. Milling yield as affected by machine type was shown in Table 5. The observation indicated that Engelberg produced less white rice per unit weight of paddy. This results in less recoverable rice and therefore less revenue. SB 30 is superior to SB 10 and the Engelberg in terms of milling yield.

Parboiling is a processing procedure in which the paddy is soaked in warm or cold water followed by steaming and drying before milling. The effect of this procedure was evaluated on three released (Gumara, Kokit, and Tigabe) and one local (X-Jigna) rice varieties using Selam Rice Whitener (SRW), which is locally manufactured by SELAM. According to Zewdu *et al.* (2013), mean milling recovery of parboiled rice increased by 22.10% for Gumara followed by Tigabe 9.84% and Kokit by 0.65. However, the milling recovery of X-Jigna reduced by 7.74% from that of raw milled rice (Table 4). The result also showed reduced whole grain for local x-Jigna variety due to parboiling and while increased for the improved varieties.

Table 4. Effect of Parboiling on milling quality

Heat treatment	Varieties				
	Gumara	Kokit	Tigabe	X-Jigna	Mean
Milling recovery (%)					
Parboiled	88.73	81.83	87.51	77.80	83.97
Raw rice	72.67	81.33	79.67	84.33	79.5
Whole grain (%)					
Parboiled	41.33	31.03	50.7	27.63	37.68
Raw rice	31.67	26.73	20.63	36.63	28.93

Source: Zewdu et al., 2013

The implication of the different milling machines on the percentage of broken grains produced can have adverse implications on the rice farmer's income as whole or head grains rice have a much higher price than the broken rice in the market. Broken rice is not actually a loss because it is to be consumed particularly in Ethiopia where the familiar traditional food, *enjera*, is made from rice flour. However broken rice kernel is worth about one half of head (whole) rice (Hui, 1992) that will be boiled for cooking. High milling yield and low foreign material content provide more income.

Table 5. Milling yield as affected by equipment type

Machine	Milling yield (%)	Bran weight (%)	Husk weight (%)
SB30	67.30	14.53	18.13
SB10	66.00	17.87	16.1
Engelberg	63.33	36.67	0
CV	3.3	8.7	7.2

Conclusions and Recommendations

According to reviewed literatures, delayed harvesting and shattering, the lack of modern drying practices and efficient storage facilities are a serious problems that have to be reckoned in the Ethiopian rice production. As a result, farmers usually incur greater quantitative losses, increased breakage during milling and downgraded milling quality, lower sales price and income. In this regard improved post-harvest management of crops and using tools, implements, and machineries of appropriate type, size and power ratings is important in reducing losses and to improve the efficiency of human time and labor. Significant reductions in post-harvest loss were achieved using reaper harvester, motorized threshers, hermetic storage and modern milling machines. Farmer could store rice grain for longer periods to benefit from seasonal price rises if access to PICS bag and well-built metal silo are guaranteed. Although there are few rice mills in Fogera and Guraferda woredas, the availability of efficient de-hulling and milling equipment are reported to be the major constraints in rice production. However, farmers did not have enough information of and access to rice post-harvest technologies which negatively affected the harvested yield and milling rate thus the income realized from rice production. Therefore, the following actions are recommended to introduce and promote improved post-harvest and processing, as well as other agricultural technologies:

- Conduct socioeconomic studies to evaluate the practicality, acceptability and affordability of technically proven technologies and developing business models to link different stake holders;
- Introduced milling machines that produce higher percentage head grains and make local rice milling more economically competitive;
- Demonstration of available improved rice post-harvest technologies like reaper harvesters, milling equipment and modern practices of drying and storage with periodic training on their proper handling and operation; and
- Encouraging farmers for cluster farming and facilitate credited system to acquire mechanization based post-harvest technologies

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Rice Processing and Consumption Experiences: Implications for Research in Ethiopia

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Introduction

Rice was introduced to Ethiopia in the 1970s. Since then, the production of rice grew fast and reached 151,018 tons per annum of produce (CSA, 2018). However, the consumption and processing of rice-based products are still at infant stage. Its preparation and utilization limited to use as plain, parboiled and as flour or in combination with other crops. Postharvest handling packages for rice such as harvesting, drying, threshing, milling and storage techniques were not very developed. During milling, the broken rice percentage is high. Moreover, the existing rice varieties were not studied for their milling and processing qualities. Rice properties are known to be dependent on the variety of rice, methods of cultivation, processing and cooking conditions. As rice being introduced recently in Ethiopia, the sector lacks the exposure, experience, and expertise in rice handling and processing. Hence, it is relevant to discuss on the experience of rice processing technologies in the world, the physicochemical properties of rice, its impact on food security, human health and the environment. The lessons we learn may help to ease some of the challenges existing in the Ethiopian rice sector. Therefore, this paper is a review on experiences of rice-based food processing in the world for adoption in the Ethiopian situation. Desk review was used to prepare the review document.

Classifications of rice quality

A little over 600 million tons of paddy (rough rice) is marketed and consumed in various forms in the world every year (Ajala and Gana, 2015). The different quality characteristics of the grain play a decisive role in determining the palatability of the products, and the selection of varieties, products and processing conditions for the different end uses.

There are several rice varieties that differ in size, shape, color, aroma, structure, morphology, histology, macro, and micro chemical make-up. Additional differences are introduced by drying, storage, milling, parboiling and other processing of the grain. All these differences affect the handling, processing, marketing, product-making, cooking, and organoleptic properties, and use-value of rice in general. These diverse criteria, appropriately classified and codified in terms of the various use-values of the grain, constitute its quality.

Rice shows a wide range of properties or variations relating to its inherent genetic differences and the large part of the genetic variation sticks to a broad geographical pattern. There are three fairly distinct zones such as South Asia, Southeast Asia, and Northeast and East Asia, in terms of grain size and shape, amylose content, texture and eating quality after cooking, and product-making quality of rice. In south Asia, the preferred rice has rather smallish, longish, and slender grains, and a high amylose content (≥ 26%, db). These types yield a firm, dry and non-sticky texture after cooking. Another clear preference is for well-aged rice. There is also a preference for even more hard and free flowing texture of cooked rice achieved by parboiling in parts of the region. In northeast and east Asia the preference is for short, round, glossy grains; low amylose (≤ 20%, db); soft and sticky texture when cooked; rice fresh after harvest (without ageing); and cakes and cooked and formed products made more often. In Southeast Asia, the preference is intermediate between the above mentioned two extremes (Muthayya et al. 2014).

Milling plays a major role on milled and cooked mostly in whole grain form (Atungulu and Pan, 2014). Cracks or fissures in the grain are great concern in rice milling; therefore, need to be avoided. Husk content, tightness of husk interlocking, presence of ridges on the endosperm, presence of immature, infested and chalky grains, types of cracks/fissures, dimensions of the grain, moisture content and degree to which the rice is desired to be milled also affect the milling qualities (Ruiten, 1985). Poor rice drying techniques and bad storage play a crucial role in the economy of rice milling (Bhattacharya, 2011).

Age of rice after harvest strongly affects its organoleptic and eating quality. Rice cooks to a soft and sticky texture soon after harvest, but progressively yields firmer and free-flowing cooked grains as it ages. The method of cooking, the rice water ratio, the cooking system, the duration of cooking all differ. All of the above mentioned problems affect the degree of softening, the grain elongation, curling, segmentation, breakage of the grain after cooking, water uptake and solids loss during cooking (Bhattacharya, 2011).

In this context, Ethiopian released rice varieties need to be studied for their amylose content, other physico-chemical and functional/processing qualities. Improved threshing, drying techniques and feasible storage equipment shall be promoted in the rice growing areas.

Global experiences of rice processing

Rice processing is a combination of several operations to convert paddy rice into well-milled silky-white rice, which has superior cooking quality attributes (Roberts, 1979). The rice-milling process generates by-products, such as husks, bran, and broken kernels. The majority of consumers including in Ethiopia prefer well-milled rice with little or no bran remaining on the endosperm. It has also been reported that consumer preferences vary from region to region on the degree of stickiness. The Japanese like well milled sticky rice, but Americans prefer semi-milled long grain or even brown rice, whereas people in the Indian sub-continent prefer well milled parboiled rice (Lyon et al, 2010). In Ethiopia, non-sticky are more preferred.

Rice grain can be milled to flour and used in different rice-based products such a confectionary, bread and crackers. They also used in beverages like Sake, beer and alcohols. The by-products like broken rice and bran used in different product making (Figure 1).

These high-tech industries should be introduced to Ethiopia in order to effectively utilize rice grain and trigger farmers to produce more rice grains with high industrial quality.

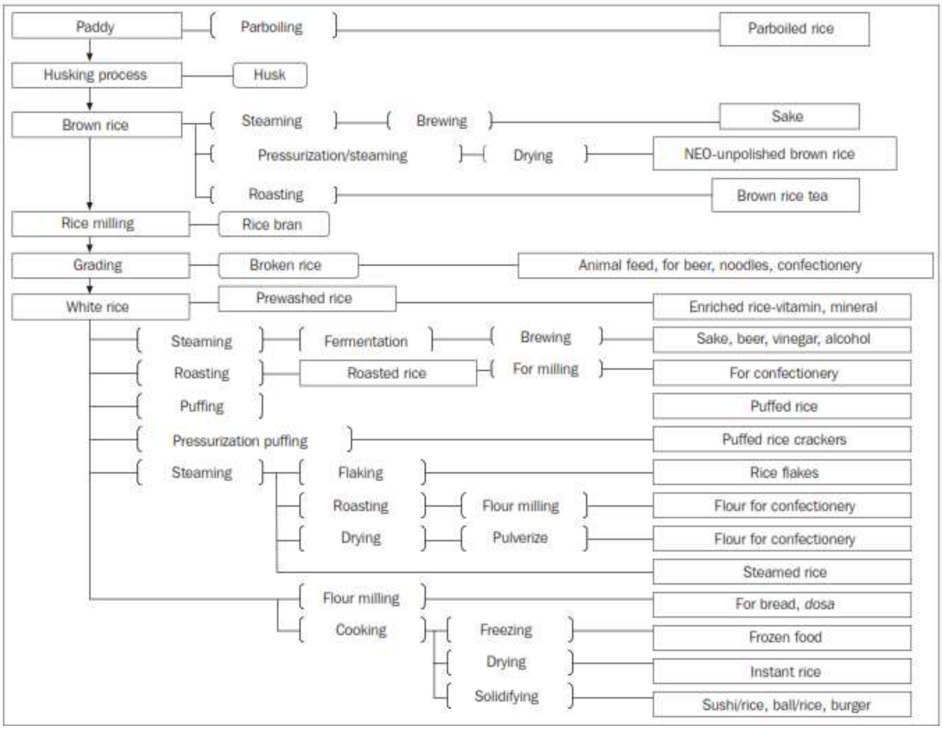

Figure 1. Use of rice and by-products in the rice industry (source: Shimizu et al, 2005)

Parboiling

Parboiled rice is a precooked in paddy form and then dried back before being milled. Parboiled rice has more nutritional advantages than milled white rice. The process causes many changes in the grain constituents, leading to distinct grain properties. Cracks and chalkiness are healed during the kernel's cooking, so that breakage of rice during milling of parboiled rice is dramatically reduced. Vitamins and micronutrients are not easily removed during milling of parboiled rice, making it nutritionally superior. The process of partially boiling rice while still in the husk (rough rice) is referred to as parboiling. This process typically involves three basic steps: soaking, steaming, and drying. Several countries practice rice parboiling, and nearly 50% of rice produced in the world is parboiled.

Parboiled rice has been produced by both traditional and modern methods. Various parboiling devices and techniques have been developed. The local/traditional parboiling devices range from pottery to boiler, use direct or indirect heating and single or double steaming, which consume all different amounts of energy. In the traditional rice parboiling process, rough rice is initially soaked in water at ambient temperature overnight then boiled or steamed at 100 °C. The boiling or steaming process gelatinizes the rice starch and, at the same time, the grain starts to expand, initiating separation of the hull's lemma and palea (Pillaiyar, 1988). The next step involves cooling and sun drying of the rough rice, which is then stored or milled right away. Recent techniques of rice parboiling use hot water at 60 °C to soak rough rice for a few hours. Due to concerns that aflatoxin contamination could be increased by these soaking steps, dry heat, or pressure to induce parboiling have been used to mitigate aflatoxin contamination. To achieve high-quality products from the pressure parboiling process, vacuum infiltration is used to desecrate the grain before pressure soaking. Other techniques, such as heated sand drying, have also been used for parboiling of very high-moisture grain. Therefore, the quality of parboiled rice depends on the paddy rice, intensity of parboiling, drying condition, and moisture content after drying, degree of milling and the milling devices (Roy et al., 2011).

In Ethiopia, parboiling activities are conducted in traditional way. Great care should be taken in the food safety aspect during parboiling. The above-mentioned techniques and technologies can be adopted in order to get safe and high quality parboiled rice for both domestic consumption and international market.

Dehulling and milling

Dehulling and milling are process of removing the outer part of paddy rice (husk and bran) to make it fit for human consumption. The entire paddy grain is not edible. One-fifth of its weight is a husk or hull that is inedible and must be removed by a process called dehulling. The resulting grain is called brown rice (dehulled rice) which has a somewhat fibrous and fatty covering which prevents its easy cooking in boiling water. Due to a friction to the grain surface to remove the husk, a certain percentage of breakage cannot be avoided. The dehulling machine efficiency is measured by the percentage of grain hulled with a minimum of breakage. There are different types of hulling devices such as stone dehullers, rubber rolls, and impeller type huskers. Stone dehullers are still common in tropical Asia, where brown rice is immediately milled with an abrasive, or a friction mill (Shitanda et al. 2001).

Bran also needs to be removed at least partially by a process of attrition or abrasion, this process being called whitening or pearling or simply milling or polishing. The generic name milling also refers to the entire process of producing milled rice or white rice from paddy.

The degree of milling is a quantification of the amount of bran that has been removed from kernels during the milling process. The degree of milling is influenced by the grain hardness, size, shape, depth of surface ridges, bran, thickness, and milling efficiency. Harder rice requires greater energy to obtain the same degree of milling (Roy et al., 2011). Mass loss and breakage are affected by cultivar, kernel shape, and thickness of the aleurone layer. The flow ability of short grains is higher than that of long grains through the milling chamber of friction type milling machine, which results in lower degree of breakage during milling, and leads to the production of greater amounts of head rice. The overall energy consumption during dehulling and milling is reported to be greater in the case of parboiled rice compared to the untreated rice (Roy et al., 2011). The rice properties desired by consumers include whiteness, translucency, low percentage of damaged or broken grains and low foreign matter.

In Ethiopia rice milling is done using stone mill and other outdated dehulling and milling equipment. Thus, the breakage percentage during milling is high. This might be caused due to inappropriate drying methods, in efficient hulling machines and absence of milling optimization for specific cultivars. Therefore, research should be conducted on the cultivar milling qualities and adopt best dehulling and milling equipment as well as drying techniques.

Germinating / sprouting of brown rice

In the Asian diet, sprouted brown rice is considered as an important and nutritious delicacy because of high levels of γ-aminobutyric acid and calcium. However, in the west, sprouted brown rice is not yet well known (Atungulu and Pan, 2014). The steps involved in preparing germinated brown rice (GBR) include, first of all, selecting high-quality brown rice for germination, then soaking the brown rice at 30–40 °C for 20 h or until they just begin to bud in water. The soaking water is changed depending on the smell developed and the final step involves washing the GBR lightly before cooking. The potential health benefits and superior quality of GBR have attracted public attention and it has become a popular healthy food, and different local governments (prefectures) in Japan are promoting the consumption of GBR (Roy et al., 2011). Because of its popularity, modern rice cookers have also been developed to facilitate the production of GBR at households with various shelf l ife (6–15 h). In this process, washed BR is used to put in the rice cooker vessel with adequate amounts of water. Processors of GBR pack the product either dry (at a moisture level of 15%) or wet (at a moisture level of 30%).

The soaking step used during GBR production helps improves rice texture and allows nutrients in the seed to become easier to digest and absorb (Shahidi and Naczk, 1995). The process of producing GBR substantially increases the availability of nutrients, such as vitamin E, vitamin B_6, vitamin B_{12}, lysine, magnesium, fiber, inositol, potassium, zinc, and magnesium; and GBR processing also heightens bioavailable forms of protein and fiber. In addition, it has been reported that γ-aminobutyric acid and calcium levels drastically improve, increasing several fold, when the rice is germinated. Studies indicate that GBR is nutritionally richer than white rice (Atungulu and Pan, 2014).

The germination process affects the phenolic content of rice, which is important since phenolic compounds have antioxidant properties and can protect against degenerative diseases (Shahidi and Naczk, 1995). Upon rice germination, free phenolic acid content increases significantly. The germination process affects total content of insoluble phenolic compounds.

Sprouting brown rice has also been noted to improve absorption of nutrients during rice consumption and, in particular, is very helpful in neutralizing phytic acid, a compound found in brown rice, with limiting effects on the availability of nutrients for absorption during digestion (Dexter, 1998).

Although there is an experience of germinating and sprouting of pulses such as broad beans in Ethiopia, the knowledge on germination of brown rice is limited. As we have discussed above that germination enhances the bioavailability of nutrients, the technology of germination of rice should be adopted in the rice growing areas and by consumers.

Rice fortification and enrichment

The World Health Organization (WHO) and the Food and Agriculture Organization of the United Nations (FAO) defined fortification as the practice of deliberately increasing the content of essential micronutrients, such as vitamins and minerals (including trace elements), in a food irrespective of whether the nutrients were originally in the food before processing or not, with the goal of improving the nutritional quality of the food supply and providing a public health benefit with minimal risk to health (Dexter, 1998). Enrichment, on the other hand, is defined as synonymous with fortification and refers to the addition to food of micronutrients that are lost during processing.

Coating and dusting techniques used to apply for commercial rice enrichment and fortification practices. Although coating and dusting practices are still used, new and alternative methods using hot- and cold-extrusion techniques are gaining popularity (Atungulu and Pan, 2014).

The use of coating or whole-grain enrichment of rice is typically accomplished by applying high concentrations of vitamins and minerals to rice and then adding a water-insoluble food-grade substance on the rice surface as a coating. The coating material does not rinse off when rice is washed (Dexter, 1998).

In the case of dusting, a pre-blended powder mix containing enrichment, such as B vitamins and iron is used. The enrichment could be added to rice as it undergoes different processing stages of milling and packaging. Powder enrichment is most effective when it is added soon after milling white or parboiled rice because the temperature and moisture at the grain surface are optimal for the powder to adhere to the grain. Powder enrichment is relatively inexpensive compared to other methods of enrichment. However, a significant portion of nutrients is lost during cooking steps. In countries where rice is traditionally washed before cooking, it is common to lose up to 20% of the vitamins in the washing step (Dexter, 1998).

Hot extrusion, relatively a sophisticated technique, used to manufacture high-quality fortified rice with high micronutrient retention. The products have a similar polish, consistency, and transparency as natural rice. This method is typically associated with high capital investment, but has relatively lower running costs (Atungulu and Pan, 2014).

Cold extrusion produces rice-shaped simulated kernels in a similar manner as the hot-extrusion process, except the dough of rice flour, fortificant mix, and water are passed through a simple pasta press at normal temperature to produce a premix. The product from cold extrusion resembles natural rice but is slightly laced with an opaque appearance. Compared to hot-extrusion processing, this approach has lower start-up and capital costs but relatively higher running costs.

Food fortification such as iron fortification of wheat flour and iodized salt started recently in Ethiopia. Rice fortification and enrichment can be one solution to enhance the micronutrient level of rice. Bio-fortification and micro-fertilization should also be considered as alternative options to food fortification.

Impact of processing on nutritional profile of rice

Generally, the composition of whole rice grain is comprised of 63.60-73.20 % carbohydrate, 1.50-2.30 % fat, 5.80-7.70 % protein, 7.20-10.40 % fiber and 2.90 -5.20 % ash (Juliano and Bechtel, 1985). Rice grain contains three main parts including endosperm or white rice (~70%), hull/husk (~20%) and bran (~10%) (Fig 2). The white rice is commonly consumed by humans, due to its soft texture and pleasant appearance. This part is comprised of carbohydrate up to 76.7%, which is the main source of energy while protein was found about 7.4% (Cao *et al.*, 2009). Whereas, hull fraction contains high fiber content (34.5-45.9%) and therefore the product has hard texture property not suitable for consumption. However, bran which is part of the outer layer has health benefits such as soluble fiber, minerals, vitamins and polypehnols. Therefore, consumption of brown rice increased in the world.

During milling, the removal of the germ and bran from the brown rice produces milled rice which contains less food nutrients. On the other hand, water soluble nutrients disperse into the endosperm but fat moves out during parboiling treatment, hence parboiled milled rice contains more water soluble nutrients and lesser fat for a certain degree of milling (Roy et al., 2011). However, the protein content of brown or milled rice was unaffected by parboiling process. The solubility of protein decreases after parboiling (Lamberts et al., 2007).

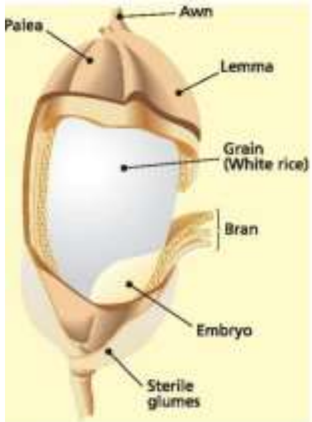

Figure 2. Rice kernel components (source: intechopen.com)

Rice processing and consumption trends

Though rice is introduced to Ethiopia in the 1970s, the promotion of improved varieties and extension services was started in the 1990s. Since then, farmers who were included in the extension services started producing and consuming rice with increasing taste and preference. In recent years, rice production expanded at a higher rate in terms of area coverage, number of sub-districts, and number of farmers.

Considering the significance of rice sector to the country's economy, and food security, the Government of Ethiopia (GoE) has developed strategy that encompasses research and development to ensure food security. Because of its astonishing expansion and the fact that rice answered the food security question of a number of farmers, the Government of Ethiopia names rice as a “millennium crop" (Bekele, 2017).

As per the strategy the country has about 20 million hectares suitable land for the production of rice under rain-fed and irrigation conditions. The area allocated for rice cultivation at national level for the last eight years increased and the output grew from 90, 412 to 151,018 tons (CSA, 2018), however the land covered by rice is still very small compared to the availability of suitable area in the country.

Rice is becoming a staple food in some parts of Ethiopia, where other cereals are not grown in large–scale, and where the imported rice is available (Kim, 2014). The consumption of rice at rice producer level is also showed an increment. As per the utilization survey report, 53 % of rice produced used for own consumption (CSAb, 2018). It is consumed as plain, parboiled rice, as flour or in combination with other crops. Women in the producing areas can prepare rice-based traditional foods such as enjeraenjera and bread with or without mixing with other cereals, decorticated rice, thin porridge, thick porridge, humus like product and local beverage called tella. Even though the above mentioned rice-based food preparations exist, the utilization aspect is very weak mainly due to recent introduction of rice farming in the country. To tackle the utilization problem SAA/SG2000 and other organizations introduced rice recipes and trained targeted farmers.

In Ethiopia, rice consumption per capita has risen tremendously at about 20% per annum due to changing consumer preferences Table 1 (FAO, 2018). But the consumption per capita is quite very low compared to global average that is 61.4 kg in 2015/16 (AgroBig, 2016).

Table 1. Average rice consumption per capita per annum

Year	Average per capita consumption, (kg)
2009	1.17
2010	1.21
2011	1.47
2012	1.84
2013	2.25
2017	4.77

(Source: FAO STAT)

In Ethiopia, the total rice consumption in 2017 amounted to 477,226 tons which is equivalent to per capita consumption of 4.77 kg per person (Table 2). However, Ethiopia depends largely on imported rice to make up the deficit in rice supply. On average, the ten-year annual rice import was 157,000 tons (MoR, 2019) (Figure 3). Therefore, the Ethiopian rice market is described by two distinct types of demands; Local and imported rice market which is mainly linked with income levels of consumers and end use of rice (AgroBIG, 2016). Urban dwellers with high and middle income prefer to consume imported rice brands from neighboring countries and parboiled rice (Basmati) from Pakistan, India, and Thailand. The imported rice product type differ in amount from year to year and consistently increasing (Figure 4). The self-sufficiency ratio of rice in Ethiopia has declined from 68 % in 2010 to 32 % in 2017. The rice import bill is estimated at US $160 million in 2017 and it is becoming a source of concern to the government.

Table 2. Production and import of rice (t)

Year	Production	Import
2010/2011	90,412.00	43,248.00
2011/2012	88,619.00	81,816.00
2012/2013	121,042.00	122,884.00
2013/2014	92,363.00	153,760.00
2014/2015	131,822.00	187,723.00
2015/2016	126,807.00	275,470.00
2016/2017	136,001.00	311,827.00
2017/2018	151,018.00	326,208.00

(Sources: CSA and MOR)

The local rice mostly mixed with tef is consumed by rural dwellers and low-income groups. Urban dwellers with different income groups, tef flour suppliers and hotels use of rice to mix with tef and other crops is increasing. Mixing some amounts of rice flour to tef flour has advantages such as relatively cheaper cost to produce enjera, increment of the number of enjera pieces from 100 kg and looks more attractive and stays longer than enjera made from sole tef flour (AgroBIG, 2016). The reasons for huge rice import are shortage in supply of locally produced and processed rice and massive presence of broken rice in the produce. Ethiopian rice processors lack adequate technology of rice processing to meet international standards. According to the study done by AgroBig (2016), high breakage (32-35 %) of milled rice, poor technologies, and techniques at processing, production and storage levels, use of poor quality seeds, and mixed use of multiple varieties are among the main problems facing the rice sector.

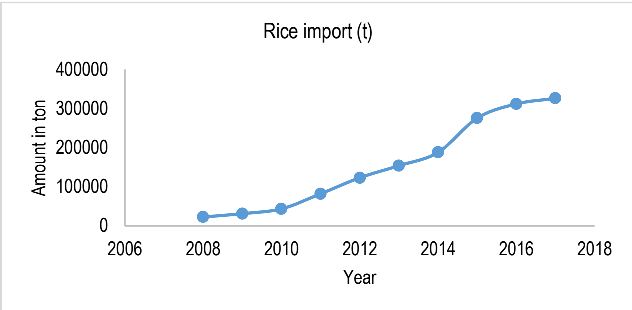

Figure 3: Rice import trend for the last ten years (source: MoR, 2019)

Figure 4: Amount of rice product type imported in the last five years (source: MoR, 2019)

Conclusion

Rice production, rice-based food varieties and consumption levels are high in many rice producing countries. The rice sector in Ethiopia is also growing in terms of production and consumption. However, there is still a gap to fill the fast growing demand for rice in the country. Introducing and validating rice processing technologies, profiling the nutritional and functional properties of released rice cutivars and developing varieties of rice-based food recipes for production of bread, noodle, cake, cookies, muffin, pre-mix, beverage, vinegar, and some other recipes will trigger production of quality rice and open a job opportunity to rice growing community.

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Value-added Food Products of Ethiopian Rice Varieties

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Introduction

In the bakery industry, rice flour has become a useful ingredient due to excellent extrude potential and other unique attributes such as attractive white color, hypoallergenic nature and ease of digestion (Kadan *et al.,* 2003; Ibanoglu *et al.,2005*; Sangita *et al.,* 2005 ; Clelici and El-Dash, 2006). Moreover, rice starch gelatinized easily and forms a clear and soft food similar to potato starch. Due to all these, rice has been used for industrial applications in many Asian countries (Wang, 1983). The fiber type in rice is water-soluble that has positive nutritional and health value by improving gastrointestinal relaxation, stomach eminency and intestinal biota conservation (Truswell, 2002).

Due to better industry and nutritional properties of rice, blending tef and rice found to be scientifically sound (Lindenmeier and Hofmann, 2004). Rice protein has unique hypoallergenic properties compared with other cereal and legume proteins. It is a suitable protein source for infant formulas as well as gluten and corn free products. These properties make rice protein a competitive ingredient in a variety of food and pharmaceutical products. Products from tef and rice would be better to improve the dietary fiber, fat, B-vitamins and minerals and increased gluten free foods. It seems in Ethiopia, rice is consumed with, any forms of household made foods, however, in industry aspect, there are no works related to blending rice, and tef to make rice-tef-based food products including gluten free breads. From literatures, it can be possible to blend rice and tef products can be developed at home and industry level (Lazaridou *et al*., 2007). Also, there is gap in such product development from locally available food items in Ethiopia even though there is a potential for production and supply of rice and tef (USAID, 2012). Therefore, this paper presents the findings of the study on physico-chemical properties and sensory characteristics of rice-tef blended products.

Materials and Methods

Source of raw material

Three varieties (X-Jigna, Edget and Nerica-4) of rice were considered for the study as they are produced by many farmers. For the study, brown tef (Fuffa) variety was used because of its low price and affordability.

Preparation of sample flour

Raw tef and rice grain cleaned, 3 kg of each

↓

Milled to flour

↓

Sieved to size of 0.6um and weighed

↓

Blended with the ratio of Rice: tef (50:50, 70:30 and 90:10)

↓

Rice –teff composite flour packed and used for analysis

Figure 1: The experimental flour preparation flow chart for rice and tef

Experimental design

The mixture design was used to formulate rice-tef blends and limit the upper and lower level of the components. The effect of rice variety and proportions of rice and tef on bread quality was studied using the design. The proportions of rice were ranged from 50 to 90%, whereas tef from 10 to 50%. The proportion ranges were decided based on a preliminary study. Rice bread (100%) was used as a control. The formulations had 9 runs (Table 1) and were done in triplicate.

Table 1: The rice and tef percentage of the formulated sample

Runs	Rice	Tef	Rice variety
1	90	10	V1
2	70	30	V2
3	90	10	V3
4	70	30	V3
5	90	10	V2
6	50	50	V3
7	70	30	V1
8	50	50	V2
9	50	50	V1

Where: X-Jigna= V1, Edget= V2 and Nerica-4=V3

Experimental analysis

The parameters included in this study were proximate composition such as moisture content, crude protein, crude fiber, total ash, total carbohydrates, and total energy. The minerals analyzed in the study were iron, zinc, and calcium in mg/100g value. The sensory qualities analyzed were appearance, flavor, taste and overall acceptability of rice-tef based bread samples. For the analysis moisture, CP, CF, total ash, and crude fat AOAC (1995) standard method was used. The total carbohydrate content was determined by nutrient difference (100 – % moisture + % protein + %fat +%fiber + % ash). The energy density (kcal) was calculated using standard food energy conversion factors: 4 kcal/g of carbohydrates; 4 kcal/g for proteins and 9 kcal/g for crude fat. The minerals, Ca, Zn and Fe were analyzed by using atomic absorption spectrophotometer (Model: 6505, U.K, GENWAY) (AACC, 2000). The anti-nutritional content, phytic acid was determined through phytate phosphorus (Ph-P) analysis according to AOAC (1990) method 720 – 65.

Sensory analysis

An acceptance test using a 7-point Hedonic scale with ‘‘1’’ representing dislike extremely and ‘‘7’’ representing like extremely was used for the sensory evaluation of the gluten free breads prepared from the formulations. Duplicates of bread samples were prepared from nine formulations and each sample was served randomly to each panelist after cooling the baked breads. Bottled water was supplied to panelists for refreshing their palates before tasting subsequent samples and to rinse their mouth between each test to remove all traces of the previous sample. The panelists instructed to observe the appearance, taste and evaluate the samples on evaluation sheets. Twenty mothers were selected and trained to assess the samples in a better way. Sensory attributes assessed were appearance, flavor, taste, and overall acceptability. Finally, the scores of all panelists were added and divided by the number of panelists to find the attribute mean score. The rice-tef bread making is presented in Figure 2.

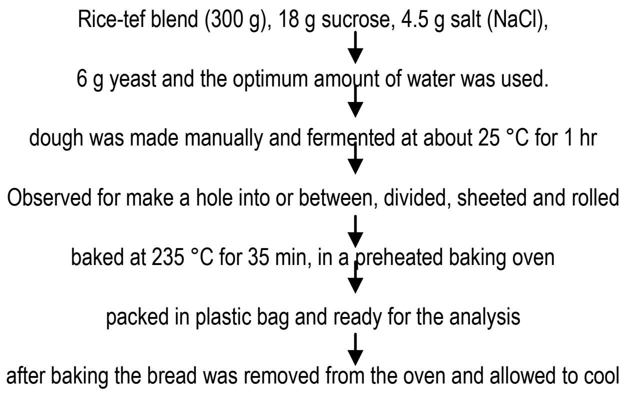

Figure 2: The rice-tef bread making flow chart

Statistical analysis

The data of rice-tef based bread samples were analyzed using the procedures of Statistical Analysis Systems software (version 9.4 SAS Institute Inc., Cary, USA). Probability values ≤ 0.05 were considered significant. The difference between the treatments was determined by analysis of variance (ANOVA). Design- Expert® version, 2010 was used for product formulation. Data from mixture design was analyzed using contour plots to determine the most desirable formulations and to determine the effect of each component.

Results and Discussion

Proximate composition

Crude protein content

The crude protein content of the tef grain (Fuffa variety) was 9.58% which is in the range of 9% to 13% (Bultosa and Taylor, 2004). Crude protein content of Edget, Nerica-4 and X-Jigna rice varieties were 8.42, 9.61 and 8.24%, respectively. The result obtained is in agreement with the findings of Ebuehi and Oyewole (2007) (8.3%). Cereal grain proteins are rich in the essential amino acids cysteine and methionine. Lysine is the primary limiting amino acid in cereal protein, but rice contains more lysine (3.8 g/16 g of N) than other cereal protein (wheat 2.3, corn 2.5 g/16 g of N) (Bultosa and Taylor, 2004).

Crude fat content

The crude fat content of Edget, Nerica-4 and X-Jigna rice varieties were 1.89, 1.61 and 1.78%, respectively. The results of this study are in agreement with the one reported by Juliano (1985b) of 0.9 to 1.97% fat. Milling of rice removes the outer layer (aleurone layer) of the grain where most of the fats are concentrated (Frei and Becker, 2003). The crude fat content of tef grain (Fuffa variety) was 3.07%, which is in the range of 2.0 to 3.09% (Bultosa and Taylor, 2004). Inherently, tef has higher fat than rice and other grains like sorghum and millet (Mongi *et al.*, 2011).

Crude fiber content

The crude fiber content of Edget, Nerica-4, and X-Jigna were 0.11, 0.17 and 0.27%, respectively, which is closer to the mean value (0.21%) obtained by Sotelo *et. al.*, (1990). Milling of rice to white grain rice generally decreases the fiber content of rice. The crude fiber content of tef (Fuffa variety) was 2.04%. The crude fiber observed in the grain tef variety was in the range of 2.0 to 3.5% (Bultosa and Taylor, 2004). The fiber content of tef grain is apparently higher than most other common cereals, because the grain is very small and the bran is proportionally large and milled as whole meal (Bultosa and Taylor, 2004).

Total carbohydrate

Total carbohydrate for tef grain was in close agreement with the reported value of NRC (1996) (72%). Carbohydrates have special significance in cereals, which usually comprise 50 to 80% on a dry weight basis (Shelton and Lee, 2000). Starch is the most abundant cereal polysaccharide and is a major food reserve of bulk nutrient and energy source in the human diet. Rice starch has a neutral taste and hence does not affect the final flavor of the product where it is incorporated in (Bao and Bergman, 2004). Rice starch has the smallest granules of the commercial starches (2 - 9 µm) (BeMiller, 2007) and it is known to form a soft gel, making it a desirable fat mimetic in a wide array of food products. In addition, rice starch does not contain gluten and therefore do not invoke allergic responses in humans (Bao and Bergman, 2004). The carbohydrate content of tef was 71.35± 0.14 and rice varieties were ranged 77.71 ± 0.29 to 78.74 ± 0.27.

Table 2: Proximate composition of three rice varieties and tef grain

Grain	Moisture (%)	Ash (%)	Crude fiber (%)	Crude fat (%)	Crude protein (%)	Carbohydrate (%)
EdgetEdget	10.10 ± 0.09^{bc}	0.73 ± 0.04^{c}	0.11 ± 0.00^{d}	1.89 ± 0.02^{b}	8.42 ± 0.17^{b}	78.74 ± 0.27^{a}
Nerica-4	10.26 ± 0.13^{ab}	0.64 ± 0.04^{d}	0.17 ± 0.03^{c}	1.61 ± 0.03^{d}	9.61 ± 0.14^{a}	77.71 ± 0.29^{b}
X-Jigna	10.09 ± 0.05^{c}	0.94 ± 0.04^{b}	0.27 ± 0.03^{b}	1.78 ± 0.07^{c}	8.24 ± 0.07^{b}	78.69 ± 0.20^{a}
Tef (Fuffa variety)	10.41 ± 0.05^{a}	2.94 ± 0.01^{a}	2.04 ± 0.02^{a}	3.07 ± 0.01^{a}	9.58 ± 0.16^{a}	71.35 ± 0.14^{c}

Values are in Mean ± SD on dry matter basis except moisture (wet basis). Means within a column with the same letter are not significantly different at $p>0.05$.

Mineral contents

As indicated in Table 3, the mg/100 g values in dry weight basis of Zn, Fe and Ca, in this study differs significantly ($p \leq 0.05$). The zinc content of Edget, Nerica-4 and X-Jigna rice varieties were 3.08, 3.62 and 2.71 mg/100g, respectively, which is in a close agreement with Sotelo *et al.* (1990) (1.6 – 3.1 mg/100g). tef contained 3.45 mg/100g zinc. In this study, the zinc content of tef grain was higher than 2.86 mg/100g, reviewed by Abebe *et al*. (2007). The calcium content of Edget, Nerica-4 and X-Jigna were 10.72, 8.34 and 9.91 mg/100g, respectively, which was in the range of 3 to 11 mg/100g (Marr *et al.,* 1995), and the calcium content of tef was 91.90 mg/100g. The calcium content of tef grain was lower than 124.00 mg/100g, reported by Abebe *et al*., (2007). Phytic acid content of Edget, Nerica-4, and X-Jigna were 1.45, 2.70, and 2.43 mg/100g, respectively, which is a little bit higher than reported by Kennedy *et al.* (2002a).

Phytic acid content of flour depends on several factors such as cultivar, weather condition and milling parameters such as bran content and the extraction rate (Clarke *et al.*, 2004). The iron content of tef was 17.18 mg/100g, which was found to be, less than 37.70 mg/100g (Abebe *et al.*, 2007) might be due to the variety and location difference. In general, deficiency of minerals in rice is due to their low concentration and the presence of inhibitors. Earlier studies showed that minerals in rice occur at low levels and that they are influenced by many factors. For example, iron levels in rice differ with growing regions. Whereas high iron levels (0.026 mg/100g) were found in Australian rice, Korean rice had only 0.007 mg/100g (Kim *et al.* 2004).

Table 3: Mineral composition (mg/100 g) of three rice varieties and tef grain

Grain	Fe (mg100g)	Zn ($mg100g^{-1}$)	Ca ($mg100g^{-1}$)	Am/Amp ratio (%)	Phytic acid (mgg^{-1})
Edget	0.00^{b}	3.08 ± 0.00c	10.72 ± 0.81^{b}	28.68 ± 0.27^{a}	1.45 ± 0.17^{d}
Nerica-4	0.00^{b}	3.62 ± 0.03^{a}	8.34 ± 0.44^{c}	27.96 ± 0.12^{b}	2.70 ± 0.07^{b}
X-Jigna	ND	2.71 ± 0.01^{d}	9.91 ± 0.48^{b}	28.70 ± 0.32^{a}	2.43 ± 0.10^{c}
Tef	17.18 ± 0.07^{a}	3.45 ± 0.01^{b}	91.90 ± 0.48^{a}	27.89 ± 0.30^{b}	5.00 ± 0.03^{a}

Values are in Mean ± SD on dry matter basis. Means within a column with the same letter are not significantly different at p>0.05. Where: ND= not detected Ca=calcium, Fe=iron, Zn=zinc and Am/Amp = amylose/amylopectin.

Phytic acid content and mineral bioavailability

Phytic acid content of Edget, Nerica-4 and X-Jigna were 1.45, 2.70 and 2.43 mg/100g, respectively. Phytic acid content of flour depends on cultivar, weather condition and milling parameters such as bran content and the extraction rate (Clarke et al., 2004). Minerals in rice occur at low levels and that they are influenced by many factors such as Phytic acid. (Kim et al., 2004).

Table 4: The effect of rice variety and blending proportion on the proximate composition of the composite flour bread

Runs	Ingredient(%)		V	Moisture (%)	Ash (%)	Crude fiber (%)	Crude fat (%)	Crude protein (%)	Carbohydrate (%)
	Rice	Tef							
1	50	50	E	4.58 ± 0.05^{b}	3.48 ± 0.03^{c}	1.60 ± 0.00^{a}	1.90 ± 0.05^{a}	9.74 ± 0.14^{a}	77.84 ± 0.09^{f}
2	70	30	E	4.42 ± 0.02^{c}	3.10 ± 0.04^{e}	1.40 ± 0.05^{b}	1.12 ± 0.01^{e}	10.30 ± 0.01^{a}	79.66 ± 0.07^{cd}
3	90	10	E	4.72 ± 0.04^{a}	2.71 ± 0.00^{g}	0.63 ± 0.04^{f}	0.85 ± 0.03^{f}	9.71 ± 0.00^{b}	81.37 ± 0.07^{ab}
4	50	50	X	4.78 ± 0.13^{a}	3.74 ± 0.01^{a}	1.35 ± 0.04^{b}	1.81 ± 0.03^{b}	10.38 ± 0.45^{a}	77.95 ± 0.59^{f}
5	70	30	X	4.79 ± 0.05^{a}	3.12 ± 0.02^{e}	1.24 ± 0.04^{c}	1.19 ± 0.01^{e}	10.52 ± 0.15^{a}	79.14 ± 0.16^{e}
6	90	10	X	4.79 ± 0.09^{a}	2.87 ± 0.02^{f}	1.00 ± 0.07^{d}	0.90 ± 0.06^{f}	10.49 ± 0.16^{a}	79.95 ± 0.30^{c}
7	50	50	N	3.77 ± 0.05^{e}	3.55 ± 0.01^{b}	1.56 ± 0.05^{a}	1.65 ± 0.02^{c}	10.26 ± 0.01^{a}	79.20 ± 0.05^{ed}
8	70	30	N	4.14 ± 0.06^{d}	3.22 ± 0.02^{d}	1.53 ± 0.09^{a}	1.29 ± 0.09^{d}	10.75 ± 0.19^{a}	79.07 ± 0.07^{e}
9	90	10	N	3.80 ± 0.03^{e}	2.86 ± 0.01^{f}	0.80 ± 0.01^{e}	0.87 ± 0.06^{f}	10.58 ± 0.59^{a}	81.09 ± 0.49^{b}
Co	100	0	X	4.69 ± 0.07^{ab}	2.70 ± 0.05^{g}	0.46 ± 0.01^{g}	0.63 ± 0.01^{g}	9.74 ± 0.14^{b}	81.78 ± 0.03^{a}

Values are in Mean ± SD on dry matter basis except moisture (wet basis). Means within a column with the same letter are not significantly different at p>0.05. Where: V=rice variety, E=Edget, X=X-jigna and N=Nerica-4.

Amylose/amylopectin ratio

Amylose is the linear portion of the starch with glucose residues linked by α-D-(1-4) bonds and it does not dissolve easily in water and forms rigid gels (McCleary *et al.*, 2006). It is the main component of starch, which undergoes retrogradation, or the recrystallization of gelatinized starch (Hizukuri, 1996). Amylose/amylopectin ratio of Edget, Nerica-4 and X-Jigna rice varieties were 28.68, 27.96 and 28.70%, respectively. This result is in line with the range 20 - 30% reported by Zhong *et al.* (2006). The amylose/amylopectin ratio of tef was 27.89% (Bultosa *et al.*, 2002) indicating normal starch composition. Rice varieties are usually classified in terms of amylose content as waxy (1 - 2% amylose), very low (2 - 9%), low (10 - 20%), intermediate (20 - 25%), and high (25 - 30%) (IRRI, 2007).

Crude protein content

The analysis shows there is a slight numerical difference and the protein content is increased as the proportion of tef increased. The protein content of the rice-teff blend bread had ranged from 9.71 to 10.75% (Table 4). All blended products were found to have higher crude protein contents than the control (9.74%) except Edget rice variety (9.71%) which blended at 50% with 50%tef (Table 4). The combined effect of the rice variety and blending proportion on crude protein was insignificant ($P>0.05$). The linear terms of rice and tef had significant effect on crude protein content ($p<0.0001$).

Ash content of the bread

The ash content of the product had ranged from 2.71 – 3.74% (Table 4). The ash content of the control was 2.7%, which was significantly ($p<0.05$) increased on blending with tef at different proportions. Bultosa (2007) reported that tef grain ash content had ranged from 3.16 to 1.99% with mean of 2.45%. The highest ash content (3.74%) was obtained when 50% X-Jigna rice variety was blended with 50%tef and lowest ash content was obtained when 90% Edget rice variety blended with 10% tef. The combined effects of rice variety and blending proportion on ash content was significant ($p<0.0001$). In general, ash content is related with mineral content and tef contained higher ash content than rice, because of the higher mineral content in tef than rice. In addition, tef grain with bran could contribute for increasing of total ash content as reported by (Bultosa and Tailor, 2004).

Crude fiber content

The crude fiber content of the blended products had ranged from 0.63 to 1.60% (Table 4) which is higher than 100% wheat flour bread (0.29%) (Mongi *et al.*, 2011). The crude fiber content of the control was 0.46%. Blending rice with tef significantly ($P<0.05$) increased the crude fiber content of the product (Table 4). This is due to the high fiber content of tef grain (Table 6). The highest value of crude fiber was obtained when 50% Edget rice variety and 50% tef were blended. The lowest value was obtained when 90% Edget rice variety and 10% tef were blended. The combined effect of rice variety and blending proportion on crude fiber were significant ($P<0.0001$).

Crude fat content

The crude fat content of the products had ranged from 0.85 to 1.90%. The crude fat content of the control (0.63%) was significantly ($P<0.05$) increased on blending with tef (Table 4); because the crude fat content of tef is higher than rice (Table 6). High crude fat content was obtained when 50% Edget rice variety and 50%tef were blended and low value was obtained when 90% Edget rice variety and 10% tef were blended. The combined effect of the rice variety and blending proportion on crude fat content was significant ($P<0.0001$). Rice varieties Edget, Nerica-4 and X-Jigna had no significant effect on crude fat content ($P<0.05$).

Carbohydrate

The carbohydrate content of rice-tef blend bread had ranged from 77.84 to 81.37% (Table 4) and, a significant ($P<0.05$) decrease in carbohydrate content was observed with an increase tef proportion (Table 6). This may be due to the fact that rice flour is higher in carbohydrate as compared to tef flour (Edaogu *et al.* 2007). The carbohydrate content of the control (X-Jigna rice variety) was 81.78% which was significantly ($p<0.05$) decreased when blended with tef (Table 6). The lowest carbohydrate content (77.84%) was obtained when 50% Edget blended with 50% tef.

Odetokun (2000) had reported that increase in carbohydrate content during fermentation might be due to a reduction in the fiber content and increase in both reducing sugars and total soluble sugars. This may also be attributed to the fact that during fermentation carbohydrate including cellulose, pectin, lignocellulose and starch are broken down by fermenting microorganisms thereby reducing the fiber content of such food (Raimbault and Tewe, 2001). The combined effect of the rice variety and blending proportion on carbohydrate content was significant ($p<0.0001$). The linear terms of rice and tef were significant ($p<0.0001$) and Nerica-4 and X-Jigna rice variety were significant ($p<0.05$).

Table 5. The effect of rice variety and blending proportion on the Fe, Zn, Ca, and phytic acid in (mg/100g) and loaf volume of bread in (cm^3g^{-1})

Run	Rice (%)	Tef (%)	V	Fe	Zn	Ca	Phytic acid	Specific loaf volume
1	50	50	E	11.22±0.56[c]	3.90±0.10[b]	61.25±0.26[a]	0.52±0.02[c]	3.64±0.01[b]
2	70	30	E	7.96±0.05[d]	2.70±0.02[g]	46.72±0.91[c]	0.41±0.01[e]	3.52±0.01[c]
3	90	10	E	2.73±0.11[h]	3.69±0.01[c]	26.01±0.30[f]	0.36±0.01[f]	2.83±0.01[g]
4	50	50	X	11.75±0.17[b]	4.14±0.09[a]	59.10±0.29[b]	0.62±0.01[a]	2.74±0.01[h]
5	70	30	X	8.04±0.22[d]	2.69±0.08[g]	47.19±0.64[c]	0.56±0.01[b]	3.09±0.01[f]
6	90	10	X	5.70±0.18[e]	2.95±0.06[f]	28.02±0.11[e]	0.35±0.01[f]	2.84±0.01[g]
7	50	50	N	12.97±0.15[a]	3.56±0.02[d]	59.99±0.83[b]	0.53±0.01[c]	3.39±0.01[d]
8	70	30	N	4.77±0.00[f]	2.98±0.03[f]	44.44±0.57[d]	0.44±0.01[d]	2.67±0.01[i]
9	90	10	N	3.12±0.09[g]	3.73±0.03[c]	25.31±0.64[f]	0.31±0.01[g]	3.27±0.02[e]
Control	100	0	X	0.00±0.00[i]	3.46±0.00[e]	17.97±0.00[g]	0.21±0.01[h]	3.88±0.01[a]

Values are in Mean ± SD on dry matter basis. Means within a column with the same letter are not significantly different at p>0.05. Where: V=rice variety, E=Edget, X=X-Jigna, N=Nerica-4, Ca=calcium, Fe=iron and Zn=zinc.

Zinc content

The zinc content of the blended products had ranged from 2.70 to 4.14 mg/100g (Table 5). In addition, the analysis illustrated that there is a significant ($P<0.05$) difference in zinc content of the product. The zinc content of the control was 3.46mg/100g. The highest value (4.14mg/100g) was obtained when 50% X-Jigna and 50%tef were blended and the lowest value was obtained when 70% Edget rice variety and 30%tef were blended. The combined effect of the rice variety and blending proportion was significant ($p<0.0001$). The trend observed in the study is as tef blending ratio increased, the zinc content positively increased and this might be the interaction effect and better mineral content like zinc in tef than rice.

Calcium content

Calcium content of the blended products had ranged from 25.31 to 61.25 mg/100g (Table 5). The analysis indicated that treatment means with different letters were significantly ($P<0.05$) different and this shows that the calcium content of the product is significantly different. All the blends had higher calcium content than the control (17.97mg/100g). Highest value (61.25 mg/100g) was obtained when 50% Edget rice variety and 50% tef were blended and the lowest value was obtained when 90% Nerica-4 and 10% tef were blended. High Ca content may be contributed by high calcium content of tef (Umeta *et al.*, 2005). The combined effect of the rice variety and blending proportion on calcium content was significant ($p<0.0001$). Nerica-4 rice variety had significant effect ($p<0.05$) whereas Edget and X-Jigna were insignificant ($p>0.05$) on calcium content of the product.

Iron content

The iron contents of rice-tef blended bread product were shown in Table 5. The value had ranged from 2.73 to 12.97 mg/100g. The iron content of the product was significantly ($P<0.05$) increased on blending with tef (Table 5). The increment in iron content in the blends was due to the high iron content o tef compared to rice. Maximum value of iron was obtained when 50% Nerica-4 and 50% tef were blended and minimum value was obtained at 90% Edget and 10% tef.

The combined effect of the rice variety and blending proportion were significant ($p<0.0001$). The linear terms of rice ($p<0.05$) and tef ($p<0.0001$) had significant effect on iron content. The interaction effect between rice and tef had a significant effect ($p<0.05$) on iron content of the product. In addition, Edget and Nerica-4 rice varieties had no significant effect ($p>0.05$) on iron content of the product.

Phytic acid content of rice-tef blend bread

The combined effect of rice variety and blending proportion on phytic acid were significant ($p<0.0001$). The linear terms of tef and X-Jigna rice variety had significant effect on phytic acid ($p<0.0001$). The linear term of tef, Edget and Nerica-4 rice varieties had significant effect on phytic acid ($p<0.05$). Fermentation significantly decreased the phytic acid content of the blended product (Table 5).

Specific loaf volume of rice-tef blend bread

The loaf volume of wheat bread in the specific volume of the rice-tef blend bread had ranged from 2.67 - 3.64 cm^3g^{-1} (Table 5). This values varied significantly ($P<0.05$) with both rice varieties and blending proportions and decrease in specific volume was observed with an increment of tef blending proportion. The specific loaf volume of the control (100% X-Jigna rice variety) was 3.88 cm^3g^{-1}, which was higher than all blended products and decreased when blended with tef at different ratios (Table 5). The lower loaf volume (2.67 cm^3/g) was obtained when 70% Nerica-4 rice variety was blended with 30% tef. However, the loaf volumes of the breads in the study were smaller than that of breads made of wheat and other gluten rich foods. This is because loaf volume is associated with the level of gluten and as gluten content increases in the ingredient directly loaf volume increase and visa-vise (ISO 5530–4: 2002).

Sensory analysis values

The average score given for appearance, texture, aroma, and overall acceptability were presented in Table 6. The analysis showed that there was a significant ($P<0.05$) difference between means of the product appearance among treatments ranged from 4.84 to 7.00. Higher score for appearance (7.00) was obtained when 70% X-Jigna rice variety blended with 30% tef and lower score was obtained when 90% Nerica-4 rice variety was blended with 10% tef. The combined effect of rice variety and blending proportion on appearance was significant (p<0.0001). The mean score given for texture on seven hedonic scales was ranged from 4.36 to 6.86 (Table 6). The analysis revealed that there was a significant (P<0.05) difference between means of the texture. Least (4.36) score for texture was given for the 50% Nerica-4 rice variety and 50% tef blend bread when compared to others. High score (6.86) was obtained when 70% X-Jigna rice variety and 30% tef was blended. The combined effect of rice variety and blending proportion on texture was significant (p<0.0001).

The highest aroma score (6.74) was obtained when 70% X-Jigna rice variety and 30% tef were blended. Equal aroma score (6.00) was obtained when 70% Nerica-4 and 30% tef, 90% X-Jigna and 10% tef, 70% Edget and 30% tef and 50% Edget and 50% tef were blended. Moreover, these are better aroma score as compared to the control (5.20). The least aroma score (5.00) was obtained when 90% Nerica-4 rice variety was blended with 10% tef. This is because fermentation improves sensory characteristics such as aroma of breads (Rehman *et al.,* 2007). The overall acceptability of the blended product was significantly (P<0.05) increased as tef proportion increased to 30% (Table 6). Because, tef starch granules are very small, smooth, and uniform size, they offer good functionality as a fat substitute, flavor and aroma carrier, similar to other small-granule starches. In addition, because of its slow retrogradation tendency, it could have attractive applications where starch staling is preferred to be reduced (Bultosa and Taylor, 2004).

The higher score (7.00) for the overall acceptability was recorded when 70% X-Jigna was blended with 30% tef and the least (5.00) was recorded when 90% Nerica-4 rice variety was blended with 10% tef. Fermentation is known to contribute better flavor, texture and nutrition (Liu *et al*., 2005).

Table 6. The effect of rice variety and blending proportion on sensory acceptability of the product

Run	Rice (%)	Tef (%)	V	Appearance	Texture	Aroma	Overall acceptability
1	50	50	E	5.76±0.59^{de}	5.18±0.39^{d}	6.00±0.00^{c}	5.30±0.46^{c}
2	70	30	E	5.86±0.53^{cd}	5.90±0.46^{c}	6.00±0.00^{c}	6.00±0.00^{b}
3	90	10	E	5.96±0.60^{cd}	6.08±0.53^{bc}	5.74±0.82^{d}	6.00±0.00^{b}
4	50	50	X	5.54±0.50^{e}	5.96±0.35^{c}	6.26±0.44^{b}	5.30±0.46^{c}
5	70	30	X	7.0±0.00^{a}	6.86±0.35^{a}	6.74±0.44^{a}	7.00±0.00^{a}
6	90	10	X	6.06±0.24^{c}	6.22±0.51^{b}	6.00±0.00^{c}	6.00±0.00^{b}
7	50	50	N	4.96±0.78^{f}	4.36±0.48^{f}	5.74±0.44^{d}	5.00±0.46^{d}
8	70	30	N	4.98±0.47^{f}	4.80±0.49^{e}	6.00±0.00^{c}	5.36±0.48^{c}
9	90	10	N	4.84±0.88^{f}	4.98±0.32^{e}	5.00±0.00^{f}	5.00±0.00^{d}
Control	100	0	X	6.36±0.59^{b}	4.96±0.73^{e}	5.20±0.49^{e}	4.46±0.50^{e}

Values are in Mean ± SD. Means within a column with the same letter are not significantly different at p>0.05. Where: V=rice variety, E=Edget, X=X-Jigna and N=Nerica-4.

Conclusion

Rice varieties and blending proportion lead to significant difference in the physico-chemical properties and sensory characteristics of rice-tef blend bread. The protein content of the bread product was not influenced by the rice variety and blending proportion of rice and tef. Carbohydrate content decreased with increasing the proportion of tef blend for all varieties. Ash, crude fiber, and fat content increased with the increased proportion of tef blend. Addition of tef to rice increased the iron, zinc and calcium, and phytic acid contents of the product. The loaf volume of the bread product was decreased as the blending proportion of tef increased. From the study, Edget variety was found to be suitable for nutrient dense bread development and for the sensory quality aspect X-Jigna found to be better.

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The Potentials of Rice-Livestock Integration in Ethiopia

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Introduction

An integrated farming system consists of a range of resource-saving practices that aim to achieve improved and sustainable productivity, while minimizing the negative effects of intensive farming and preserving the environment (Gupta *et al.*, 2012). Mixed crop-livestock farming combines crop and livestock enterprises in a supplementary and/or complementary manner, by which farmers produce crops and rear livestock together to ensure sustainable agriculture (Iiyama *et al*., 2007. In crop-livestock mixed systems, the by-products (crop residues) of one enterprise can be used as an input in the livestock production component, from which the animal power and manure produced are in turn used as an input for crop production (Thomas *et al*., 2002). Within this framework, an integrated crop-livestock farming system represents a key solution for enhancing both crop and livestock productions and attempt to safeguard the environment through prudent and efficient resource use (Walia and Navdeep, 2013).

Crop production and animal husbandry are the two sub-systems in the broad mixed crop–livestock system in the high and mid altitude areas of Ethiopia (Wuletaw and Kindu, 2018). Under the present conditions and for years to come, crop and livestock farming integration will remain to be the main form of farming system in the Ethiopian highlands. Currently food insecurity, malnutrition, and stunted growth are the key challenges in Ethiopia. In such situations, the role of livestock (dairy, poultry and fishery) is very important to ensure food and nutrition security by providing nutrient concentrated foods that comprise essential amino-acids. However, animal feed is a scarce resource in the mixed farming systems of the Ethiopian highlands critically challenging how to sustain livestock keeping in the system. Rice production in Ethiopia is rapidly growing in areas like, Fogera, Gambella, Somali, Pawe, Assosa, Afar, and many other places where the agro-ecological conditions are suitable. This practice helps to integrate rice production with ruminant livestock farming to make use of rice straw as animal feed and hence improve household income and food security. The main objectives of this paper are to provide highlights on major complementarities of rice- livestock productions, to review /rice-livestock mixed farming in Ethiopia and learn lessons from other countries to suggest priority areas of interventions in the integrated mixed rice-livestock productions in Ethiopia.

Crop-livestock systems

Integrated crop-livestock systems are characterized as systems designed to exploit synergies and emergent properties because of the interactions in the soil-plant-animal-atmosphere compartments (Moraes *et al.,* 2013). The integrated farming system is a farming system that combines two or more fields of agriculture, which is based on the recycling biological concept, and linked use of input-output between the commodities, with the approaches of low-external-input utilization. This is done through the utilization of once products and by products like animal manure, as an input to the others for the purpose of increasing the production and productivity and eventually increase farmer's income and can create condition that are environmental friendly farming (Mukhlis *et al*., 2018). This scenario should consider several aspects, namely: - sustainability, environmental friendly, social acceptability, economic viability and political acceptability (Mukhlis *et al*., 2018). The global natural resource has the two main agricultural activities in the fields of crops and animals. All these natural resources are meant to support crops and livestock where they are operating in integration to create synergy in the process.

Rice-livestock integrated farming systems

Rice production in Ethiopia covers 48,418 ha of land by about 150,041 households producing 1,360,007 quintals of grain yield in 4 rice producing regions (CSA, 2017). As a cereal crop, its practice in the crop livestock systems is very similar to other common cereals like wheat, barley, and tef. However, the integration of rice and livestock farming is very strong. Rice farming especially the paddy rice, the one widely adopted in Ethiopia, is practiced in areas of waterlogging conditions. Plowing of such soils for cropping rice currently takes place with the use of draught oxen and the use of appropriate machineries for paddy fields will be very unlikely for the coming some years. Therefore, the major role of livestock for rice production is providing farm power and manures for both paddy and upland rice systems, while, the straw of rice is mainly used as animal feed.

Complementarity of rice and livestock production

Rice and its byproducts as feed for livestock

Rice production could provide a wide range of products that could be used as animal feed. These includes; straw, husks, bran, whole grain, broken grain (Figure 1). The major byproduct of rice is the straw, but generally, the straw has low feeding value to ruminant animals. It is low in palatability and digestibility due to the high content of silica (12 to 16 % of the dry matter) and low crude protein contents (2 to 6 % of the dry matter), (Nour, 2003). The quality of rice straw can be improved through selection of rice varieties, improving agronomic practice (harvesting time, fertilizer level), and storage conditions with the application of different straw treatment techniques such as urea treatment.

The rice husk has also very low feeding value to livestock while the bran is a very good source of feed as a supplement. Depending on the level and target of production broken rice grain during dehulling, and even whole grain are also very good source of energy feed source for both mono-gastric and ruminants.

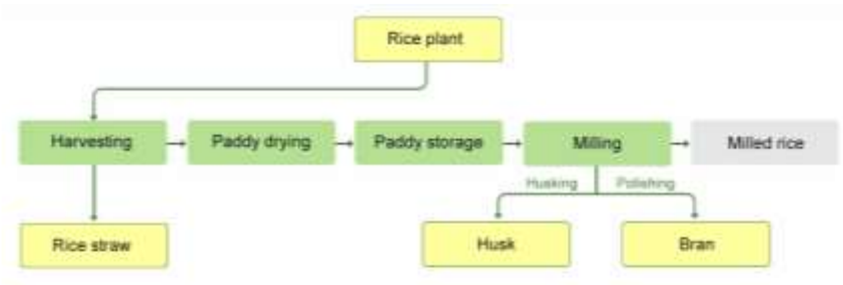

Figure 1 – Major products and by-products of rice crop

The other option of feed production in the rice-based systems is through integrated forage-rice production. As rice is a cereal, crop rotation practices with legumes like soya bean, lablab, pigeon pea and other suitable annual forage crops could be possible to produce quality feed for livestock and improve soil fertility. Such practice has also the advantage of breaking life cycles of pests in addition to ameliorating fertility status of the soil.

Livestock as sources of draft power in rice production

In the countries like Ethiopia the main role of livestock especially cattle in rice production is in the preparation of rice fields and transportation of farm goods. Rice fields particularly paddy rice fields have wet heavy soils, which require hard work from draught animals and sometimes inconvenient and expensive to use farm machinery like tractors for smallholder farmers in countries like Ethiopia (FAO, 2010). With the current state of development in Ethiopia, integrated use of animal power for rice production is very appropriate. However, information is lacking on the use of the local plow (“maresah”) for land preparation of paddy rice fields. Use of appropriate farm tools helps efficient use of animal power and improved field preparations. In addition, as the traction ability of draught animals is highly associated with their nutrition, health status and other husbandry aspects, improving the integration would enable the animals to deliver their optimal potential.

In addition to this animal power they could also provide services in transportation of materials like input supplies to the fields and also straws and grains to homesteads, which otherwise poses a drudgery on women. This is normally a big burden for rural women. Use of animal power for transportation makes the farm work relatively easier. and efficient, and minimizes the burdens of women.

Livestock byproduct (manure) as source of fertilizer

Rice production requires heavy fertilization and the use of organic fertilizers like manure has many economic and environmental advantages. Livestock manure could be more efficiently utilized if applied after making composts. Hence, crop livestock mixed system is considered as eco-friendly approach. The use of manure increases soil organic matter, nutrients, and maintains soil productivity for a prolonged time, and reduces production costs (Basuni, 2012). Although the main challenge of livestock production in relation to climate change is about greenhouse gas emission, effective use of the rice straw (to reduce methane gas production) and manure could reduce its greenhouse gas emission. Use of manure for biogas production and then the use of the remains as fertilizer remarkably reduce greenhouse gas emissions (Pathak *et al*., 2009).

Water use efficiency in crop-livestock systems

Crop-livestock mixed production systems also enhance land productivity, improve water use efficiency and maintains water quality (Walia and Navdeep, 2013; Dashora and Singh, 2014). One of the principles of increasing water productivity is improving the plant water uptake through sufficient soil nutrient application. When there is sufficient nutrient in the soil, plants grow vigorously and take up water for photosynthesis (Amare et al., 2009). This ensures higher biomass yield and crop water productivity. As crop residues are used for animal feed, under higher crop water productivity scenario the livestock water productivity (LWP) will also be higher, particularly when animal fed on crop residue are supplemented with high quality feed sources (Ayele, 2012).

Allows multiple production

If water is not a limitation then rice production could be intensified by integrating with aquaculture/ fish farming, poultry (chicken/ducks) and others (swine or ruminants), which allows an efficient utilization of resources, diversified products at a time and more income, improved family nutrition. For instance, in China, the integration of fishpond production with ducks, geese, chicken, sheep, cattle, or pigs increased fish production by 2 to 3.9 times (Chen et al., 1996), while there were added ecological and economic benefits of fish utilizing animal by-products. Environmentally, sound integration is ensured where livestock droppings and feed leftovers can be poured directly into the pond to constitute feed for fish and zooplankton. Vegetables can be irrigated from the fishponds, and their residues and by-products can be used for feeding livestock (Ehsanul, 2016).

Apart from animal feeding, rice straw can be used as mushroom production (rice straw used as bedding source to create straw mushrooms) and the straw could be used as paper making, house thatching, conservation agriculture (as mulching). Rice hulls and straw are widely burnt across the world as a source of energy to generate electricity. Moreover, rice hulls are good bedding materials for dairy that then could be manure/mulch in crop fields or pasture lands

Improve family nutrition

Mixed rice livestock farming enhances food production for the household, to maintain the natural resource base that contributes to food and nutrition security and the well-being of the rural people, to contribute to income generation, and to be accepted by local communities (Ehsanul, 2016). Given that Ethiopia is not food and nutrition secured country, food and nutrition security should be an area of priority. Crop-livestock mixed systems would give wider opportunity to have better nutrition security especially for smallholder farmers in Ethiopia. Livestock products makes rice based foods more nutritious and balanced (eggs, fish, milk, meat, etc), reduces health risks, stunting and wasting.

Conclusion

Global experiences showed that crop-livestock mixed system can increase productivity, profitability, income and nutritional safety for farmers through recycling of organic nutrients. Rice-cattle farming integration has also a comparative advantage in which, the former provides rice bran/straw as animal feed; the later produces manures for soil fertility. Mixed crop-livestock farming was the dominant system in Ethiopia, in which animal feed, manure, animal powers are the basis for integrated farming. Rice-cattle integrated farming is a major phenomenon in Fogera District, which helps to maintain and improves suitable cattle breeds like Fogera for dairy in rice production systems in Ethiopia.

Despite rice production becomes important in Ethiopia and the acreage increasing over the years, information on the role and interdependence of rice-cattle / livestock integrated farming is scant, which needs further research. Improve integrated production of rice, small animals, poultry and fish need to be adopted and demonstrated. In safeguarding the environment technologies related in safe use of water, manure, minimizing pollution and greenhouse gas emission are also pertinent. Other feasible technologies (varieties, agronomic practice, etc) that increase better outputs (rice grain and good quality straw) and rice straw treatment to improve its palatability and nutrient quality should be adopted or developed. Different actors like research, development, extension, public, private, and many other actors along the value chain of different commodities should work in harmony and need to create synergy to promote crop/rice-livestock mixed systems.

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Rice Seed System in Ethiopia

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Introduction

Seed sector development has received due attention in Ethiopia in recognition to its importance in boosting the aspired increase in production and productivity of the agricultural sector, which is the country's major economic sector in terms of its contribution to the national economy, foreign currency earning and creation of employment opportunities (MoA, 2015). The Growth and Transformation Plan (GTP) of the government indicates an ambitious increase of certified seed production from about 1.9 million tons in 2015 to 3.6 million tons by the end of 2020 to ensure increased productivity level. The target for rice is to increase the average national productivity level from 2.8 t/ha in 2015 to 4.1 tons/ha by 2020 (MoA, 2015).

Overall, the supply and use of certified seed in the country generally vary considerably with the type of crop and the development of the seed system for a particular crop. Generally, availability of hybrid varieties and high yielding varieties encourage seed replacement rate and varietal change, creating demand for quality seed. The seed sector development strategy of Ethiopia recognizes three types of seed systems that operate in parallel, each playing different role based on crop and its breeding system (MoA & ATA, 2017). These are the formal, intermediate, and informal seed systems. The formal seed sector, which is dominated by public seed enterprises and few private seed companies, plays an important role in supplying certified seed of improved varieties, especially for commercially viable crops like hybrid maize and bread wheat. Similarly, the intermediate seed system mainly involves farmers organized into seed producer cooperatives and it shares some features of the formal and informal systems. It plays important role especially in ensuring access to certified seed of crop varieties for which there is limited commercial interest for seed companies. However, it is the informal seed sector that plays dominant role in terms of coverage and for some crops, it is the only source of seed.

It is also argued that the formal seed system is in an early growth stage where the performance in terms of maize and wheat, and promotion of newly released and better varieties (AGRA, 2013). This has resulted in limited varietal change and seed replacement rate almost for all crops (Spielman *et al*., 2010).

This paper presents an overview of the national rice seed system, the performance in terms of the trends in the demand and supply of certified seed along with the designed strategies for ensuring better access to quality seeds of preferred improved rice varieties. It also documents existing challenges and emerging opportunities for rice seed sector development.

Overview of the rice seed system

Seed system is often described considering the development and performance of processes related with varietal development, variety registration and release, early generation seed production, certified seed production and marketing and use, together with actors engaged in each stage, regulations and policies that govern the system. We characterize the rice seed sector considering the trends in varietal development, trends in early generation and certified seed, type of actors engaged and policies and strategies put in place.

Policies, strategies and directives

The policies and strategies that are relevant for rice seed sector are of two types. The first ones are those that emanate from the general national seed system and the second ones are those specific to rice seed sector. The strategies, policies, regulations, and directives with relevance to the rice seed sector development are presented in Table 1. Overall, the overarching National Seed Industry Policy since 1992 governs the national seed system, which is now under revision. Unlike other commodities, rice seed sector has official public seed sector development strategy linked with the recognition to the importance of rice sector development in general and rice seed sector in particular.

Table 1 Policies, strategies and directives relevant for rice seed sector

Type	Authority	Name
Policy	Council of ministers /Ministry	1992 – National Seed Industry policy
Proclamation	Parliament	• Access to Genetic Resources and Community Knowledge, and Community Rights Proclamation (482/2006) • Seed Proclamation (782/2013) • Biosafety Proclamation (896/2015) • Plant Breeders' Rights Proclamation (1069/2017) • COMESA seed trade harmonization
Regulation	Council of ministers /Ministry	• Seed Regulation (375/2016) • Fee for seed competence and related services (361/2015)
Directives	MoA	• Quality declared seed • Certificate of competence • Eliminating quality deteriorated seed • Variety release procedure
Strategy	MoA	• The national seed system development strategy (MoANR & ATA, 2017) • National Rice Seed Sector Development Strategy (MOANR, 2017a)

Rice seed value chain and actors

In general, the actors engaged in rice seed production are research centres that are mainly engaged in germplasm and variety development as well as in the production and supply of early generation seeds (breeder, pre-basic and basic seeds) and certified seed is produced mainly by the public seed enterprises (Ethiopin Seed Enterprses,ESE; Amhara Seed Enterprises, ASE; Oromia Seed Enterprises, OSE; and South Seed Enterprises, SSE). There is only one private seed company engaged in certified rice seed in SNNPR (Table 1). Recent trends indicate the emergence of seed cooperatives engaged in rice seed production mainly through the support of development projects especially in the Fogera areas.

Table 2 Actors engaged in production of different seed classes of rice

Category	Actors
Germplasm development and variety development	Fogera, Pawe, Shire-Maitsebri, and Gode Research centers; also with access to germplasm from AfricaRice
Variety registration and release	National Variety Release Committee under the Ministry of Agriculture
Breeder seed production	Fogera, Pawe, Shire-Maitsebri, and Gode Research centers; also with access to germplasm from AfricaRice
Pre-basic seed production	Fogera, Shire- Maitsebri, Pawe, Bonga, and Gode research centers, and ESE
Basic seed production	Pawe, Bako, Fogera, Gonder, Shire-Maitsebri, Gode research centers and ESE
Certified seed production	ESE, SSE, ASE, OSE, and private seed company (Fikerte Newayeselasie Integrated Agri.Dev. PLC); Muez SPC, Tikdem SPC, Hunde Misooma SPC
Seed quality control & certification	Regional seeds laboratories under regional Seed and other Agricultural Inputs Regulatory Authority

Source: National Rice Seed Sector Development Strategy (MoANR, 2017a)

Though the actors stated in Table 1 reported to engage in seed production, the extent is very minimal linked with the limited varietal and seed demand creation along with the limited commercial benefits from rice seed production. Moreover, there are seed producer cooperatives (SPC) dealing with rice seed production. These are Muez SPC, Humera, Western Zone, Tigray; Tikdem SPC, Libo Kemkem, South Gondar Zone, Amhara; and Hunde Misoma SPC, Chewaka, Buno Bedele Zone, Oromia (ISSD Annual Report, 2015; ISSD Annual Report 2018), although they are suffering from limited market opportunity.

With expected expansion of rice production, there will be a need to develop different rice seed business models that can involve in the different aspects of seed business activities including the development of locally adapted and farmer, industry and consumer preferred varieties, awareness and demand creation, production and supply of seed in the required quantity at the required time and place.

Germplasm and variety development

The national rice research program has been engaged in germplasm and variety development of improved rice varieties with focus on three major agro-ecologies: rain fed lowland, rain fed upland, and irrigated rice agro-ecologies. The Fogera National Rice Research and Training Center of EIAR nationally coordinate the rice research program. Moreover, Pawe and Werer of EIAR; Mai-Tsebri of TARI; Bako of OARI; Bonga of SARI and Gode of SoPARI are also engaged in collaborative rice varietal development program in the country. The national rice research program closely collaborates with the international research programs, mainly with AfricaRice and International Rice Research Institute (IRRI). Through concerted efforts, 15, 11 and 9 rice varieties are registered and released for upland, lowland, and for irrigated agro-ecology, respectively (MoANR, 2017b). Among the 11 lowland varieties, three were hybrid rice varieties released by an Indian company ViBHA Seeds Ethiopia PLC, though, there was no seed production until now as the company has abandoned its operation in the country.

Rice was introduced into Ethiopia in late 1970s. The first introduced variety known as X-Jigna is still very popular in the country. There is an ongoing effort by the national rice research program to get the variety registered, following purification through pure-line selection or mass selection.

In variety development, Ethiopia needs to focus on exploiting the opportunities available globally as rice is the most researched crop in the world. This requires strengthening collaboration not only with international rice research organizations (IRRI and AfricaRice) but also bilaterally with countries especially in south and southeast Asia that have well advanced rice research for development Program.

Rice seed demand and supply

The approaches and procedures of assessment of the rice seed demand in the country emanates from the overall seed system prevailing in the country along with the key actors involved in the system. In general, the procedure of seed demand assessment follows bottom up approach starting from *kebele* (lowest administrative level) to national level and it is done one season before to ensure the production of the seeds of the demanded crop varieties. The demand at *woreda* (district), zone, region, and national levels are adjusted based on trends in the previous years and development plans (Lakew and Alemu, 2012). The demand assessment is not linked with demand creation, which has created a situation where farmers reveal their demand only to those varieties for which they have been exposed. Similar to other crops, the revealed demand for rice similarly tends to the old known varieties and in areas like Fogera farmers still stick to the initially introduced X-Jigna variety.

Rice has many desirable features for seed production, such as high degree of self-pollination and hence requiring only 3-5 meter isolation distance, seed multiplication factor, i.e, seed yield/seed rate) of 1 to 80; slow seed degeneration (after 3 -4 seasons of recycling) (JICA, 2014; Gauchan et al., 2016). The rice seed rate varies with the methods of seeding such as dibbling, drilling and broadcasting as well as requirement for gap filling. Commonly dibbling and drilling need lower amount of seed (about 0.07 t/ha than broadcasting up to 0.14 t/ha (JICA, 2014; MoA, 2014; MoA, 2016).

The amount of certified rice seed supplied compared to the amount of potential seed requirement is estimated to be very low, by considering the total area covered with rice in Ethiopia and taking two important assumptions, i.e., seed rate (taking minimum and Maximum) and seed replacement rate of 3 season (Table 2). Considering the two assumptions, the amount of supplied certified seed of rice over the past five years was in the range of less than 1% to 3% of the total certified seed required except the 2014 production season, when there was considerably high volume of certified seed production. This was mainly due to the inclusion of recycled seed (i.e. 2nd generation of C1) as C2 seed class in the official data reporting, which has inflated the figure.

Table 3 Rice seed requirement and seed supply.

Assumptions /Year	Area ('000 ha)	Actual certified seed supplied ('000 tons)	Seed rate (0.14 t/ha) and seed replacement rate (3 years)		Seed rate (0.07 t/ha) and seed replacement rate (3 years)	
			Total certified seed required ('000 tons)	% of actual seed supplied over total required	Total certified seed required ('000 tons)	% of actual seed supplied over total required
2013/14	33	1.480	1.54	96.10	0.77	192.21
2014/15	47	0.014	2.19	0.64	1.10	1.27
2015/16	45	0.013	2.10	0.62	1.05	1.24
2016/17	48	0.034	2.24	1.52	1.12	3.04
2017/18	53	0.010	2.47	0.40	1.24	0.81

Source: Estimated based on CSA data;

This trend indicate the huge gap in use of quality seed of available improved varieties of rice at national level and major dependence of rice farmers on the informal seed system, which includes use of own farm-seed and/or locally exchanged seed as well as local grain/seed market, i.e. when farmers opt to use grain purchased from local market for seed purpose (Sperling *et al.*, 2008).

Seed quality assurance mechanisms

According to Ethiopian Seed Law 2013, like any other commercial seed, rice seed has to meet the field and laboratory standards. Field inspection, seed sampling, testing and certification is being conducted by regional seed laboratories affiliated to their respective regional seed and other agricultural inputs regulatory authority. The authority is also mandated to give certificate of competence (CoC) for seed producers meeting criteria for quality seed production, processing, packaging, storage, marketing and distribution as well as annually evaluating and renews the CoC of each capable seed producer (public, private and seed producer cooperatives). Seed that does not fulfill the Ethiopian seed standards (both field and laboratory Standards) may be used as only informal seed.

Seed marketing and distribution

Inefficiency in seed marketing and distribution is most limiting factor in the Ethiopian seed system, including that of the rice seed system. Whatever amount of rice seed produced remain unmarked by public seed enterprises and seed producer cooperatives, discouraging continuous production of rice seeds of different improved varieties. This is largely due to limited degree of promotion, weak seed information exchange and poor market intelligence of the seed producers. Although direct seed marketing is now expanded to more number of woredas, it still deals only with hybrid maize seed and to some extent with seeds of wheat and tef, leaving out rice seed only government distribution system.

Key challenges and opportunities

Challenges

The status of the rice seed sector described above indicates the prevailing main challenges for the rice seed sector development, which can be categorized into two. The first category of challenges are those that emanate from the overall seed system challenges in the country and the second category of challenges are those that are specific to rice seed sector.

Week seed sector governance

This is the overarching challenge not only for the rice seed system but also for the overall seed sector in the country. These are related with the challenge of timely and efficient implementation of the following issues

- Proclaiming and implementing seed policy and regulatory frameworks (policy, strategy, law, regulations, directives, standards, guidelines);
- Controlling and assuring of seed quality;
- Licensing of seed producers and accrediting seed laboratories;
- Registering and releasing varieties following tests of value for cultivation (VCU) and, distinctness, uniformity and stability (DUS);
- Ensuring a continuous and stable supply of quality seeds of improved rice varieties;
- Ensuring the promotion and commercialization of new improved varieties; and

- Prioritizing breeding goals and objectives to generate demand driven technologies

Limited supply of early generation seed (EGS)

With poor planning and limited multiplication capacity of research centers, there is often shortage and/or mismatch of supply of EGS for demanded rice varieties. Even though there is an on-going effort to ensure proper annual planning by bringing together the research system as the supplier of EGS and seed suppliers (public and private) through contractual arrangement, the implementation is not still fully effective due to lack of accountability as per the memorandum of understanding. In recognition to this challenge, the MoA has drafted a new directive on public EGS management directive, which mainly targets promotion of proper planning and accountable contract arrangement between EGS supplier and seed companies.

Limited incentive for seed companies

Due to the low level of demand for seed of rice linked with the lack of proper promotion about use of quality seed of improved varieties, both public and private seed companies are not interested to engage in production and marketing of certified seed of available varieties. This is demonstrated by the fact that, for example in Fogera area, farmers still prefer the initially introduced variety called X-Jigna, which is currently considered as local variety. The low demand is also associated with the considerable volume of carry over every year from the limited amount of certified seed produced by public seed enterprises.

Limited recognition to alternative seed suppliers

Experiences in other countries especially in south and southern Asia show that quality seed of preferred improved varieties can be supplied through alternative actors than actors of the formal seed system. These are related with local seed businesses (LSBs), which refers to organized farmers as seed producer cooperatives (SPCs) (Ayana *et al*., 2015). Recent trend indicates the considerably growing importance of LSBs/ SPCs in supplying quality seeds at local level, especially for those crops with limited commercial interest like rice. It is expected that the role of LSBs/SPCs will be enhanced linked with the recent directive that allows marketing of quality declared seed (QDS).

Inefficiency in promotion, marketing and distribution

Though there is an effort in promoting direct seed marketing (DSM) to improve the efficiency of the seed distribution system, still seed marketing in general and of rice seed in particular is very much focused only to distribution by the public entities such as the regional bureaus of agriculture and cooperative promotion agency as well as cooperatives and cooperative unions. The specificity of rice seed requires its own seed marketing strategy specific to the seed business models that need to be developed.

Low level of implementation capacity of actors
The actors engaged in rice seed sector (Table 2) are highly constrained with limited technical (human), financial and physical capacities. In addition, the commercial viability of rice seed production under the current system provides limited incentive for actors to build their capacity. This implies the need to design a viable rice seed business models.

Emerging opportunities for the rice seed sector development
The main opportunities in the Ethiopia rice seed sector emanate from the potential of the overall rice sector growth, the increased demand of smallholder farmers for adoption of quality seed of improved varieties, the considerable improvement of the national agricultural research capacity, the government commitment towards improving the seed sector governance, and the increased interest of development partners.

Potential of the rice sector: With the dramatic increase in domestic rice consumption and the huge potential for domestic production, the demand for rice technologies especially of quality seed of improved rice varieties will increase considerably, creating the opportunity for different seed actors to join the rice seed business.

Increased demand of smallholder farmers for adoption of quality seed of improved varieties: Evidences show that with proper demonstration of available improved varieties, smallholder rice farmers are willing to adopt the use of quality seed of improved varieties.

Improvement of the national agricultural research capacity: With the establishment of the Fogera National Rice Research and Training Center and with its strong link with AfricaRice (Ethiopia is a member since 2016) and the International Rice Research Institute (IRRI), the national research capacity has improved considerably, providing opportunities for developing improved rice varieties with good performance and adaptability to diverse farming systems in the country.

Improvement of the seed sector governance: Recent trends show that the government is committed to improve the overall governance of the seed sector through approval of diverse policies and directives, including the development of the rice specific seed sector development.

Increased interest of development partners: Several development partners are engaged in promotion of rice seed sector, recognizing the importance of rice to the country. The most important development partner supporting rice are the EthioRice Project supported by Japan International Cooperation Agency (JICA), which is involved in strengthening the capacity of the national rice research, EDGET project (Ethiopians Driving Growth through Entrepreneur and Trade) implemented to empower the rice value chain through MEDA (Mennonite Economic Development Associates), an international NGO, with the financial support from Government of Canada, and the Integrated Seed Sector Development (ISSD) Project supported by the government of the Kingdom of Netherlands.

Conclusions

The performance of the rice seed sector is still weak mainly in terms of availability and accessibility of quality seed of improved varieties and varietal and seed replacement rates, and limited engagement of seed actors. However, there is a huge potential for growth, given the emerging opportunities, which includes the strengthened national rice research program, the expansion of rice production and the public and development partners' interest to promote the domestic rice production.

In order to enhance the performance of the rice seed sector, it will be important to:

- Encourage the participation of private and seed producer cooperatives in addition to the public seed enterprises in rice seed production and marketing, considering the specificities of the different rice production hubs in the country;
- Explore the development of rice seed business models as the commercial interest of the formal seed actors is very limited;
- Engage in demand creation for newly released varieties and quality seed use. This requires adequate promotion of improved varieties through different approaches including extensive demonstrations. It will also be important to promote small seed packs, given the average rice farm size at household level. It is estimated that the national average rice farm size is 0.33 ha, which requires 23 kg/ha to 46 kg/ha based on the 70-140 kg/ha recommended seed rate; and
- Strengthen integration and coordination of rice value chain: the improved performance of the value chain implies the need for use of quality seed of preferred rice varieties, which enhances the performance of the rice seed sector.

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Costs and Returns of Rice Production under Smallholder Farming in Fogera and Pawe

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Introduction

Rice offers several advantages to farmers compared to other field crops grown in Ethiopia including more yield per unit area next to maize with productivity of 2.84 tons/ha (CSA, 2018) and contributes a lot to food security. It is also valued for its variety of uses in the preparation of local food and beverages either alone or mixed with other crops. Rice could be considered as one of the best and the cheapest alternative technology available to farmers for efficient utilization of their scarce resources, especially the land and water in swampy and waterlogged environments. In addition, owing to its length of growing period, rice is suitable for sequential cropping and it is primarily a cash-earning crop while the bran, hull, and straw are used as animal feeds. Considerable amount of arable lands is usually flooded during the rainy season, especially July and August, and vast area of land is left for open grazing in the country so that huge underutilized cultivable lands potentially suitable for rice cultivation exist in many parts of the country (Ayele, 2012).

Despite all the potentials and untapped opportunities on rice cultivation and challenges of spending scarce foreign currency on rice import, its production economics peculiarly costs and benefits associated in rice production is not well known and documented. This research, therefore, aimed at identification and estimation of production costs and its components as well as assessing the returns of rice production under smallholder farmers' condition in the major rice growing area of the country namely Fogera plain and Pawe area.

Material and Method

The study area

This study was conducted in Fogera and Libo kemkem districts of North Gonder Zone of the Amhara regional state and Pawe District of Metekel Zone, Benishangul Gumuz Region, northwestern part of Ethiopia. Libo Kemkem District has 31 rural kebele administrations out of which 18 kebeles are rice producers (8 kebeles produce upland and 10 kebeles produce lowland). The district has 46,604 farm households, of which 42,014 are male-headed and 4,590 are female-headed households. Farmers participating in rice farming are 17,384, of which 17,006 are male-headed and 378 are female-headed households. Fogera District has 33 rural kebele administrations, of which 27 kebeles produce rice (21 kebeles produce lowland rice and six kebeles produce upland rice). The district has 47,440 households, of which 40,918 are male-headed and 6,522 are female-headed households. In Fogera District, 21,945 ha of land were covered with rice in 2017. The total number of farm households participating in rice farming was 40,968, of which 40,579 were male-headed and 390 were female-headed households (Alemu *et al.*, 2018). Pawe District has 20 kebeles from which 5 kebeles produce upland rice. The district covers an area of 63,400 hectare with estimated population of 59,127 (50.76% male) inhabitants with mixed crop-livestock farming system dominated by cereals.

Sampling, data collection and statistical analysis

A multistage sampling procedure was used for selection of major rice producing districts, kebeles, and farmers. At first major rice growing districts were identified based on area coverage and production statistics then two districts were selected based on agro-ecological differences on rice production system. Libo kemkem District for upland agro-ecology and Fogera District for lowland agro-ecology from Fogera plain and Pawe District from Metekel zone representing upland agro-ecology. From Fogera plain four sample kebeles were selected from each district and from Pawe area two sample kebeles were selected followed by random selection of sample households. In Fogera plain three strata were grouped based on their land size and sample farmers randomly selected from each stratum using probability proportional to size of households, whereas in Pawe, sample farmers were selected using random sampling from the list of rice producing households.

Table 1: Sample size by district for Fogera plain and Pawe area

Area	District	Agro-ecology	Population	Sample size
Fogera plain	Fogera	Lowland	36969	50
	Libo kemkem	Upland	15851	48
Pawe	Pawe	Upland	2079	105
Total			54899	203

Data were collected through well-structured questionnaire that allow addressing the set of objectives of costs and returns of rice production under rain fed lowland and upland agro-ecologies. Data collection executed in 2016 in Fogera plain and in 2015 in Pawe area. The data and analyzed using descriptive statistics mainly using gross margin analysis and benefit cost ratio.

Gross margin analysis

Gross margin analysis was employed to better understand the relationship between revenue and cost structures (Kay, 1986). It is given by the following relationships:

$$GM = TR - TVC$$

Where, GM is Gross Margin, TR is Total Revenue and TVC is Total Variable Cost. The total revenue represents the value of the output and byproduct from the farm multiplied by the prevailing market prices. Total variable cost is specific cost that varies directly with the level of production and includes expenditure on seeds, fertilizer, chemical and labor.

Benefit cost ratio

Benefit Cost Ratio (BCR) compares benefits to costs and directly proportional to the net return. If BCR is above 1, then the farm is earning a net return while if it is less than 1 or negative, then the farm is in loss. It is given by:

$$BCR = TR / TVC$$

Results and Discussion

Demographic and Socioeconomic Characteristics

Among majority of the sample households in Fogera plain, 88% in upland agro-ecology and 81% in lowland agro-ecology, were male-headed with majority in illiterate education category followed by ability to read and write or religious education (Table 2).

Table 2: Demographic characteristics of rice producer farmers in Fogera plain

Particular	Upland			Lowland	
	N	%		N	%
Households headship					
Male headed	44	88		39	81
Female headed	6	12		9	19
Education level of household head					
Illiterate	23	46		26	54
Read &write/ Religious school	13	26		13	27
Primary and junior secondary (1-8)	12	24		8	17
Secondary school (9-12)	2	4		1	2

Source: Survey results, 2016

In Pawe area, 89.5% of the sample households were male headed and92% married. Regarding level of education, 63.47% were at least capable of reading and writing (Table 3).

From Fogera plain upland agro-ecology the mean age of household head was 43 years and household size of the about five people owned average of 0.93 hectare of cultivated land of which 0.45 hectare was allocated for rice production with ownership of 2.78 TLU (Tropical Livestock Unit). For lowland agro-ecology the mean age of household head was 49 years and household size of 5 persons. On average households, owned 0.85 hectare of cultivated land of which 0.62 hectare was allocated for rice production, which was more than half of the cultivated land with 5.3 TLU of livestock, owned (Table 4).

Table 3: Demographic characteristics of rice farmers in Pawe area

Particular	N	%
Households headship		
Male headed	94	89.5
Female headed	11	10.5
Marital status		
Married	97	92.3
Divorced	3	2.9
Widowed	5	4.8
Education level of household head		
Illiterate	38	36.54
Able to read and write	24	23.08
Primary school (1-4)	7	6.73
Junior school (5-8)	24	23.08
Secondary school (9-12)	11	10.58

Source: Survey results, 2015

Table 4: Socioeconomics characteristics of sample households in Fogera plain

Particular	Upland			Lowland		
	N	Mean	SD	N	Mean	SD.
Age (years)	50	43.0	15.81	48	49.0	14.75
Household Size	50	4.8	2.13	48	4.7	2.02
Cultivated land size (ha)	50	0.93	0.49	48	0.85	0.52
Rice cultivated land (ha)	50	0.45	0.21	48	0.62	0.34
Livestock Ownership (TLU)	50	5.30	3.37	48	2.78	2.61

Source: Survey results, 2016

The sample households in Pawe area reported average family size of about 6 people with 52% of male proportion and mean age of about 42 years with average TLU of 11.5 livestock asset. Farmers were observed to have 21 years of experience of farming from which 14 years of experience of rice cultivation (Table 5).

Table 5: Socioeconomic characteristics of sample households in Pawe area

Particular	N	Mean	SD
Household size			
Female	104	2.84	1.538
Male	103	3.00	1.365
Total	105	5.76	2.110
Age of the house hold head	101	42.50	13.410
Total land holding	105	3.88	2.383
Livestock ownership (TLU)	106	11.50	10.270
Years of experiences in farming activity	101	21.39	11.847
Years of experiences in rice production	105	14.51	8.431

Source: Survey results, 2015

Input use and costs in rice production

In Pawe area, 30% of rice grower farmers practiced twice plowing and twice weeding. Majority of rice grower farmers ploughed rice plots two to three times and two to three times weeding by 75% of sample farmers while 23% of farmers weed only once (Table 6).

Table 6: Plowing versus weeding frequency of rice field in Pawe

Particular		Weeding frequency				
		1	2	3	4	Total
		Percent of farmers				
Plowing frequency	1	6	4	0	0	10
	2	16	30	16	0	62
	3	1	14	9	2	26
	4	0	1	1	0	2
	Total	23	49	26	2	100

Source: survey data, 2015

In Fogera plain material cost of rice production was Birr 3,374.44 in upland and Birr.74 in lowland which included the cost of seed and fertilizer (Table 7). In Pawe area, 58% of farmers reported using of chemical fertilizer and 78% use of herbicide. A total of Birr1473.62 spent for materials in rice production (Table 8).

Table 7: Material expenses of rice growers in Fogera plain

Cost Item	Upland				Lowland		
	N	Mean (Birr/ha)	SD		N	Mean (Birr/ha)	SD.
Seed	50	1565.38	517.99		48	1906.45	641.45
Fertilizer	50	1808.06	814.76		48	1498.29	1074.12
Total		3374.44				3404.74	

Source: survey data, 2016

Table 8: Material expenses of rice growers in Pawe area

Cost item	N	Mean	SD
Seed (Birr/ha)	105	513.03	222.566
Fertilizer (Birr/ha)	61	720.93	1282.959
Herbicide (Birr/ha)	82	386.46	578.606
Total	105	1473.62	1042.850

Source: survey data, 2015

In Fogera, average operational cost of Birr 9,698.41 was incurred for upland rice production of which weeding contributed 36.5% followed by land preparation (17.1%). For lowland rice production agro-ecology average of Birr 13,332.95 of operational cost incurred of which weeding contributed 44.7% followed by harvesting and pileup (15.6%) (Table 9).

Table 9: Operational costs related to rice production in Fogera plain

Cost Item	Upland				Lowland		
	Mean (Birr/ha) (N=50)	SD	% share		Mean (Birr/ha) (N=48)	SD.	% share
Land preparation	1656.15	341.47	17.1		1962.87	685.77	14.7
Water Management	737.38	726.68	7.6		62.38	94.33	0.5
Planting	540.21	257.20	5.6		548.65	341.82	4.1
Weeding	3539.52	1750.51	36.5		5949.47	4262.65	44.7
Fertilizer Application	38.46	54.25	0.4		63.78	51.97	0.4
Bird scaring & Roughing out	488.51	768.19	5.0		0	0	0.0
Harvesting and Pileup	1010.47	477.64	10.4		2083.18	1979.54	15.6
Threshing and winnowing	1208.84	322.54	12.5		1516.92	684.52	11.4
Transporting	478.93	157.47	4.9		1156.24	1325.59	8.7
Total operational cost	**9698.47**		**100**		**13,332.95**		**100**

Source: survey data, 2016

For Pawe area total labor cost of Birr 6910/ ha incurred associated with rice production from which weeding labor cost contributed 57.8% (Table 10).

Table 10: Costs related rice production in Pawe area

Particular (Birr/ha)	N	Mean	SD	% share
Ploughing labor cost	85	706.67	552.168	10.2
Weeding labor cost	101	3990.89	3470.918	57.8
Harvesting labor cost	94	897.66	708.940	13.0
Trashing labor cost	90	514.44	259.403	7.4
Winnowing labor cost	90	303.11	238.137	4.4
Total labor cost	90	6909.89	3903.051	100.0

Source: survey data, 2015

Productivity of rice

On the basis of land allocated to rice production, the sample households in Fogera plain were categorized in to three groups (small below 0.5 ha, medium 0.5-1 ha and large more than 1 ha). From upland rice growers 52% and 65% in lowland agroecology were allocated medium land size for rice production followed by small and large land size for rice production. Average productivity of 2.7 t/ha in upland and 3.6 t/ha in lowland agroecology recorded irrespective of operated land size (Table 11).

Table 11: Rice productivity in upland and lowland agro-ecologies in Fogera plain

Category	Upland			Lowland		
	N	%	Yield (t/ha)	N	%	Yield (t/ha)
Small (<0.5 ha)	23	46	2.6	13	27	3.5
Medium (0.5-1 ha)	26	52	2.9	31	65	3.8
Large (> 1 ha)	1	2	2.1	4	8	3.4
Total	50	100	2.7	48	100	3.6

Source: survey data, 2016

Rice grower farmers in Pawe area produced on average 2.93 tons/ha rice which was above the national average of 2.83 t/ha (CSA, 2015) however the productivity of improved rice varieties up to 4 t/ha (MOA, 2010) so that yield gap of more than a tone observed. Rice straw was used by the community mainly for livestock feed which made rice an integral component of the farming system to which 40% of farmers attached economic value for rice straw with mean yield of 5.6 t/ha (Table 12).

Table 12: Distribution of rice grain output from sample farmers in Pawe area

Grain yield (t/ha)	N	%
up to 0.99	5	5.88
1.00 to 1.99	11	12.94
2.00 to 2.99	22	25.88
3.00 to 3.99	25	29.41
above 3.99	22	25.88
Total mean: 2.93	85	100.00
SD: 1.19		
Straw yield (t/ha)	N	%
below 3	1	3.03
3.1 to 5	16	48.48
5.1 to 7	5	15.15
Above 7.1	11	33.33
Total mean:5.61	33	100.00
SD:4.45		

Source: survey data, 2015

Return, gross margin and benefit cost ratio

Rice production under smallholder farmers have two components that are the rice main component and the by-product (straw) component. The mean values of both components were considered to compute the gross returns of rice production. The mean value of rice and straw were Birr 22,001.89 and Birr 3,154.51 per hectare, respectively and with gross return of Birr 25,156.4 per hactare in upland agr-ecology. Similarly, in lowland agro-ecology the mean value of rice and straw were Birr 29,135.17 and Birr 4,021.25, respectively with total return of Birr 33,176.70 per hectare (Table 13).

Table 13: Per hectare returns of rice production in Fogera plain

Item	Upland			Lowland	
	Mean (n=50)	SD		Mean (n=48)	SD
Rice	22,001.89	6579.39		29,155.45	8576.62
Straw	3,154.51	1644.66		4,021.25	1417.79
Total return (TR)	25,156.4			33,176.70	9248.45

Source: survey data, 2016

In Fogera plain, on average, the sample households earned TR of Birr 25,156.39/ ha and incurred TVC of birr13,071.93 per hectare under upland agro-ecology thus average of GM of Birr 12,084.46 with earned with BCR of 1.92. Under the lowland agro-ecology GM of 16417.92 earned by farmers from TR of Birr 33,156.43 and TVC of Birr 16737.65 per hectare with BCR of 1.98 (Table 14).

Table 14: Analysis of Gross margin and Benefit-cost ratio of rice production for Fogera plain

Variable	N	Mean	SD	95% confidence interval	
Upland agro-ecology					
TR (Birr/ha)	50	25,156.39	7447.16	23018.45	27294.35
TVC (Birr/ha)	50	13,071.93	3459.19	12078.85	14065.02
GM (Birr/ha)	50	12,084.46			
BCR	50	1.92			
Lowland agro-ecology					
TR (Birr/ha)	48	33,156.43	9151.545	30,470.96	35,841.90
TVC (Birr/ha)	48	16,737.65	7073.185	14,662.94	18,814.09
GM (Birr/ha)	48	16,417.92	10900.77	13,219.16	19,616.67
BCR	48	1.98			

Source: survey data, 2016

In Pawe, mean TR of Birr 15304.09 of rice cultivation computed with TVC of Birr 8625.31 resulted in GM of Birr 6048.2 per hectare with BCR of 1.78 from a hectare (Table 15).

Table 15: Analysis of Gross margin and Benefit-cost ratio of rice production in Pawe area

Variable	N	Mean	SD	[95% Conf. Interval]	
TR (Birr/ha)	88	15304.09	7274.123	13132.27	16214.75
TVC (Birr/ha)	88	8625.31	4215.381	7732.16	9518.468
GM (Birr/ha)	88	6048.20	7381.202	4484.27	7612.125
BCR	87	1.78	1.195		

Source: survey data, 2015

Conclusion

Even though other competitive enterprises were not included in the study, rice production was observed to be labor intensive and low use of productivity enhancing inputs resulted in up to a tone of yield gap where both gross margin analysis and BCR indicated appreciated return over TVC. Attention should be given on labor saving technologies and use of inputs so that profitability of rice production could be further amplified through both decrease in cost and increase in return of rice cultivation that would be accompanied by expansion in rice production, local consumption and marketable surplus. Due attention also needs to be given to make available rice technologies which embrace quality parameters of the galloping local market so that import substitution would be possible.

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Rice Commercialization and Livelihood Pathways of Farmers' in Fogera Plain

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Introduction

In developing countries, commercialization of agriculture is seen as the pathway to agricultural transformation (Pender and Alemu, 2007; von Braun and Kennedy 1994). Similarly, promotion of commercialization of smallholder agriculture is considered as essential part of the process of agricultural modernization, specialization, and structural transformation of the economy toward more rapid and sustainable growth (MoA, 2015; MoFED, 2010). Conceptually, agricultural commercialization occurs when those engaged in agricultural production (smallholders, commercial farms) rely increasingly on the market for the sale of produce and for the acquisition of production inputs, including labor (Poulton, 2017). With increased level of agricultural commercialization, livelihood options of smallholder farmers' are expected to expand creating better opportunities for increased livelihood outcomes. Livelihood options at household level are generally related with the capabilities, assets (stores, resources, claims, and access) and activities required for a means of living (Chambers and Conway, 1991).

In this regard, it is important to understand the contribution of agricultural commercialization to rural transformation specifically in shaping the opportunities for rural livelihood options in Ethiopia. This is more significant considering the importance of agricultural commercialization in agricultural and rural development policy in Ethiopia and its potentially strong and favorable impacts on agricultural productivity, rural poverty reduction, and overall rural transformation.

In this paper, we focus on rice, which has become one of the multifaceted agricultural commodities serving as cash, food security and farming system-enhancing commodity in the country. As it is in other African countries, rice has become one of the stable crops in Ethiopia due to increased domestic consumption linked with changes in preference and urbanization (GRiSP, 2013; MoANR, 2010). This has created both opportunities and challenges. The opportunities are related with the possible exploitation of available rice production potential and what it offers in building local economy. The main challenge is related with consistent decline of rice self-sufficiency and the burden of meager foreign currency reserved. With increased rice demand, domestic rice production in Africa in general and in Ethiopia in particular has increased with parallel trend of increased imports. It was estimated that Africa has imported one-third of rice available in the world market in 2009 costing USD 5 billion (AfricaRice, 2011). Imports of rice in Ethiopia has also increased from about 43 thousand tons in 2010 with a value of about 25.76 million USD to about 312 thousand tons in 2016 with a value of 170.69 million USD, which is about 3.75 billion Birr (ERCA, 2010, 2016).

The increased trends in domestic production and imports of rice indicate that rice has become more of a cash crop for smallholder farmers especially in the niche rice production areas of the country like the Fogera plain. We focus the study on Fogera plain as it was one of the known food insecure areas in the country that has become a surplus producing areas with considerable changes in livelihood options due to the introduction of rice in late 1970s (Alemu et al., 2018). We look into the major livelihoods of smallholder rice farmers considering the changes over time in the engagement of different rice related activities. We consider the engagement in rice production as commercial orientation of the smallholder farmer given the nature of the crop, which is considered as cash crop. Conceptually, the term commercialization is defined considering different perspectives. In general, agricultural commercialization is the extent of dependence of agricultural enterprises and/or the agricultural sector on the market for the sale of produce and for the acquisition of production inputs, including labor (Leavy and Poulton, 2007; Pender and Alemu, 2007). Thus, commercialization can be looked considering the participation in cash crop production, extent of participation in output markets and/or input markets.

Following the introduction of rice in the 1970s in the Fogera plain, there have been considerable changes in the farming systems, livelihood options and agrarian changes in the area (Alemu et al., 2018). The main objective of this paper is to identify the main livelihood pathways prevailing in the Fogera plain based on observed changes in the livelihood options that the smallholder rice farmers are engaged with over years. In addition, we characterize the smallholder rice farmers considering the livelihood pathway followed in terms of socio-demographics, resource ownership, access to services and commercial orientation.

Methodology

Data generation

The study used the data generated through a formal survey using a pre-tested questionnaire from randomly selected smallholder rice farmers and an informal survey through Key Informant Interviews (KIIs) and Focus Group Discussions (FGDs) with target individuals knowledgeable about the rice production in the Fogera plain. Assessment of changes and trends over years requires historical data. In this regard, the information about changes was generated through recall methods by comparing the situation before five year ago and during the time of survey. Five-year trend was opted to improve the quality of responses.

Sampling and sample size

Stratified sampling procedure was followed for identification of respondents. Given the importance of rice and observed agrarian changes in the whole Fogera plain, all the three rice-producing districts (*woredas*) in the Fogera plain were considered. The total sample 723 was allocated to these districts considering the total land allocated based on proportion to population where 64% of the rice land in the Fogera plain was found in Fogera District, 28% in Libokemkem District and the rest 8% in Dera district. Accordingly, 470 respondents from Fogera District, 199 respondents from Libokemkem and the rest 53 respondents were selected from Dera district (Table 1).

In order to select randomly, the number of villages to be selected were further determined considering the proportion of land allocated, accordingly, using the total list of *kebeles* (villages) engaged in rice production for each of the districts, 13 kebeles from Fogera, 6 kebeles from Libokemkem, and 2 kebeles from Dera District were selected using systematic random sampling. Recognizing the more or less similar population of farmers at kebele level (around 1000 farmers/*kebele*), equal number of sample farmers was allocated for each kebele, which was 35 farmers. The last stage then considered again systematic random sampling to select respondent farmers using the list of farmers at kebele level. Expecting unavailability and rejection to participate in the survey, the sample size at kebele level was increased to 37 for each kebele. The survey was facilitated using guides, whom were development agents (DAs) working in each of the kebele as extension agents. The DAs assisted the survey not only by providing the list of farmers in each kebele but also fixing appointment with the selected farmers and guiding the contact place and time.

Table 4. Sample size by district, Fogera plain

District	Number of the *kebeles*	Sample size
Fogera	13	470
Libokemkem	6	200
Dera	2	53
Total	21	723

Data analysis

The first step in the data analysis was the identification of major indicators of changes over the years based on the responses of rice farmers related with the different types of livelihood options. Using the identified indicators of livelihood options, main livelihood pathways were identified, which were used to categorize smallholder rice farmers into groups. The farmers in each group were further characterized in terms of socio-demographics, resource ownership, access to services and commercial orientation.

Livelihood pathways and characteristics of smallholder rice farmers

Identification of livelihood pathways

Livelihoods approaches, perspectives, methods and frameworks have been central to rural development related discussions and policymaking. In general, a livelihood is commonly defined in relation to what it comprises to make a living by a household mainly in rural setting (Scoones, 2009; Murray, 2001; Dorward et al., 2006). Accordingly, a livelihood is about capabilities, assets (including both material and social resources) and activities for a means of living. Different authors have come up with different livelihood pathways or strategies. Scoones (1998) identifies three main livelihood strategies considering rural development perspectives, which are agricultural intensification, livelihood diversification, and migration. Dorward et al. (2006) suggested three livelihood pathways namely, 'stepping-up', where investments are made in existing activities to increase their returns, 'stepping-out', where existing activities are engaged in to accumulate assets as a basis for investment in alternative, higher-return livelihood activities, and 'hanging-in', where activities are undertaken to maintain livelihood levels at a 'survival' level. Both perspectives indicate that livelihood pathways or strategies are about progress made on existing activities and the extent of engagement in new ventures over time to ensure one's improved means of living.

In line with the literature, the results of this study indicate that there are different activities defining livelihood options in the Fogera Plain. These are presented as key indicators in (Table 2), which were identified during the FGDs. Accordingly; we identified livelihood pathways of smallholder rice farmers considering the different livelihood frameworks stated above and the specificities of the role of rice in influencing the livelihood pathways of smallholder rice farmers. We consider as key assets, capabilities and activities within the context of smallholder rice farmers in the Fogera plain the extent of engagement in rice and vegetable production, engagement in non-farm activities, and associated capabilities that allow respective smallholders to engage in the different activities linked with the opportunities rice provided and the emerging livelihood options.

The introduction of rice into the Fogera plain has shifted the production system where vegetable and pulse crops production has become important (Alemu et al., 2018). In addition, improved incomes from rice created the opportunity for smallholder farmers to engaged or invest in non-farm activities. Accordingly, we identified four major livelihood pathways that smallholder rice farmers are following. Since livelihood pathways happens over a given time period, we identified the pathways considering the changes observed over the last five years. The five-year range was selected to minimize the error in recalling trends.

Table 5 Indicators considered for identification of Livelihood pathways of smallholder rice farmers

Indicators considered	Identified livelihood strategy/ pathways	Associated livelihood strategies
Rice production increased Area allocated for rice increased No engagement in vegetable production No engagement in non-farm activities	Specialization pathway	Agricultural Intensification or intensification (Scoones, 2009) Stepping up (Dorward et al., 2006)
Area allocated for rice either remained the same or increased Started to engage in vegetable production	Diversification pathway	Livelihood Diversification (Scoones, 2009) Stepping up (Dorward et al., 2006)
Area allocated for rice either remained the same or increased No engagement in vegetable production Started to engage in non-farm activities	Non-farm activity pathway	Stepping out (Dorward et al., 2006); Livelihood Diversification (Scoones, 2009)
Area allocated for rice has decreased No engagement in vegetable production No engagement in non-farm activities	Hanging-in pathway	Hanging-in (Dorward et al., 2006) Migration (Scoones, 2009)

Source: own survey, 2018

Livelihood pathways

The four livelihood pathways were identified based on the criteria considered among rice farmers in the Fogera plain, where the summary of the distribution of smallholder rice farmers by livelihood pathways is presented (Table 3). Accordingly, 45% of the rice farmers followed specialization livelihood pathways, which presents the expanded engagement in rice production over years. Rice farmers that followed diversification pathway are about 21%, where while engaged in rice production, they started to engaged in high value crop production mainly vegetables. Vegetable production is new to the farmers in the Fogera plain and the production requires investment mainly in irrigation facilities. About 16% of the rice farmers followed non-farm activity pathways, where they started to engage in non-farm activities that can generate more income like transport service provision, petty trading, restaurant and hoteling etc. The rest 18% of the farmers seems to remain in “hanging in” livelihood pathway, where they engage in rice production with reduced areas and level of production and without any other type of engagement. These trends indicate that rice commercialization has considerably contributed in boosting the livelihood options of smallholder farmers either through expansion of rice production, diversification to other agricultural production or creating the possibility to invest in non-farm activities for improved income and livelihoods.

Table 6 Distribution of smallholder rice farmers by livelihood pathways

Livelihood pathway	%	N
Specialization	45.2	327
Diversification	20.9	151
Non-farm activity	16.0	116
Hanging-in	17.8	129
Total	100	723

Source: Own survey, 2018

Socio-demographic characteristics

The descriptive analysis indicates that there are statistically significant differences in many of the demographic indicators among farmers pursuing different livelihood pathways (Table 4 7). Specifically, there is statistically significant difference in age, experience in farming, family size, education level of the household head, and household type among smallholder rice farmers in the different livelihood pathways. On average, younger farmers with smaller years of farming experience tend to follow livelihood pathways related with specialization in rice production and in non-farm activities compared to those in the "hanging in" and diversification livelihood pathways. In term of family size, households that follow diversification pathway, on average, had higher family size compared those following other pathways. This is in line with expectation that as the household diversify its farm activities, there is a need to have more labor. In line with expectations, households following non-farm activity pathway were on average better-educated (number of years with formal education) compared to those with other livelihood pathways (Table 4).

Table 4 7 Smallholder rice farmers

Livelihood pathways	Indicator	Household head			Household size	Years of formal education
		Age (years)	Farming experience (years)	Experience in growing rice (years)		
Specialization pathway	Mean	41.82	21.34	11.46	5.42	1.45
	Std	12.01	12.04	6.02	1.97	2.23
Diversification pathway	Mean	45.72	24.56	12.67	5.89	1.60
	Std	10.83	10.37	6.55	2.22	2.29
Non-farm activity pathway	Mean	40.62	20.35	11.92	5.41	2.59
	SD	10.69	9.81	5.64	1.93	3.34
Hanging-in pathway	Mean	51.22	29.73	14.28	5.43	1.21
	SD	12.69	11.71	7.43	2.10	2.01
Total	Mean	44.12	23.35	12.29	5.52	1.62
	SD	12.25	11.76	6.42	2.04	2.46
Mean difference test	F-value	24.46***	20.41***	6.49***	2.19*	8.03***

Source: Own survey, 2018

The household types among smallholder rice farmers can be based on the sex of the household head and also based on the sex and marital status of the household head. Considering the sex of the household head, there is no statistically significant difference in the distribution of female-headed households among the different livelihood pathways, where the proportion of female-headed households is about 11% among smallholder rice farmers in the Fogera plain. However, there is statistically significant distribution of households by household type considering both sex and marital status (Table 5). On average, there was higher proportion of single male headed and female headed households among those who followed a “hanging in” livelihood pathway, which is in line with expectation that most of them elderly.

Table 5. Distribution of farmers by household type and livelihood pathways

Category	Indicators	Livelihood pathways (% of respondents				Total	Chi-square
		Specialization pathway	Diversification pathway	Non-farm activity pathway	Hanging-in pathway		
Sex of household head	Male	89.9	91.4	87.9	86.0	89.2	2.45
	Female	10.1	8.6	12.1	14.0	10.8	
Type of household	Male Headed (Single)	14.4	17.2	12.1	23.3	16.2	10.44*
	Male Headed (monogamous)	75.5	74.2	75.9	62.8	73.0	
	Female Headed	10.1	8.6	12.1	14.0	10.8	

Source: own survey, 2018

Resource ownership

The key resources considered more relevant for livelihoods of smallholder rice farmers are related with land and livestock ownership. Land ownership of households was characterized considering the total land owned, its fragmentation in terms of number of plots owned along with the proportion of land allocated for rice considering the different livelihood pathways followed by the smallholder rice farmers.

The size of total land owned per household was not statistically different across the different livelihood pathways indicating that on average a smallholder farmer owned about 1.2 ha of land (Table 6). On the other hand, there was statistically significant difference in the land fragmentation at household level across the different livelihood pathways. On average, households with diversification livelihood pathway managed more plots of land estimated at 6.34 plots followed by those with non-farm activity pathways with 5.58 average number of plots per household. In terms of the number of plots allocated for rice did not show statistically significant difference among households in the different livelihood pathways. However, the proportion of land allocated for rice from the total land owned showed statistically significant difference with the highest proportion allocated by households with specialization livelihood pathways. The size of livestock owned in term of TLU was found to be different among households in the different livelihood pathways with the highest number of TLU owned on average by households with diversification livelihood pathways (Table 7).

Table 6. Land ownership and land allocation for rice

Livelihood pathway	Indicator	Total land size owned (ha)	Number of plots		Proportion of land allocated for rice
			All crops	Rice	
Specialization pathway	Mean	1.24	4.82	2.65	0.67
	SD	4.17	2.50	1.36	0.28
Diversification pathway	Mean	1.29	6.34	2.69	0.53
	SD	0.65	3.01	1.47	0.27
Non-farm activity pathway	Mean	0.97	5.58	2.67	0.57
	SD	0.65	2.90	1.36	0.27
Hanging-in pathway	Mean	1.06	4.75	2.42	0.62
	SD	0.68	2.39	1.20	0.28
Total	Mean	1.18	5.25	2.62	0.62
	SD	2.84	2.73	1.36	0.28
Mean difference	F-Value	0.41	13.42***	0.97	10.99***

Source: Own survey, 2018

Table 7. Livelihood pathways and livestock ownership in TLU

Livelihood pathway	Mean (TLU)	SD
Specialization pathway	3.93	2.76
Diversification pathway	4.44	2.66
Non-farm activity pathway	3.57	2.35
Hanging-in pathway	3.59	2.55
Total	3.92	2.66
Mean difference (F-value)	3.30***	

Source: Own survey, 2018

Note: TLU – Tropical Livestock Units estimated using Chilonda and Otte (2006)

Access to services

The study considered services like agricultural extension, credit, and cooperative membership for comparison across the livelihood pathways. Statistically significant difference across the households in the different livelihood pathways were observed only for access to extension services. Farmers with diversification livelihood pathway had better access to the service compared to those in the other livelihood pathways. On average, 66% of the respondents had access to credit and about 48% were members of cooperatives having different services like access to inputs (Table 8).

Table 8 Access to extension, credit and cooperative services by livelihood pathways.

Type of service	Livelihood pathways (% of respondents)				Total	Chi-square
	Specialization	Diversification	Non-farm activity	Hanging-in		
Access to extension	72.2	82.1	68.1	74.4	74.0	7.85**
Credit access	62.4	66.2	71.6	72.1	66.4	5.62
Cooperative membership	46.3	46.4	51.3	48.4	47.5	0.97

Source: own survey, 2018

Livelihood pathways and commercial orientation

Overall, an average household in the Fogera plain produced 28 quintals of rice, three quintals of stock from previous harvest, and consumed eight quintals. These figures are different across households in the different livelihood pathways, where on average a household with specialization livelihood pathways produced about 30 quintals, 27 quintals in the diversification, 26 quintals in the non-farm activities and 25 quintals in hanging-in livelihood pathways. On the other hand, households in the diversification livelihood pathways kept more stock of rice from previous harvest compared to households in the other livelihood pathways (Table 9).

Table 9. Rice production and utilization by livelihood pathway

Livelihood pathway	Parameter	Total production in 2017meher season) (q)	Stock before Meher season harvest (q)	Total available stock after 2017 harvest (q)	Amount used for household Consumption (q)
Specialization	Mean	29.86	2.78	32.64	8.22
	SD	19.61	3.95	21.12	6.67
Diversification	Mean	27.54	3.15	30.89	7.75
	SD	19.24	4.13	22.05	7.48
Non-farm activity	Mean	25.95	2.75	28.74	7.90
	SD	16.90	3.39	18.47	7.23
Hanging-in	Mean	24.55	1.78	26.50	7.83
	SD	14.39	2.95	15.77	6.28
Total	Mean	27.81	2.68	30.57	8.00
	SD	18.37	3.76	20.17	6.86
Mean difference	F-value	3.11**	3.33**	3.24**	0.23

Source: Own data, 2018

The amount of rice used for household consumption per year did not show any statistically significant difference among households in the different livelihood pathways and the total amount of rice used per household per year is estimated to be 8 quintals on average (Table 10).

Table 10. Livelihood pathways and commercial orientation of smallholder rice farmers

Livelihood pathway	Distribution		Quantity sold from the total annual stock (kg)		Proportion of volume sold from total available*	
	%	N	Mean	SD	Mean	SD
Specialization	45.2	327	1,043.82	914.76	0.326	0.186
Diversification	20.9	151	859.25	965.16	0.279	0.193
Non-farm activity	16.0	116	947.83	819.48	0.314	0.190
Hanging-in	17.8	129	852.87	717.28	0.310	0.167
Total	100	723	956.10	881.90	0.312	0.185
F-Value			2.28*		2.25*	

Source: own survey 2018
*Note: * indicates stock and production*

The estimated figures indicate that there is statistically significant difference in the total volume of rice sold and proportion of sold from the available stock, where on average households with specialization livelihood pathway sold more volume of rice and also higher proportion from the total rice stock available.

Conclusions

The paper presents the dynamism of the livelihoods in the Fogera plain linked with rice commercialization along with the characteristics of smallholder rice farmers by the different livelihood pathway followed. In general, we found based on over all trends of indicators that there are four major livelihood pathways associated with the production and commercialization of rice in the Fogera plain, which are

- specialization livelihood;
- diversification livelihood;
- non-farm activity livelihood; and
- hanging-in livelihood pathways.

A considerable proportion of smallholders (45%) are in the specialization livelihood pathway. Many of those following the specialization pathway are younger farmers and those who rent-in land, as they intensify their rice production for the market. Those farmers with access to nearby markets, which provide outlets for rice sales and value addition (processing) tend to specialize. However, the specialization pathway may decline in future, as emerging opportunities to access irrigation, credit and other services may enhance the other options, mainly the diversification and non-farm livelihood pathways.

The dynamism in the livelihoods of smallholder rice farmers in the Fogera plain indicates the wider contribution of rice commercialization in provide diverse option of livelihoods for smallholders. With increased demand for rice and the improved investment in production technologies (irrigation, inputs, and mechanization) and value addition (processing and packaging), this contribution is expected to enhance the dynamism of livelihoods for smallholder' farmers, youth and women in the Fogera plain covering both lowlands and uplands.

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EthioRice Project for Enhancing Fogera Rice Research and Training Center

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Introduction

The Project for Functional Enhancement of Fogera National Rice Research and Training Center (EthioRice) was commenced in December 2015 as JICA's cooperation to improve food security in Ethiopia. The Fogera National Rice Research and Training Center (FNRRTC) was established in 2013 by the Ethiopian Institute of Agricultural Research (EIAR) as a research center specialized on rice. The project aims to enhance the capacity of FNRRTC in research, training provision, and information delivery. The project has been supporting FNRRTC to develop its capacity through technical advisors, counterpart training, and provision of equipment and development of research facilities. The project is also a part of JICA initiated continental-wide Coalition for African Rice Development (CARD). This paper introduces the project and its activities since 2015 up to now and planned activities for the remaining period until 2020.

Japanese Cooperation and the Project Formulation

Project formulation

FNRRTC is expected to take responsibilities to provide technical solutions through research and training to those who are involved in rice production and value chain. To realize those responsibilities, the center needs to have functions of

- Grasping issues in rice production and its value chain;
- Conducting researches on selected issues in collaboration with research centers in rice growing areas;
- Delivering technical information for researchers, DAs, farmers, millers and other stakeholders; and
- Capacitating rice researchers, DAs, farmers, millers and other stakeholders on rice related topics in a way well-coordinated and aligned with general agricultural extension and development activities.

EthioRice was designed based on the JICA's experiences in a rice promotion project in Uganda and commenced in December 2015 as a JICA-EIAR technical cooperation project.

EthioRice

Project framework

The project purpose of EthioRice is to enhance the functions of the National Rice Research and Training Center for rice industry development thus contributing to the overall goal, which is expansion of rice farming in and around rice growing areas. This project purpose is realized through activities in three areas: research outputs are adapted, developed, and accumulated for rice industry development; capacities of stakeholders are improved for rice industry development; and appropriate technologies and information become available for rice industry development. EthioRice is planned to last for five years between December 2015 and November 2020 and its main targets are researchers, DAs, farmers, millers and traders in Fogera and other major rice growing areas.

Inputs and JICA's contribution

JICA's technical cooperation projects, in principal, have three major inputs, namely technical advisors, counterpart training, and equipment provision. EthioRice has three long-term advisors stationed in Ethiopia. In addition, some short term advisors in various technical areas are dispatched based upon the project needs. Rice researchers at FNRRTC are EthioRice's counterparts, and a number of candidates selected from them are sent for short and long-term trainings in Japan and third countries. Equipment necessary for enhancing the capacity of the Center in research, training and information delivery are procured, some minor constructions of facilities are supported. In addition, JICA support some local expense necessary to implement the project.

Activities

Personnel allocation

Three long-term advisors in areas of rice research, rice agronomy and training/monitoring are assigned permanently in the project. During the period between December 2015 and November 2018, JICA advisors in 10 disciplines worked with EthioRice (Table1). Short-term advisors were dispatched in extension, civil engineering, gender, participatory research, aagronomy, and plant protection.

Table 1. JICA advisors for EthioRice (December 2015 - November 2018)

Category	Technical area	Period(man-month)
Long-term advisors	Rice research	30
	Rice agronomy	33
	Training/monitoring	39
Short-term advisors	Extension	19
	Civil engineering	1.5
	Gender	3.5
	Participatory research	0.3
	Agronomy	0.3
	Plant protection	1.5
	Training material development	2.0

During the same period, FNRRTC's personnel increased from 14 researchers and 29 supporting staff in December 2015 to 32 researchers and 49 supporting staff as of November 2018.

Capacity building of the counterparts

Several counterpart researchers were exposed to new experiences and information through the project's counterpart training (Table 2). The project has sent 14 researchers to 5 kinds of short training courses, which the training period varies from 1 month to 8 months in Japan. There are currently 6 researchers in Japan, who are pursuing their MSc and PhD degrees in rice related subjects. Four groups have had exchange visits to three countries, where sister JICA projects were operated.

Table 2. Counterpart training programs in Japan (December 2015 – November 2018)

Category	Subject	No. of researchers
Short-term trainings	Development of core agricultural researcher for promotion of rice production in sub-Saharan Africa	4
	Post- Harvest Rice Processing for African Countries	3
	Upland Rice Cultivation, Seed production and Variety Selection Techniques	2
	Rice Quality Variety Development and Variety Maintenance	4
	Empowerment of Rural Women	1
Long-term trainings	Rice Plant Protection, MSc, 2016-2018, Tokyo University of Agriculture	1
	Rice Agronomy, MSc, 2016-2018, Tokyo University of Agriculture	1
	Rice Breeding, PhD, 2016-2019, Hirosaki University	1
	Crop Protection, PhD, 2017-2020, Kobe University	1
	Agricultural Machinery Engineering, MSc, 2018-2020, Yamagata University	1
	Rice Agronomy, MSc, 2018-2020, Iwate University	1
Technical exchange visits	Rice research and training, PRiDe in Uganda	5
	Weeder development, PAPRIZ in Madagascar	2
	Rice training and management, TanRice2 in Tanzania	6
	Rice research and training, PRiDe in Uganda	4

Availing Equipment

A large part of the project budget went to equipment (Table 3). Total of 144 items of equipment with total value of 65.6 million Yen (approx. 16.7 million Birr) have been procured by the project for research and center management purpose.

Table 3. EthioRice funded equipment procurement (December 2015 – November 2018)

Category	No. of items (major items)	Total value (Birr in Million)
Vehicles	6 (bus, pickups, station wagons)	6.7
Agricultural machineries	3 (tractor, etc.)	1.1
Laboratory equipment	92 (microscope, balance, etc.)	5.8
Others	43 (generators, computers, etc.,)	3.1

Facility construction

While Ethiopian Government, through KR2 counterpart fund, is financing the construction of FNRRTC complex, the project funded some basic infrastructure development (Table 4). One machinery shed and two laboratories were completed and started serving for their purpose. One borehole for the planned irrigated experimental field was completed. With the joint facilitation of EthioRice and EIAR, A borehole for the campus has been worked by Ethiopian Water Technology Institute (EWTI), which is incomplete and behind the schedule. As of January 2019, contraction work of irrigated experimental field of 2ha has started.

Table 4. EthioRice funded constructions (December 2015 – November 2018)

Item		Total cost (Birr in million)
Laboratory modifications	Two laboratories were modified, and basic equipment installed.	0.35
Borehole for buildings	Drilling in collaboration with EWTI underway.	0.34
Irrigated experimental field	Construction of access road, irrigation systems, paddy field, borehole and reservoir tank underway.	19.89
Machinery shed	Completed (partial cost provision)	0.25

Activities related to researchers' capacity development

Research activities

Apart from government and development partner funded activities at FNRRTC, the project has planned and conducted some research and survey activities (Table 5). Topics are limited to basic ones to supplement and support ongoing research conducted by Ethiopian researchers.

Table 5. Research related activities (December 2015 – November 2018)

Topic	Contents	Status
Improvement of variety maintenance	Establish variety management practice under irrigated condition, line cultivation, quality control, storage, dedicated field management, development of manual.	Ongoing
Improvement of seed production management	Improve management practices and development of manual	Ongoing
Improvement of direct sawing practices	Test different types of production practices such as weeders under semi-aquatic condition.	Suspended
Cold weather damage	Collect basic information of Fogera rice production conditions.	Completed
Dry season rice in lake shore	Test potential of rice production in dry season.	Suspended
Flood level survey	Collect basic information of Fogera rice production conditions.	Completed
Monthly planting	Test plant growth at different seasons. The field is used for training.	Ongoing
Effect of seed and field condition on germination and plant establishment	Test germination and plant establishment with different conditions of seed and field.	Ongoing
Improvement of rice research protocol	Improve detailed protocol, development guideline and training materials.	Ongoing
Development of rapid on spot yield survey method	Develop and test survey tools (suspended)	Suspended
Improvement of field day	Improve field day planning and implementation.	Ongoing
Informal seed system	Survey informal seed system and test some intervention.	Ongoing
Survey of millers	Survey millers in Fogera and identify research issues.	Ongoing
Highland rainfed rice production (with SATREPS)	A part of the SATREPS research by Bahir Dar and Tottori University on rice production and land resource management under highland rainfed condition.	Ongoing
Appropriateness testing of introduced equipment	Test equipment mainly introduced from Japan.	Ongoing

Workshops, trainings and seminars

Several workshops, trainings, and seminars were conducted in collaboration with EIAR and/or FNRRTC mainly to enhance the capacity of researchers at FNRRTC (Table 6). Some workshops included researchers from other research centers. Some DAs and farmers from Fogera participated in a few workshops.

Table 6. EthioRice funded workshops, training and seminars (December 2015 – November 2018)

Category	Subject	Target/participants	No. of activities	No. of participants
Trainings	Participatory approach	Researchers	2	28
	Quality seedlings	Researchers, DAs and farmers	2	10
	Scientific paper reading and discussions	Researchers	8	24
	Operation and maintenance of research equipment	Researchers	Whenever necessary	
	Training material development	Researchers	On-going	
	Hands on training on various subject	Researchers	At any time	
Workshops	Gender in Rice Research	Researchers	4	71
	Rice farming practices in Fogera	Researchers, DAs and farmers	3	109
Seminars	Participatory research (launching FRG book)	Researchers, administrators, development partners	1	60
	Seminar on Gender and Rice Research	Researchers	1	58
	Seminar on Agricultural machinery	Agricultural officers, DAs, farmers	1	79
	Activity and challenge in EthioRice	Researchers	1	6

Other activities

Discussion for developing a concept of FNRRTC's training program along with developing a training curriculum and materials has started. Improving operation and maintenance of laboratories, agricultural machineries and irrigated experimental field have been progressing through establishment of different committees.

Changes in human and physical resources of FNRRTC

FNRRTC, which officially established by EIAR in 2013, was still operating at temporary offices rented from the Woreta Agricultural College with 8 ha trial fields transferred from the Adet Agricultural Research Center. The trial field had no irrigation facilities, access roads, and drainage. Construction of the FNRRTC buildings using the KRII counterpart fund was continuing, which delayed significantly from its initial schedule. As of November 2018, FNRRTC's building construction was near completion with remaining works for electricity and water supplies. The center's buildings included administration, research, and laboratory, training hall, canteen, general store, seed store, machinery workshop, guest house, dormitory and staff quarters. The trial fields expanded to 18 ha with a borehole, which would supply water to the irrigated trial plots of 1.6 ha under construction.

While the center had 14 researchers in 7 disciplines in December 2015 when EthioRice commenced, the number increased to 35 in 9 disciplines in November 2018. Higher degree holders also increase from 1 PhD and 7 MSc in 2015 to 2 PhD and 18 MSc in 2018.

EthioRice's Fogera office, together with FNRRTC, moved to newly constructed administration building in August 2016 and the researchers started moved to the research and laboratory building from October 2016. Along with the increment of human and physical resources of the Fogera center, EthioRice supported capacity building on management of facilities and equipment, development of rule and regulations along with researchers' capacity development through on-the-job training.

Challenges

There were three major challenges EthioRice has been facing. Firstly, a majority of the planned construction and research related activities was affected by security situation particularly in part of 2016 and 2017. Secondly, JICA advisors were not allowed to visit Bahir Dar in considerable period at different times. Thirdly, JICA had an acute budget shortage in the 2018 fiscal year and the project's budget had to be cut by 40%. Thirdly, all the construction works have been much delaying and some of the construction outputs have problems of low quality.

Because of the above challenges, several planned short-term advisors were cancelled and some of the planned activities related to research, facility improvement, visit to rice growing areas among others were not carried out. The planned construction work of the irrigated experimental field was not able to start, except a small part of the access roads, which affected much on a number of intended researches related activities.

Way forward

EthioRice has completed about three fifth of its project period. Security situation with travel ban to Bahir Dar imposed on JICA personnel and the delay of the construction of FNRRTC complex coupled with JICA's budget shortage have significantly affected EthioRice's activity. The delay of the irrigated experimental filed had serious consequence on planned capacity building of FNRRTC's research and training functions. However, some basic equipment was availed and a considerable number of researchers were sent for training. The center's training concept has been developed and trial-training programs are being implemented while the center will continue gradual improvement of research capacity.

The completion of the irrigated experimental field will enable the center conducting research activities under controlled ways, covering wider research topics including operation and maintenance of irrigation facilities. The development of the FNRRTC training concept will be finalized and agreed with EIAR management for while trial-training programs are implemented. Developing the capacity of FNRRTC the operation and maintenance systems for laboratories, irrigation facilities, and agricultural machineries is in place for further improvement. FNRRTC's operation models in major rice growing areas need to be discussed, which require close collaboration with the Ministry of Agriculture and development partners such as AfricaRice.

Experiences of MEDA in Rice Promotion in South Gondar Zone

Mekuria Yimer
MEDA, Bahir Dar, Ethiopia

Background

MEDA (Mennonite Economic Development Associates) is a Canadian based international NGO with more than sixty years of experience in international development. MEDA's motto is "creating business solutions to poverty". MEDA is registered and licensed as a Foreign Charity by the ChSA (Charities and Societies Agency) under Ethiopian law of proclamation number 621/2009.

Since 2011 for five consecutive years, MEDA has been working on rice value chain in Fogera and Libokemkem woredas of South Gondar Zone of the Amhara region, through EDGET Project (which stands for Ethiopians Driving Growth through Entrepreneur and Trade). EDGET project has accomplished many activities to increase income of 6536 households of which some of the important intervention includes; increasing productivity through implementing improved agricultural practices, strengthening market linkages, value addition, creating access for affordable environment friendly technologies and financial support, organizing trainings, field days, workshops, platforms and forums.

In the first phase of the project, producer's productivity has been increased from the baseline collected data 43 q/ha to 51q/ha (18%) for broadcasting and 25% yield increment recorded for row planting practice compared to the same production year. Factors contributing for yield growth are the capacity building training provided to government agents and producers, use of cleaned seed, practicing pre-germination, row planting, weeding and fertilizer application. Moreover, Area coverage on upland areas is significantly increasing from year to year.

The continuous discussions, workshops, forums, experience sharing, trade fairs and platforms facilitated helped processors and producers to identify limitations and get involved to take corrective measures. Accordingly, producers have started sorting out to reduce mix of varieties, harvesting at the right time and threshing on canvas. From the processors side to motivate producers to supply quality paddy, processors have incentivised producers with additional payments and price discount.

To strengthen the market linkage between producers and processors marketing groups were organized in each locality following all weather roads. These marketing groups take the responsibility to collect quality paddy taking in to account moisture content that ranges 11-14% and mix of varieties is not greater than five per cent. As marketing groups reported equivalent to one truck amount paddy is collected, processors went to the area to check if parameters are satisfied and quality standard is met. When requirements are attained processors pay additional payments; and when it is below the set standard will not pay the incentive. The challenge between processors and wholesalers were poor quality, which appears during processing, varying weight than the pack size and packing only in 100kg size. To improve market linkage between processors and wholesalers they agreed to use labelled pack (name, telephone number, specific address, grain amount) in different sizes.

In the value addition practice, parboiling has been started using the locally manufactured machines. Parboiling has been introduced by SG2000 for Quhar Women Association. However, the business was limited to the local condition and was not extended. With the support of EDGET, the machines were manufactured with cost sharing and distributed to Micro, Small and Medium Enterprises (MSMEs). Market linkage was created for parboilers with Addis Ababa and Bahir Dar traders and to promote the product, price discount was arranged.

After the price discount stopped more of the parboiling business ceased out, however some persons continued the business. The critical challenges facing the parboilers include not limited to; smaller capacity of the parboiling machine, longer time taking to steam, and power leakage during steaming, inconvenience to upload the steamed rice and poor drying mechanism.

Different technologies were introduced and distributed through cost sharing approaches for producers and MSMEs. Some of the technologies include; tractors for multipurpose farmers cooperatives, weeders for producers; harvesters for producers, cooperatives and processors, processing machines for processors and cooperatives, grading machines for processors, moisture testers for processors s and plastic storage bags for producers.

Some of the technologies like grading machine, moisture tester, processing machines and plastic bags are successfully underuse. Other technologies have the following drawback; weeders are not effective due to poor soil preparation and in appropriate spacing for row planting, pin breakage for harvesters, working space unavailability for some of the processing machines and miss use of tractors.

The second phase of MEDA is working through the EMERTA project (which stands for Ethiopians Motivating Enterprises to Rise in Trade and Agri-business and means 'to leap to great heights' in Amharic) aims to run from 2017 to 2022 with the objective of contributing to increase income and employment opportunities for 16,000 women and men producers and 275 MSMEs. In addition to rice, EMERTA project is working on vegetable and gemstone and the geographic focus of the project for rice is Amhara region, South Gondar zone, Dera, Fogera and Libokemkem woredas. However, the market systems extend well beyond the region's boundaries.

Goal and objectives of the Project

Improved incomes and employment for 8880 working in rice women (25%) and men (75%), largely in Amhara and 152 MSMEs working in rice, with a focus on women. The project envisions achieving its objective through enhancing improved practices, facilitating market linkage, improving access to finance, promoting appropriate and affordable technologies and other supporting services. The specific objective includes

- To improve the business performance of rice producers, particularly women, to compete in the market;
- To improve the business performance of MSMEs, particularly women led, engaged in rice, trading and processing, for stronger market linkages;
- To create improved gender -sensitive business environment for fostering growth of rice producers and MSMEs; and
- To promote the use and application of environmentally friendly technologies in rice production and marketing by the different market actors.

Strategy

The Project is not directly involved in the implementation of activities, it plays support and facilitation role. Implementation of activities is the responsibility of stakeholders, partners, MSMEs, and producers. Hence, the project intends to achieve its objective through enhancing improved practices, facilitating market linkage, improving access to finance, promoting appropriate and affordable technologies, and other supporting services.

Major Accomplishments

The project has identified the rice sector constraints by the survey conducted on the value chain and market analysis. Below is a series of issues that affect the capacity of farmers and MSMEs (women and men) to maximize the benefit they gain from the rice sector.

- Weak agronomic practices persist among farmers;
- Development Agents (DAs) mandated to support farmers frequently lack knowledge about rice;
- No commercial seed system for rice exists. Research institutes develop promising varieties but there is no way to bring these to market;
- Both women and men report constraints on their time and labour, but appropriate environmentally sustainable technologies are not commercially available;
- Farmers prefer to store rice after harvest and sell quantities, as they need cash. Inadequate storage reduces quality and leads to high losses;
- Most processors use multi-purpose processing machines that produce a low-quality product. Waste or by-products are not reused;

- Production of table grade and parboiled rice products is very limited and market recognition and demand for these products is underdeveloped;; and
- Financial institutions are reluctant to lend to informal MSMEs. Therefore, aggregators/traders, processors, wholesalers and retailers lack access to finance.

To address the above-mentioned constraints of the rice sector, activities are under implementation partnering with stakeholders. Major activities so far implemented are explained under five main categories which are; stakeholders and beneficiaries oriented to the project, strong market linkages to MSMEs, value chain actors have improved access to financial services, coordination and Networking with stakeholders and, capacity building of beneficiaries, stakeholders and project staffs.

Stakeholders and beneficiaries oriented to the Project

Regional launching workshop conducted

Regional project launching workshop was conducted in 2017 with the presence of 25 (female1) participants pulled from governmental and non-governmental organizations, private sectors and the value chain actors. The presentation was delivered on the goal and objective, major sectoral constraints and interventions, the project focus and its approach. After presentation, pertinent questions like project geographic area, physical plan and budget distribution by project woredas and extent of flexibility were raised and discussed satisfactorily.

Plan orientation and awareness creation workshops conducted

In the last two years the sector has conducted plan orientation and project implementation approach awareness creation workshops one in each year. Participants were brought from different sectors which include service provider organizations, non-governmental organizations, business operator's, development agents, woreda agricultural experts, woreda trade and market development experts and kebele administrators to familiarise with project beneficiaries' selection procedures.

In the event 132 (29 female) participants are involved. As an introduction, there was a presentation which comprises of goal and objective, theory of change for rice, the project focus and its approach, the 2017 and 2018 annual work plan activities under each category. The participants discussed the topics listed below, among other planned activities.

- Lack of improved rice varieties: producers need improved varieties with high productivity and disease resistance ;
- Greater market competition for local market due to imported rice: It was discussed that rice processors need to improve processing quality; and
- Improved technology use: participants appreciated the project for the arrangement of training on the operation and maintenance of rice processing machines. However, it was strongly mentioned about the importance of improved processing technology, row makers, planters, weeders and harvesting technologies to lessen the labour and time constraints.

In each year, agreed annual plans are produced after a thorough discussion with value chain actors and support giving governmental organizations.

Client MSMEs and producer's selection facilitated

In the first year of the project a 40 MSMEs, of which (2 female), were selected for business development support. For the same support, 30 MSMES were selected in the second year. The selection was done with the involvement of woreda trade industry and market development office and TVED experts. The selected MSMEs included 12 processors, 12 wholesalers, 8 aggregators, 2 parboilers, 1 distributor and 5 retailers. MSMEs were selected based on the linkage with producers, interest and willingness to work with the project modality and potential in reaching to more producers.

In the plan orientation workshop access to finance, technology unavailability, low business skill, marketing system dominated by brokers and poor quality are identified as major constraints. In addition, for each constraint, possible solutions are suggested, and responsible institutions to act are identified.

Target kebeles are selected with woreda office of agriculture taking in to account potential of the kebele for rice production, access to market and road, availability of Farmers Training Centers (FTCs) with demonstration plot and other related facilities required to conduct training and demonstration, presence of farmer's multipurpose cooperative working on rice processing and/or trading. Hence, 27 kebeles are targeted; 3 for Dera, 10 for Fogera and 14 for Libokemkem.

From the 27 targeted kebeles, DAs, Kebele administrators and woreda experts have selected beneficiary producers. Thus, a total 890 (Female 96) producers in the first year and 1,780 (398 female) rice producers are selected and registered as project client.

The producers are selected based on availability of suitable land for rice production at least 0.5 and 0.125 hectares for men and women, respectively. Volunteer to use inputs and technologies, apply extension advices, willing to work with the project modality, willing to learn from others and share experiences, farmers with common interest to be clustered and production purpose dominantly for commercial. On the other hand, producer who are getting similar support by other projects are not targeted; as a guiding tool both women and men producers are considered with a special focus for women.

Strong market linkages to micro, small and medium enterprises

Trade fairs and food taste events organized to promote rice and create market linkages

Rice traders have been supported to participate in trade fairs, bazaars and expose facilitated in Bahir Dar and Addis Ababa to promote their products and create market linkages.

Events organized at Bahir Dar

In a trade fair organized at Bahir Dar from April 2 to 12, 2017, three private business owners and one cooperative have participated. They displayed white milled rice, red and white parboiled rice. In this event buyers became aware through the explanation, brochures and banners made available by participants, so that consumers developed positive attitudes. Sellers have accumulated knowledge in marketing skills and linked with buyers. The event created an opportunity to sell 948 kg rice.

"Eat Ethiopian Rice'' event has been organized in Bahir Dar from Nov 30/2018 to Dec 2/2018 to create access for consumers to taste rice food. Parboiled brown and white rice meal was prepared with a variety of vegetables, tasty soya and other food spices. Then the nicely cooked rice food displayed and has been tasted by about 400 visitors. Awareness created for visitors about the product, health benefit, and cooking instructions using brochures and oral explanation by the chef and EMERTA rice team. Visitors who have chance to taste the rice food had indicated their interest by buying the rice on the bazar.

Two rice traders and one primary cooperative participated in food and beverage exhibition at Bahir Dar facilitated from January15-21, 2017. A total of 620 kg of both parboiled and white milled rice displayed and sold to exhibition participants. In the same event, food taste was organized in partnership with Blue Jayze restaurant; 75kg red brown and white parboiled rice prepared in different types of meals visited and tasted by 2400 Participants (Table 1).

Table 1: Food and beverage exhibition participants and amount of rice sold

Enterprise	Business type	Rice product exhibited	Amount sold (exhibited) (kg)
Yifag cooperative	Rice aggregator	White milled rice	260
Bereket rice	Parboiler	Parboiled rice	360
Blue Jayze cafe and restaurant	cafe and restaurant	Rice food for taste	75

Source: EMERTA project 2017 second quarter report

In an exhibition organized by Amhara National Regional State Cooperative Promotion Agency held at Bahir Dar from April 11-18,2018, one private rice trader (parboilers) and one primary farmers cooperative were supported and displayed table grade white rice and parboiled red and white rice. The cooperative sold 500kg of white table grade and the parboilers 400kg of parboiled rice within three days. The cooperative and parboiled rice traders were able to promote their product to consumers/buyers, generate more revenue, and create a linkage with potential buyers. Similarly, customers/buyers were interested to see improved quality local rice with a value addition. The trade fair participants distributed more than 2,000 business cards to be connected with customers (Table 2).

Table 2: Trade fair participants and amount of rice sold

Enterprise	Type of business	Rice product exhibited	Amount sold (kg)
Quhar cooperative	Rice Aggregator	White milled rice	500
Seid Parboiling business	Rice parboiler	White and red parboiled rice	400
Total			**900**

Source: EMERTA project 2018 second quarter report

In Addis Ababa

One trader has participated in the Easter trade faire conducted April 11-15th, 2017 in Addis Ababa. He has displayed 200 kg of white and brown parboiled rice 100 kg from each. The product has been planned to be displayed for 5 days, however sold in a day. 1260 visitors had visited the product and almost all of them were individual consumers. In the event brochures, banners and leaflets that comprises information on the nutrition content, food preparation procedures and health related values are distributed.

On the occasion, the trader has identified potential business actors and individual customers, awareness created for 1260 visitors on the importance of local parboiled rice, important feedbacks and market information collected from traders and customers. More importantly, he communicated 12 supermarkets for further linkage.

"Grand Trade Fair and Easter Expo'' that took place from 17th March to 7th April 2018 was organized by Century Promotion and Entertainment at Addis Ababa Exhibition centre. In this event, two rice parboilers have displayed and sold 14 quintals of red and white parboiled rice to the expo within 5 days earlier than the anticipated time. The white parboiled product has a high demand by the customers and buyers were interested to pay the selling price. Exhibition participants explained their interest and demand for parboiled rice if it becomes available in the Addis market. Some customers buy in small amounts and showed interest to buy again in bulk amounts. Some buyers advised the sellers to improve the quality of parboiled red rice, create market linkages for consistent supply, to use better packaging material with proper label and specification.

Assessment conducted to study the benefit of selling paddy over milled rice

The Project has conducted an assessment to study the benefit of selling paddy over milled rice. The prevailing traditional market system that exists among the producers and processors, producers are forced to sell their milled rice in a place where they get processing service; there is no room to sell it to others because there is no competition among millers/processors.

Ownership is transferred after the paddy rice is milled and delivered to the processor and producers believed that some of grains have gone with by-product while milling; this creates lack of trust between producers and processors.

Processors and producers explained that there is no standard for paddy rice quality measurement. Nevertheless, with common understanding among producers and processors there is a trend of categorizing the quality in to two categories; namely high and low quality. From this subjective quality parameters, if the quality of the paddy rice is taken as good the producers are not interested to sell in the form of paddy, rather prefer to sell in milled form and the opposite is true for the processors. The reason behind farmers are not selling in the form of paddy is that processors are not paying fair price rather they set lower price for paddy.

This assessment further showed that there is imperfection in the existing paddy marketing system due to concentrated market power on traders or processors. That is why; producers are forced by processors to sell in the form of milled rice to get by product together with some grain part than purchasing paddy because of price difference. This traditional marketing system is not motivating producers to improve quality.

Market opportunities assessment conducted to facilitate business linkages

Processors and cooperatives for further formal business linkage supported by contract agreement identify Rice producers who have better relation and experienced in delivering quality paddy to the rice processors and multipurpose farmers cooperatives. Thus, 250 producers are selected of which 120 by processors each 10, and 3 multipurpose farmer's cooperatives have selected 130 producers. In addition, to link processors with sustainable buyers, 11 Wholesalers, 5 retailers, 10 supermarkets and 2 trading business corporation public enterprises are identified in five market outlets (Bahir Dar, Gondar, Addis Ababa, Dessie and Woldia).

Wholesalers, supermarkets and trading business corporation public enterprises have indicated their interest to involve in the rice business provided that the product is clean free from sand, dust and other particles, graded and labelled, the supply is consistent, price is acceptable and properly weighted in different sizes. Formerly the imported rice was unbroken for table grade rice, however these days high volume of broken rice is imported from India and Pakistan to mix with tef flour to produce enjera, which is highly competitive in terms of price and quality for the country produce rice which can be taken as an emerging serious challenge.

Wholesalers, trading business corporations and public enterprises based in Addis Ababa have seen the supply of domestic rice as a good opportunity to make best use of the local rice as they are facing hard currency access to import rice from abroad and rate of using rice by Ethiopians is increasing at increasing rate. Moreover, traders and consumers are appreciating local rice food taste compared to the imported rice.

To create and strengthen business-to-business market linkage in the sector, contract agreements have been signed between processors and potential buyers. Accordingly, 18 rice processers have signed a contract agreement with 8 whole sellers to supply quality rice with payment of a premium price Birr 50 to the processors.

As the result of the backward and forward contract market linkage and the proceeding workshop, rice processors have started working to improve the quality of rice. The measures include; some of them have improved their warehouse capacity, they have distributed grain bags for producers, they have distributed canvas to producers to keep the produce clean and some provide financial support to producers to increase their purchase volume. Based on the agreement, producers have supplied 2011 quintals quality paddy rice to the processors. In turn, three rice processers have supplied 1154 quintals of milled rice for the whole sellers with acceptable quality and price.

Forum organized for rice processors and aggregators

Market linkage forum has been organized for 37 (3 females) processors and aggregators at Woreta on the 25^{th} of December 2018 to improve the supply of quality paddy rice. Challenges and proposed solutions suggested by the forum are explained in Table 3.

Table 3: Major challenges discussed at rice processors and aggregators forum

Challenge	Solution
Processors side	
Lack of improved quality paddy rice supply with reasonable price	- Target, link and capacitate potential aggregators on the importance of quality paddy supply and fair benefit distribution
Aggregators side	
Marketing skill gaps (such as quality and marketing strategy of paddy rice)	Facilitate contract agreement between aggregators and processors to improve quality paddy supply and increase the purchase volume Capacitate aggregators on marketing skill, market information, quality parameters, and improved storage practices.
Market information gaps to purchase with reasonable price	- Aggregators will be targeted by EMERTA project and linked with processors
Financial shortage to purchase more paddy	Link with financial institutions Develop a strategy that processors can supply the required amount of money Arrange modalities processors can collect from kebeles
Purchasing low quality paddy	
Hoarding for long period of time to seek high price	
High transportation cost from kebele to woreda town	

Source: EMERTA project 2018 first quarter report

The processors and aggregators agreed to create a market linkage among them to improve the supply of quality paddy rice.

Rice processors supported to develop common brand

Currently, large volume of rice is produced in the project areas of Dera, Fogera and Libokemkem woredas of South Gondar Zone, Amhara Region. The production volume is growing from year to year. Through the continuous support provided by MEDA and another partners quality is improving. Moreover, MSME's started value additions which include packing in various sizes, labelling and parboiling.

However, local rice is not recognized by large number of population due to low promotional activities and weak integration among stakeholders. Consequently, not all value chain actors are benefiting, and possibility of import substitution is not addressed, instead, even broken rice used to make enjera is imported. Promotion is important to aware the large population and create market access about the local rice. To promote a product or service it will be easier if the product is branded. In such a situation to increase the competitiveness and promote the Amhara rice brand is important for the following reasons

- To enable business actors to increase customer's loyalty for that specific brand;
- To Rise the bargaining power of the actors entering in to the business;
- Decrease the marketing cost due to share of labelling and packaging costs, to create access for financial services, technical support and consultancy services; and
- To protect consumers against misleading practices and resolve challenges associated with small size and entry to the market.

With this context, draft document has been produced for further discussion to develop a common brand for rice processors with the objective of building market recognition of the local rice. Rice processors have indicated their interest to organize themselves in processor association to own collective trademark. Following their interest, MEDA's EMERTA project has organized workshop to support the formation of rice processors association for developing collective trademark that helps to promote the local rice get wider recognition among consumers/buyers. Participants were 35 (Females 9), of which 15 were rice processors (4 Female) and 20 were from stakeholders (5 Female).

From the workshop participants BoTIMD, Amhara Intellectual Property Office (AIPO), and Conformity Assessment Enterprise (CAE) have made presentations. These organizations were selected as the lead for their mandate and support role for licensing the businesses, registering trademarks and preparing national rice grade and standard respectively.

From the BoTIMD workshop presentation, clarity has been gained on the alternative legal requirements to form processors association. One of the options is sectoral association that enables the association to resolve common problems such as lack of working space, electric power, transformer and the like. However, such associations have no legal right to own collective trademarks. With this understanding, 16 rice processors from Woreta Town are organized in sectoral association.

The second option is to organize processors association based on requirements of commercial trade law as a legal entity of any form (Share Company (S.C) and Private Limited Company (PLC) In this case, the association is authorized to own collective trademarks. After discussion, processors have agreed to organize themselves in Share Company to own common brand. Besides, BOTIMD has promised to support the rice processors to facilitate the association formation in two months' time.

Prepared to execute "Eat Ethiopian Rice" marketing campaign

Large volume of rice is being produced in the project areas of Dera, Fogera and Libokemkem Woredas of South Gondar Zone, Amhara region. Regardless of the large volume of production, the demand for local table rice is very low, market recognition is yet challenging even for improved quality table grade rice to enter into the market. This is due to lack of brand image of the product and inconsistent supply of the product to motivate the latent demand of local rice. Furthermore, consumers' awareness of the availability of local table grade rice is low.

To solve those challenges, the project together with BoTIMD has organized the first of its type ''Eat Ethiopian Rice'' marketing campaign event in Bahir Dar town for three consecutive days from Nov.30/2018 to Dec.2/2018. The Marketing Campaign was organized with the moto of "Eat Ethiopian Rice." With the objective of increasing the visibility and recognition of local rice among the large public.

To create longer time opportunity for the population to hear about the event, the event organizer has used outdoor promotion and mass media (Amhara TV and FM radio) broadcasting for announcing. To give more colour for the event and provide information for marketing campaign visitors; each displayer has posted banners at their display booth gates, distributed business cards and leaflets to promote their product.

Marketing campaign discussion panel

To give brief highlight about the objectives and importance of this marketing event; in the first day, discussion panel was facilitated at Bahir Dar for half day with the participation of rice value chain actors and respective government and Non-government organizations to create room for visitors acquire information about the local rice.

Challenges

- Problems to access working space for the new introduced processing machine;
- Weak market information and illegal market through brokers;
- Rice seed not included in the region;
- Shortage of technology suppliers or manufacturers; and
- Less attention for quality rice production and processing

Lessons

- Engagement of men and women side by side in trainings, workshops, linkages enhanced applicability of improved practices;
- Seed multiplication and marketing unions commitment to solve seed problem;
- Organizing rice processors in association and efforts done for branding is encouraging;
- Implementation of forward contract marketing agreement on paddy rice;
- The existence of suitable agro-ecologies for rice;
- Compatibility of rice with the local farming systems;
- High productivity as compared to other crops; and
- Increased trend of rice consumption

Food taste and marketing campaign event conducted

Following the panel discussion, the next activity carried out was to open food taste and marketing campaign event officially. The panel discussion participants visited products displayed by different rice processors, financial service providers, technology manufacturers, and FNRRTC

4.4 Coordination and Networking with Stakeholders

Consultative meetings facilitated

The consultative meeting has been organized with the objective of reinforcing stronger links between and among actors in the sector. Consultative meeting is an opportunity for stakeholders to deliver insight and feedback to the project team, liaise with others in the sector, share information on good practices and lessons learned, respond to project information, review project progress and discuss on key planned activities.

With this idea, two consultative meetings are conducted, the first consultative meeting has been facilitated on the 30th of June 2017 in the presence of 24 (Female2) participants drawn from service provider organizations, NGO's and private business actors. After the presentation, discussion has been facilitated to identify participants area of involvement they will be responsible. Thus; rice grain forward contract marketing system development was given to BoTIMD, Agriculture office, Processors and MEDA; private seed sector development to Agriculture office, Fogera National Rice Research and Training Center (FNRRTC), Producers, MEDA; Development of common branding to BoTIMD, Processors, MEDA; and utilization of financial products arranged by MEDA to Processors, MEDA, BIB. Accordingly, activities are under implementation.

The second sectorial consultative meeting was organized 0n 20th of July 2018 to share responsibility to support the introduction and dissemination of technologies that converts rice husk in to energy sources and how to expand the use of rice parboiling technology by the use group. Participants were 40(females 8) pulled from bureau of trade and market development, agriculture, technical and vocational enterprise development (TVED), youths and finance and economic cooperation. The workshop finalized by sharing responsibility, TVED has indicated strong commitment to select and organize the use group, to avail working space, to construct the shade and to facilitate electric power. MEDA is working to secure technologies; briquette manufacturing and parboiling machines.

Trial and demonstration conducted on improved rice varieties

Partnership has been created and contract agreement signed between EMERTA project and FNRRC to conduct rice trials and demonstration at farmers and FTC field levels. The four improved rice varieties released by FNRRTC are tested for their adaptability, productivity, yielding capacity, early maturity and other climatic required characteristics at 15 farmers and four FTCs. The varieties tested are *Shaga, Abay, Rib and Wanzaye* with the local check.

Performance evaluation conducted on improved rice seed varieties

Field days were organized from end of October to mid of November 2018 to evaluate the performance of the varieties. In the evaluation process, 314 (females 24) farmers and stake holders are involved to select the best performed varieties using (PVS) participatory Varity selection approach. As the result of this event, Shaga and Wanzaye rice varieties are selected for further scale-up in the lowlands.

To Scale-up the selected varieties FNRRTC has organized two days' work shop. In the work shop,79 (6 females) producers and 38 agricultural experts from Dera, Fogera and Libokemkem Woredas participated. As a result, 70 farmers are selected to popularize the new rice varieties and FNRRTC distributed 37.7 quintals of improved rice seed to the selected farmers (Table 4). A detail action plan has been developed for intensive follow-up to ensure farmers follow recommended agricultural practices and succeeded in the seed production

Table 4: Variety popularization workshop participants

Description of participants	Dera Woreda		Fogera woreda		Libokemkem		Total		
	Male	Female	Male	Female	Male	Female	Male	Female	Total
Producers	14	0	31	1	32	1	77	2	79
Agricultural experts	5	1	19	1	10	2	34	4	38
Total	19	1	50	2	42	3	111	6	117

Source: EMERTA project 2018 second quarter report

Learning opportunity created through radio broadcasting for rice producers

MEDA created partnership with Farm Radio International (FRI) and has signed a contract to disseminate good agricultural practices, quality improvement considerations and market information for rice producers and MSMEs through local radio programs.

The purpose of the program is to increase the knowledge and awareness level of the target listeners on market-focused production, implementing recommended agricultural practices, gender concepts and climate smart agricultural approaches, etc. As a continuation, FRI has made an agreement with Amhara Mass Media Agency FM Bahir Dar Radio 96.9 for transmitting the learning messages.

FRI organized a workshop for content development involving Agriculture office, Research Centres, Farmers and FM Bahir Dar Radio 96.9MEDA experts. FRI in collaboration with MEDA has developed the content of a radio program. The developed content broadcast commenced on the 30^{th} of May 2018. The program is produced and aired by Amhara Mass Media Agency on Bahir Dar FM 96.9 Radio.

The radio-learning message is prepared interviewing producers, extension workers, the research experts and MEDA staff. The program is being broadcasted twice a week, every Wednesday and Sunday from 1:30-2:00 in the evening and 2:30-3:00 evening (Ethiopian time), respectively. The Wednesday program is a repeat on the Sunday to give chance for those who missed the first day and maximize attending.

Capacity building

Good agricultural practice training provided to development agents and producers

To build the capacity of the Amhara Region Bureau of Agriculture, 106 development agents (21 female) and 15 woreda office experts received TOT on rice and vegetable climate-smart, environment friendly agricultural practices, and active engagement of women producers in the month of June 2017. The rice production training was provided by FNRRTC focusing on Good Agricultural Practices (*GAP)*, which includes land preparation, planting methods, use of clean seed, crop rotation, proper type and amount of input use and varietal characteristics (Table 5).

The 2017 trained agricultural development extension agents cascaded this training to 890 (Female 96) rice producers. The training evaluation indicates that farmers' knowledge on good agricultural practices has increased and they have improved their skills on recommended agricultural practices. Similarly, in 2018 the trained 216 development agents has cascaded this training to 1675 (Female 885) producers in June 2018.

Table 5: Number of GAP trainee development agents and producers

Description of trainees	Dera		Fogera		Libokemkem		Total		
	M	F	M	F	M	F	M	F	Total
2017 Accomplishment									
TOT trained DAs							106	15	121
GAP trained farmers							794	96	890
Sub total							903	108	1011
2018 Accomplishment									
TOT trained DAs	21	3	38	4	45	5	104	12	116
GAP trained farmers	190	241	328	339	272	305	790	885	1675
Total	211	244	366	343	317	310	894	897	1791

Source: EMERTA project 2017 and 2018 second quarter report

Rice post-harvest management capacity building training has been given for rice producers and government development agents up-on the contract made in partner with

FNRRTC in the month of November 2018. This training was delivered with the objectives of improving the skill of rice producers on post-harvest management practices and introducing harvesting and post-harvest technologies to improve the quality of rice, reduce their time, and labor during harvesting and threshing. Thus, 525 rice producers (females 77) and 110 Development Agents (females 21) are trained. In the training, different harvesting and post-harvesting technologies such as harvester, threshers, storage facilities and milling machine were demonstrated. In the event trainees have suggested comments that the harvester technology is good and express their feeling to own the technology if some of the defects are improved. However, they were not convinced on the threshing technology since its working efficiency was low, it has no the capacity to separate the grain from the straw and dispersing the straw everywhere.

Record keeping and customer handling training provided for MSMES

Financial record keeping and customer handling training was organized from 24-28th of October 2018 for rice processors and stakeholder experts to improve their record keeping skills, customer handling skills and how to retain customers in the market. Digital Opportunity Trust (DOT) business development service officers in collaboration with EMERTA project offered the training.

In the training that contains both theoretical and practical sessions, 32 participants (females 6) brought from rice processors, parboilers and stake holder experts have attended for two days.

The theoretical part covered the overall concept of customer handling and service delivery, record keeps costing and improving business through record keeping. In the practical session exercise and drama on four financial record toolkits, which includes; expenditure book, sales book, credit sale book, and accounting recording book are covered.

These tools are very essential to adjust their business and give evidence-based decision. After the training, trainees understand how to keep their financial records and give service to their customers. The tools are printed and distributed for trainees to practice and used for recording. Generally, the training has been found important to take informed decision based on financial records.

Rice Processing machine operation and maintenance training

Rice machine operation and maintenance training was provided for rice processors and machine operators for 5days from January 5 to 29, 2018. The focus of the training was to enhance the knowledge and skill of processors and machine operators on different types of rice machine operation and maintenance. Fourty-seven participants (owners and employed workers) attended the training. Because of the training, the following major accomplishments were realized

- Working manual was developed and handed over to rice processors for future use and reference;
- Processors are convinced to move into value addition business than provision of rice processing services for maintaining quality;
- Agreement was reached to standardize operations and maintenance from current practice;
- Consensus was reached on the need to emphasize health and safety aspects of the rice processing industry, to apply the use of personal protective equipment and precautionary measures to avoid acknowledged prevalence of accidents such as danger from rotating parts, electric shock and lightning strikes;
- Consensus was reached on utilizing appropriate tools for maintenance and operations. Tachometers were deployed to measure the speed of rotating parts, water balances were used to measure alignment of parts, moisture content measuring tools were used to show practical demonstration, etc; and
- Key stakeholders showed interest in using the training as a platform to establish partner networking such as via the Technical and Vocational Training School of Woreta, the Fogera National Rice Research and

Training Center in Woreta, private workshops and machine houses owners in Woreta as well as the Walia machinery lease services enterprise.

Coaching service provided for rice MSMEs

Coaching service was provided through DOT and the EMERTA rice team for 20 MSMEs (2 female-operated). The objective of the coaching was to encourage records of daily MSME sales, expenses, receivables and other business transactions. This helps the owner/manager to make business decisions using reliable accounting data and basic financial analysis. To start recording, the same 20 sample financial record keeping books were printed and distributed for 20 trainee MSMEs. During the coaching, four financial record keeping tools were introduced (Daily cash collection format, Daily expenditure format, Credit sale format, and cash/bank balancing format). Orientation was provided to MSMEs on how to register daily sales, expenditures, credit sales, and cash on hand and cash at bank. As a result, some MSMEs record keeping knowledge and skill improved and participants started recording their business transactions daily.

Seed multiplication and marketing cooperatives strengthened

The two-seed multiplication and marketing cooperatives (Maderie and Tikidem) found in Fogera and Libokemkem woredas, respectively are working with Guna union in the production and marketing of improved rice seed. The seed produced by the cooperatives in the last production year has full-filled the quarantine requirements. However, due to the failure to consider rice in the regional seed system and setting high prices by cooperatives the seed is not sold as seed.

To resolve this critical problem, MEDA EMERTA project, along with FNRRTC has organized a two days' workshop at Woreta town on 10 October, 2018. The objective of the workshop was to strengthen the seed multiplication and marketing cooperatives so that the cooperatives can produce and meet the demand of Guna Union for improved rice seed. In this workshop, 104 (26 Females) rice seed producers and 15 woreda and zonal Government staffs from Agriculture offices are participated (Table 6).

The workshop discussion included proper storage for the seed to keep its quality. Accordingly, the seed producers are advised to store the seed in a common warehouse instead of keeping it at their individual houses. To solve their problem of standard warehouse facility, the cooperatives agreed to construct store using MEDA's money transferred to the cooperative bank account during the previous EDGET project.

In addition, seed producers have agreed to supply the seed to the union within two months' time after harvest to insure quality. It is also suggested that the cooperatives to sell the seed following the regional seed guideline that is an addition of 15% incentive from the existing market price of the rice grain. The research center has distributed 29.6 quintals of Nerica 4 and Shaga seed varieties to 88 (6 females) seed multiplication and marketing cooperative members to cover about 30 hectares of land.

The government representative participants of the workshop confirmed to incorporate rice in the regional seed system. This will be a good opportunity to improve the rice seed system in the project woredas. At the end of the workshop, action plan was developed, and responsibility shared among stakeholders to strengthen the seed system.

Table 6: List of participants and seed distribution

Name and location of Seed Coop	Workshop participants			Seed (q)	Covered ha	Type of seed	# of seed producers		
	M	F	T				M	F	T
Tikidem: Libokemkem	36	2	38	17	17	Nerica 4	19	0	19
Madere: Fogera	57	24	81	12.6	12.6	Shaga	63	6	69
Total	93	26	119	29.6	29.6	-	82	6	88

Source: EMERTA project 2018 second quarter report

Rice model farmers' day conducted

South Gondar zone Agriculture department has organized a one-day discussion f in June 2018 with the financial support of EMERTA project. The participants of the workshop were model rice farmers, kebele administrators, woreda and zone agriculture office experts, and development agents. The model farmers discussion capacitated kebele administrators and local leaders to mobilize GAP trained rice farmers to use improved seed, seed pre-germination, row planting, time and rate of fertilizer application, water management and on time weeding. Two-hundred eighty-seven model farmers (6 females) and 45 Government staffs (one female) participated in the work (Table 7).

Table 7: Participants of model farmers' day

Woreda	Participant producers			Government staff participants		
	Male	Female	Total	Male	Female	Total
Fogera	169	3	172	24	1	25
Dera	28	2	30	7	0	7
Libokemkem	84	1	85	10	0	10
Zone				3	0	3
Total	281	6	287	44	1	45

Source: EMERTA project 2017 second quarter report

Experience sharing

In the project woredas, unlike other areas, more of the rice marketing is facilitated after the rice is milled (processed). Producers are happy to sell in the form of paddy when the paddy quality is poor. In this prevailing traditional marketing approach, quality is an important problem. If the supply from producers had been in paddy, and payments from processors differ up on quality, the problems could have been not significant.

Therefore, this experience sharing has been conducted from 22 August 2018 for 9 days to familiarize producers, processors, and support giving institutions to exploit the existing production techniques, marketing experiences, and value additions at Chewaka. The exposure visit participants were 24 (Females 2) pulled from rice producers, processors, seed multiplication and marketing cooperatives and project stakeholders having the stake of supporting rice value chain actors. The visit was accomplished effectively and creates an opportunity to scaled up the best practices in the EMERTA project areas.

Home take learning from the producer's side are; crop rotation, row planting, optimum fertilizer use, threshing on canvas, care taken not to mix varieties, market-oriented production approach and strong relationship with Bako Agriculture research center to develop the research extension linkage. Learning from processors and traders are; processors are buying paddy rice, processors are paying fair price to the farmers, the existence of market linkage with Amhara Region identified as major market destination of Chewaka producers and traders.

Different companies are visited in search of packaging materials; Ethio-Agriseft (Saudi-star) company, ROHA packaging company and classic packaging company. It has been realized that the companies are producing packaging materials are high quality and produced in different size, different companies have different minimum order, price is different depending on the quantity, thickness and row materials cost and payment modalities facilitated with 50% down payment, Saud star company has promised to test the standard of the rice from Amhara region using their laboratory.

Marketing and value chain development training provided for stakeholders

Marketing and value chain capacity building training has been given to three woreda (Fogera, Libokemkem, and Dera) government employees comprising of three offices Agriculture, Trade and Cooperative in September 2018. Such trainings for key stakeholders are very important for clear understanding and implementation of the project. It has also a contribution in smooth rapport development with government offices and sustaining impact in intervention areas.

These government offices are key in the project implementation and direct involvement in rice and vegetable production, marketing and value addition. Thirty-three (Female 9) have participated in the training from these government offices. For the sake of ownership, sustainability and even for tapping existing structure for smooth implementation of the project, government personnel are used as trainer- from Amhara BoTIMD for marketing and Agricultural Transformation Agency (ATA) Amhara Region office for Value Chain Development portion.

The training was provided for four days and presentation, brainstorming, and group discussion have been employed as training methodology. The training has covered marketing and Value Chain Development areas. Under marketing; marketing concepts, production cost estimation, market information and its analysis, market linkage, post-harvest management, quality, and standard are covered. For Value Chain Development; stakeholders in Value Chain Development, Value Chain Analysis, & tools, Value Chain Governances, Upgrading the Value Chain, Value Chain Financing, Business Development Service and Value Chain Monitoring and Evaluation are touched.

The participants remarked that the training was organized in accordance with the ground reality and found it supportive to their day-to-day activity. Finally, the training concluded by drafting next action plan to follow if delivered training has been put in practice or not.

Table 8: Basic project information

Project Title	*Ethiopians Motivating Enterprises to Rise in Trade and Agri business*
Funding Agency	Global Affairs Canada(GAC)
Implementing Agency	Mennonite Economic Development Associates (MEDA)
Value Chain commodity	Rice, Vegetable and Gemstone
Project Location	Region: Amhara Zone: South Gondar Woreda and target Kebeles Fogera: 10 Dera 6 and Libokemkem 14 Kebeles and Gemstone throughout the region
Project Duration:	Five years (January 2017 – March 2022)
Purpose	To raise the incomes and create work opportunity of smallholder male and female farmers through linking with MSMEs

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Contribution of AgroBIG in Rice Sector Development

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Background

Since 2015, AgroBIG (Ethio-Finland Agribusiness Induced Economic Growth) Program has been supporting rice sector development in Fogera basing through its intervention on a Value Chain Study. As agreed in various stakeholder consultation forums, supply of improved disease resistant variety, quality seed and the quality of rice have been identified as crucial issues. Through focusing on the rice production and processing technologies, AgroBIG is addressing these issues in multiple ways.

Within production, there are 12 organized farmer clusters multiplying the EDGET rice seed following the Community Based Rice Seed Multiplication and Marketing - approach. The foundation seed is received from the Fogera National Rice Research and Training Center (FNRRTC), of which the farmers are paying 50 %. Cluster farmers have received skill training on organizational and technical aspects, e.g. on row planting, roughing and other crop management issues. The Quarantine Authority has been inspecting the rice in the field and in the lab to test and finally prove certification. Field days have proven to be important for stakeholders to share experiences on crop management. Recently finalized Farmer Training Centers (FTCs) are also serving farmer trainings.

On technologies, AgroBIG has introduced rotary weeders as well as hand-driven and combined mini harvesters for demonstration, and supported post-harvest technologies such as 8 diesel driven rice threshers for multipurpose cooperatives through value chain funds and triple bags for storing. For processing, 8 combined rice processing machines are to be delivered to private value chain fund grantees. The machine can sort, dehusk, polish, weigh and pack all at the same time.

In addition, a women's cooperatives involved in rice parboiling received support in the form of a packaging machine and gained assistance by taking part in food fairs and demonstration events to promote parboiled rice and to create linkages with universities and supermarkets in the main towns in the Region as well as Addis Ababa.

A big investment soon to become operational is the Rice Warehouse Receipt System in Quhar Abo *kebele*. It consists of a site of 4600m2, managed by cooperatives, where farmers can bring their paddy against a voucher and sell them later on when prices are higher. A combined rice processing machine, with the capacity of 2 t/hour, attached to the warehouse will serve farmers for better quality to reach new markets.

AgroBIG has also supported rice research through its grant fund for Innovation, Demonstration and Research. Debre Tabor University trialed different rice varieties and Woreta TVET (Technical and Vocational Education and Training) Collage looked for ways to use rice husk in composting for improved production.

From 2017 onwards, AgroBIG expand to Libokemkem and Dera *woreda*s continuing the support for rice farmers and promoting Fogera rice to reach new markets with good quality.

Overview of AgroBIG

AgroBIG is a bilateral program financed by the governments of Finland and Ethiopia with the objective to contribute to poverty reduction through agriculture based economic growth in the Lake Tana sub basin. The first phase of AgroBIG (2013–2017) was implemented in Fogera and Mecha *woreda*s in the Amhara region. The Programme focused on four value chains: onion (bulb and later seed), rice, potato and maize. The second phase of AgroBIG, runs for 4.5 years, from July 2017 to December 2021. It is designed to sustain the achievements of Phase I, and further strengthen agribusiness development within the Tana sub-basin. The geographical focus of the second phase of AgroBIG is 89 *kebele*s in eight *woreda*s: North Achefer, South Achefer, North Mecha, South Mecha, Bahir Dar Zuria, Dera, Fogera and Liboemkem, falling under the Koga-Gilgel Abay, Gumara and Rib catchments. The Programme targets a total of 300,000 direct beneficiaries classified into three main groups individual farmers and farming household members; agricultural cooperatives and associations; and other private sector value chain actors such as input suppliers, traders, processers and service providers. The intended impact AgroBIG II is to contribute to the development that enables agriculture to provide decent sustainable livelihood to people in rural Amhara regional state. Its expected outcome is that value is added at various levels of selected agricultural value chains to increase incomes and create jobs for farming households and other value chain actors, with a particular emphasis on women and youth. AgroBIG II has two output objectives, which are inter-linked, causing the attainment of the intended outcome:

- Output 1: Value chain actors' access to finance and financial services is improved and sustainability of their enterprises and business initiatives is strengthened; and
- Output 2: Capacities of value chain actors are strengthened to improve their capability to seize market opportunities in a profitable and sustainable way.

The program addresses three crosscutting objectives: environmental sustainability, gender equality, and reduction of inequalities through inclusion of vulnerable groups: women, landless youths, and People with Disabilities (PWD).

AgroBIG applies a value chain approach (VCA). The program supports input suppliers, farmers, brokers, processors, wholesalers, retailers, producers, consumer cooperatives, and service providers. It gives more attention to the downstream of the value chains; to add value to the producer they deal with, to find and familiarize with profitable markets and new market segments for their produce, and thereby improve competitiveness and profitability of their business initiatives. AgroBIG continues to support four value chains that were attended to during the first phase of the Program, onion, potato, rice, and maize. Four additional value chains have been included for Phase II: tomato, dairy milk, goat, sheep fattening, and production of eggs and poultry meat. The program is coordinated by the Bureau of Finance and Economic Cooperation and key implementing partners include, Bureau of Agriculture, Bureau of Trade and Market Development, Cooperative Promotion Agency, Bureau of Technical, Vocational and Enterprise Development, Bureau of Women, Children and Youth Affairs and other partners are research and universities, the private sector and similar projects and programs. The program is fully aligned with the government system to ensure ownership and sustainability.

Rice production in Fogera

Rice production is widely expanding from time to time in Fogera, Libokemkem, and Dera *Woreda*s. In Fogera *woreda*, for instance, 30 *kebele*s grow rice and more than 38,000 farming households are engaged in the production. More than 21,000 ha land devoted and 1.6 million q of rice has been produced in 2016/17 production season (Table 1).

Table 1. Rice production in Fogera

Production season	Land coverage (ha)	Production (kg)	No of *kebele*	No of HHs	Female HHs
2008/09	11,146	72,449,000	20	19,474	790
2009/10	14,149	90,553,600	24	20,945	1,200
2010/11	15,119	92,225,900	25	20,945	1,267
2011/12	16,070	113,446,500	25	22,321	1,405
2012/13	19,310	158,736,600	25	24,649	1,599
2013/14	20,379	150,667,300	26	32,835	2,077
2014/15	20,896	160,057,500	26	35,611	931
2015/16	21,341	168,811,200	27	35,616	1,120
2016/17	21,341	166,609,400	30	38,688	2,596

Source: Fogera Woreda office of Agriculture annual reports

Constraints

A value chain analysis has been conducted by a short-term consultant hired by AgroBIG. The following are key constraints identified that has to be addressed by the program and other stakeholders.

Supply side

- The Lack of rice farmers' access to quality seeds and improved/resistance varieties;
- Poor agronomic practices by farmers, including land preparation, planting, weeding, pest and disease control;
- Weak extension support;
- Poor perception of consumers and retailer's for local rice produce; and
- Limited knowledge and skills of farmers on post-harvest handling practices;

Demand side

- Lack of quality control systems for grain rice including paddy;
- Local rice is traded with no standard and grade;
- Limited awareness of consumers on the different rice recipe and nutritional benefit;
- Limited capacity of farmers' cooperative in rice value additions and marketing;
- Poor knowledge of farmers on processing techniques and poor processing technology;
- Poor access to credit and related financial services by rice processers and other value chain actors; and
- Poor back and forward marketing linkages.

Phase I- Interventions

In order to address the above constraints and tap the potential, the programme has made several interventions, mainly in Fogera, inter alia, the following are worth mentioning.

Partnership development-

The program has made some partnership with MEDA as it has been engaged in rice value chain development in Fogera even before AgroBIG I. In this respect:

- consultative meetings and discussion made to avoid duplication of efforts mainly in identifying target intervention kebeles, technology identifications and grant fund users; and
- close relationship to invite MEDA and also be invited by MEDA in the different events such as field day events, rice multi-stakeholder platform meetings, linkage forum, new business model piloting warehoue Reciept System.

The program also made partnership with the FNRRTC in key areas:

- Established community-based rice seed production stakeholder platform;
- Supply of improved rice variety to seed growers' farmers; and
- Technology shopping and experience sharing

Moreover, AgroBIG participated and has been sharing its rice value chain experiences at rice seed development strategy stakeholder meeting organized by EARI in collaboration with JICA.

Technology demonstration

Various technologies have been demonstrated and promoted in Fogera during field day events and trainings. The following are worth mentioning- rice harvesters (mini combine harvester(?), handheld harvester (1), walking harvester (1), triple bags (200) for rice, rotary weeders (15), rice boiler (1), tractor (1) for plowing by organizing landless and jobless youth groups. However, the technologies were not properly managed and replicated by cooperatives.

Community based rice seed multiplication

One of the main constraints in the rice value chain is lack of access to improved and resistant varieties, especially for disease such as blast and cold weather condition. Cognizant of this reality, AgroBIG, as partner have signed Memorandum of Understanding with FNRRTC to promote community-based rice multiplication and marketing scheme. Community-based rice multiplication initiative has been initiated directly involving the *woreda* office of agriculture and the communities who have common interest in cluster-based seed multiplication and marketing. In this respect, in 2015/16 production season, 232 farmers were organized in 12 clusters and about 430 q of rice seed produced; FNRRTC availed about 38 quintals of improved rice (EDEGET variety) and distributed to farmers on 50% cost sharing basis. Farmers received capacity building trainings on good agronomic practices including inputs application and management practices. Field day event was also organized to promote post-harvest technologies, cluster farming and good agronomic practices. The Regional Quarantine Office through its Gondar branch office was able to regularly follow up and inspect the rice seed production and certification process.

Improved marketing practices

In order to create market linkages with existing and potential buyers, annual rice linkage forum was organized, in which rice processers, traders and service providers attended. It was also possible to display and promote new rice products including bread in a trade fair and bazar organized at Bahir Dar. A group of poor women who were engaged in rice parboiling and trading supported to improve packaging and labeling of rice products. In this respect the group were supported with 15000 piece of labeled packaging plastic bags and a sealing machine. Fogera’s rice, both parboiled and non-parboiled, were promoted for different market segments, rice food also demonstrated at Dashen brewery for its staff and potential buyers invited from Gondar town. Moreover, 78 rice millers and traders attended a training on rice quality improvement.

Capacity building

To improve the rice production and productivity, a number of capacity building trainings have been conducted and attended by farmers and extension workers. In collaboration with the Regional Agricultural Research Institute, a comprehensive rice agronomy and post-harvest handling manual prepared and distributed to *woreda* and *kebele* level agriculture extension staff and FTCs. ToT training was provided to 32 extension staff mobilized from all the rice growing *kebele*s. The training was cascaded to 361 smallholder farmers who were trained on rice agronomy and post-harvest handling. Field day events on rice seed multiplication was also organized and attended by farmers mobilized from different *kebele*s. To strengthen the overall extension system in Fogera, the program has supported constructing and equipping 8 FTCs of which two of them are model FTCs, located at Quhar Abo and Hagere Selam *kebele*s which enabled to demonstrate technologies and varieties.

Access to finance

One of the constraints in the rice value chain is lack of access to finance to support the value chain. In order to create access to finance for action research, demonstration and innovation of technologies and improved practices as well as promote value addition and processing, the program has availed some grants for applicants in a competitive and transparent manner. Call for applications was made, concept notes received and applications processed and awards made. Innovation, Demonstration and Research Fund (IDRF) is more to support innovation, demonstration and research projects with no matching requirement while the matching grant is meant to support value addition and processing and entails own contribution (15% for small and micro level and 50% for medium size investments). In phase I, the following grants were extended to applicants from Debretabor University, Woreta TVET College, multipurpose cooperatives and private rice processers. These are:

- Agro morphological studies of rice varieties for viability of their association with yield related traits by the Debre Tabor University;
- Evaluation of the nutrient content of rice husk composting and its effect on the performance of rice production by the Woreta TVET College; and
- 8 mobile rice threshers to farmers' coops, 8 combined rice processing machines.

As the trading of paddy rice is not common in Fogera, AgroBIG has initiated a community warehouse receipt scheme so that rice farmers can supply their paddy to a primary cooperative through voucher system linked to a formal bank or MFI. Farmers can benefit more if they keep their paddy in warehouses until price stabilizes. In this respect, preparatory activities have been done including construction of a warehouse with the capacity of 60,000 q. The construction work for the warehouse (3 blocks) is already completed while construction of fencing and toilet facilities is ongoing (in the latter case the support is from AgroBIG II).

Achievements

Based on the terminal report of phase I, the following achievements were recorded. These include:

- Rice production increased by 82%, largely by using quality seeds of improved varieties;
- Rice yields are up by 70%;
- Community based rice seed multiplication and marketing system in place;
- Rice market linkages with local and distant markets fostered;
- Quality of milled rice improved; and
- Various rice products introduced for urban farmers, consumers and Gondar Dashen Brewery employees and awareness created on the nutritional value of the product.

Challenges

Despite the achievements, there are challenges yet to be resolved, inter alia, the following are in the forefront:

- Shortage of basic rice seeds for seed producing farmers, groups and cooperatives;
- Limited availability of affordable and user friendly pre and post-harvest technologies such as planter and storage);
- Weak market linkage discourages rice seed producers;
- Expansion of exotic weeds; for example, water hyacinth, and partinium;
- Lengthy and unsuccessful procurement process for rice processing machines; though the grant recipients are supposed and encouraged to use the grant allocated and buy in their own; and
- Access to electric power supply for the Quahar Abo rice warehouse and processing unit.

Lessons learnt

Some lessons have been learnt from the rice value chain interventions in Fogera during phase I, inter alia, the following are worth mentioning:

- Commercial rice seed production depends, to a large extent, on market linkages and hence the role of cooperatives is crucial in rice seed marketing to link rice seed producing farmers with buyers;
- Compared to Asian countries such as Thailand, rice value chain is not yet well developed in the region. In Thailand rice value chain is well developed and can be considered as model;
- Packaging is crucial element in promoting and branding the Fogera rice as most supermarkets in Addis Ababa commented that the packaging materials are inferior in quality; and
- More coordinated effort is needed to promote the nutritional value of the Fogera rice.

Phase II- key interventions

- Strengthen community-based rice seed multiplication and marketing;
- Introduction, adoption and promotion of improved technologies and create access to those technologies through appropriate financing mechanism, Promote pre and post-harvest technologies and innovations; for example, rice planter, and storages;
- Support cooperatives in rice marketing through availing coop loan fund;
- Avail matching grant funds (50% own contribution) for small and medium size investments in processing and market system development;
- Avail women and youths loan funds for production, farm service, and value addition; and
- Operationalize Quhar Abo Rice warehouse (complete construction, power supply, management modality)

Conclusion

Rice is a major crop supporting many smallholder farmers in Fogera, Libokemkem and Dera *woreda*s. There is also a big potential to expand rice production and marketing to adjacent woredas around the Lake Tana sub basin. Some experience already exists by many farmers on the production and marketing of rice seeds. It is becoming a cash crop for many smallholder farmers. Despite the potential, a lot remains to be done to improve the rice value chains. Especially the marketing, processing, and value addition should be more strengthened. More access to finance should be created and capacity of rice value chain actor be strengthened so that the rice value chain be more competitive and profitable and even to substitute rice imports. Landless youths, both male and female, can be encouraged to be creative to engage in farm service provision and value addition activities and more cooperatives be active in rice output marketing. Private rice processers be encouraged to add value and become competitive to increase their incomes and create jobs. Overall, the role of AgroBIG and similar partner projects is to improve the rice value chain and concerted effort with research center is imperative.

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