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Review on Breeding Methods, Challenges and Opportunities of Rice Production in Ethiopia

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Rice production in Ethiopia has started a few decades ago and now the country is proved to have reasonable potential to grow different rice types for rain fed lowland, upland and irrigated ecosystems. Rice is currently considered as a strategic food security crop and its use as a food crop, income source, employment opportunity and animal feed has been well recognized in Ethiopia. Emphasis on high grain quality tends to result in unstable yields. Various breeding strategies for increasing the yield potential such as Conventional hybridization, Ideotype breeding, Heterosis breeding, Male sterility, wide hybridization, Genetic engineering, Molecular marker assisted breeding. Hence, breeding efforts should concentrate on varieties with the potential to minimize yield losses under unfavorable conditions, and to maximize yields when conditions are favorable. The productivity of rice was affected by diseases, insects, weeds and abiotic factors. There were 35 rice (15 upland, 11 lowland and 9 irrigated), varieties released for different agro ecologies of Ethiopia.

Keywords: abiotic, breeding methods, hybridization, Oryza sativa

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INTRODUCTION

Rice belongs to the family “Gramineae” and the genus “Oryza”. There are about 25 species of Oryza. Of these only two species are cultivated, namely Oryza sativa Linus and Oryza glaberrima Stead. The former is originated from North Eastern India to Southern 2 China but has spread to all parts of the world. The latter is still confined to its original home land, West Africa. Rice (Oryza sativa Linu) is one of the main staple foods for 70% of the population of the world. Africa produced an average of 26.4 million tons of rough rice (17.4 million tonnes, milled) in 2012 (FAO, 2013). Rice is among the important cereal crops grown in some parts of Ethiopia as food crop. The country has immense potentials for growing the crop. It is reported that the potential rice production area in Ethiopia is estimated to be about 5.4 million hectares. According to the national rice research and document strategy, the trend in the number of rice producing farmers, area allocated and production shows high increase rate especially since 2006. The number of farmers engaged in rice production has increased from about 53 thousand in 2006 to about 260 thousand in 2008. Similarly, the area allocated has increased from about 18 thousand in 2006 to about 90 thousand ha in 2008 along with production increase from about 150 thousand tonnes in 2006 to about 286 thousand tonnes in 2008 (NRRDS, 2009).

LITERATURE REVIEW

Rice Breeding in Ethiopia

Among the target commodities which have received due attention in promotion of agricultural production, rice is the one considered as the "millennium crop" expected to contribute to ensuring food security in the country. Accordingly, Ethiopian Institute of Agricultural Research (EIAR) has treated it as one of nationally coordinated research projects. As the crop is a recent introduction in the country, its research status is at infant stage. Almost all research activities are concentrated on variety development and there are only a few research activities on crop management, while the other research disciplines are yet hardly touched (Sewagegne, 2011). Different actors are involved in the promotion of rice production and marketing in the country. Hence, the stakeholder analysis in rice research and development in the country the area of generating knowledge about the relevant actors to understand their behavior, intentions, interrelations, agendas, interests and the influence or resources they have brought or could bring to the development of the rice sector (Dawit and Shiratori, 2011).

Rice Breeding Methods

The ultimate goal of crop breeding is to develop varieties with high yield potential and desirable agronomic characteristics. In rice breeding, the most important qualities sought by breeders have been high yield potential; resistance to major diseases and insects; and improved grain and eating quality. However, there seems to be some conflict between these aims. Emphasis on high grain quality tends to result in unstable yields. Conversely, too much emphasis on disease and insect resistance and stable yields leads to poor grain quality. Hence, breeding efforts should concentrate on varieties with the potential to minimize yield losses under unfavorable conditions, and to maximize yields when conditions are favorable. Various breeding strategies for increasing the yield potential include;

1) Conventional Hybridization
2) Ideotype Breeding
3) Heterosis Breeding
4) Male Sterility
5) Wide Hybridization
6) Genetic Engineering
7) Molecular Marker Assisted Breeding

Conventional hybridization and selection procedures

This is the time tested strategy for selecting crop cultivars with higher yield potential. It has two phases. The first phase involves the creation of variability through hybridization between diverse parents. In the second phase desirable individuals are selected on the basis of field observations and yield trials. It has been estimated that on the average about 1.0% increase has occurred per year in the yield potential of rice over a 35 year period since the development of first improved variety of rice, IR8 (Peng *et al.*,2000). The yields of crops where there is enough investment in research have been continuously increased and there is no reason why further increases cannot be attained.

Ideotype breeding

Ideotype breeding aimed at modifying the plant architecture is a time tested strategy to achieve increases in yield potential. Thus selection for short statured cereals such as wheat, rice, and sorghum resulted in doubling of yield potential. Yield potential is determined by the total dry matter or biomass and the harvest index (HI). Tall and traditional rice had HI of around 0.3 and total biomass of about 12 tons per hectare. Thus their maximum yield was 4 tons per hectare. Their biomass could not be increased by application of nitrogenous fertilizers as the plants grew excessively tall, lodged badly and the yield decreased instead of increasing. To increase the yield potential of topical rice it was necessary to improve the harvest index and nitrogen responsiveness by increasing the lodging resistance. This was accomplished by reducing the plant height through incorporation of a recessive gene sd1 for short stature.

Heterosis breeding

Rice hybrids with a yield advantage of about 10-15% over best inbred varieties were introduced in China in mid 1970s and are now planted to about 45% of the rice land in that country. Rice hybrids adapted to tropics have now been bred at IRRI and by NARS and show similar yield advantage. The increased yield advantage of tropical rice hybrids is due to increased biomass, higher spikelet number and to some extent higher grain weight. Increased adoption of hybrids in the tropics should contribute to increased productivity.

Male sterility

In rice, there are three major types of CMS/restoration systems, including CMS-BT (boro type), CMS-WA (wild abortive), and CMS-HL (Honglian). The first commercially used CMS-WA germplasm was discovered by Chinese scientist Long Ping Yuan in 1970's and was used to develop the three-line system hybrid rice. As a gametophytic system, CMS-BT is the most widely investigated rice CMS system at the genetic level, and is originally derived from the cytoplasm of an indica rice variety Chinsurash Boro II. Recently, Dr. Yaoguang Liu's laboratory published the results of a study, in which they cloned the CMS and two Rf genes in the CMS-BT/restoration system and elucidated the molecular mechanism for male sterility and fertility restoration (Wang *et al*., 2006).This is a significant contribution to hybrid rice dedicated by Chinese scientists. A number of fertility restorer genes that are involved in other CMS systems have been studied genetically. Two Rf loci, Rf5 and Rf6 (t), responding to CMS-HL, have been located in different regions of chromosome 10 (Liu *et al*.,2004).Both the CMSDT restorer gene Rf-d1 (t) and the CMS-DA restorer gene Rf-d (t) were also detected on chromosome 10(Tan,*et al*.,2004).Two CMS-WA restorer genes Rf3 (t) and Rf4 (t) have been located on chromosomes 1 and 10, respectively (Yang *et al*., 2002).

Wide hybridization

Crop gene pools are widened through hybridization of crop cultivars with wild species, weedy races as well as intra-sub specific crosses. Such gene pools are exploited for improving many traits including yield. Lawerence and Frey(1976) reported that a quarter of lines from BC2-BC4 segregants from the *Avena sativa* × *Avenasterilis* crosses were significantly higher in grain yield than the cultivated recurrent parent. Nine lines from this study when tested over years and sites had agronomic traits similar to the recurrent parent and 10-29% higher grain yield. The higher yield potential of these inter-specific derivatives was attributed to higher vegetative growth rates or early seedling vigor.Xiao *et al*. (1996) reported that some backcross derivates from a cross between an Oryza rufipogon accession from Malaysia and cultivated rice, out yielded the recurrent parent by as much as 18%. They identified two QTL from wild species with major contribution to yield increase. These QTL are now being transferred to several modern semi-dwarf varieties.

Genetic engineering

Protocols for rice transformation have been developed which allow transfer of foreign genes from diverse biological systems into rice. Direct DNA transfer methods such as protoplast based (Datta *et al*.,1990) and biolistic as well as Agro bacterium-mediated (Hei *et al*., 1994)are being used for rice transformation. Major targets for rice improvement through transformation are disease and insect resistance. As early as 1987, genes encoding for toxins from *Bacillus thuringiensis* (BT) were transferred to tomato, tobacco and potato, where they provided protection against lepidoptern insects. A major target for BT deployment in transgenic rice is the yellow stem borer.

This pest is widespread in Asia and causes substantial crop losses. Improved rice cultivar are either susceptible to the insect or have only partial resistance. Thus BT transgenic rice has much appeal for controlling the stem borer. Codon optimized BT genes have been introduced into rice and show excellent levels of resistance in the laboratory and greenhouse (Datta *et al*.,1997). Btrices have also been tested under field conditions in China (Tu *et al*.,2000) and have excellent resistance to diverse populations of yellow stem borer. Besides BT genes, other genes for insect resistance such as those for proteinase inhibitors, α-amylase inhibitors and lectins are also beginning to receive attention. Insects use diverse proteolytic or hydrolytic enzymes in their digestive gut for the digestion of food proteins and other food components.

Plant derived proteinase inhibitors or α-amylase inhibitors are of particular interest because these inhibitors are a part of the natural plant defense sys system against insect predation. Xu *et al*.(1996)reported transgenic rice carrying cowpea trypsin inhibitor (Cpti) gene with enhanced resistance against striped stem borer and pink stem borer. Several viral diseases cause serious yield losses in rice. A highly successful strategy termed coat protein (CP) mediated protection has been employed against certain viral diseases such as tobacco mosaic virus in tobacco and tomato. A coat protein gene from rice strip virus was introduced into two japonica varieties by electroporation of protoplasts (Hayakawa *et al*., 1992). The resultant transgenic plants expressed CP at high level and exhibited a significant level of resistance to virus infection and the resistance was inherited to the progenies.

Challenges of Rice production

The national average grain yield of cereals in Ethiopia is relatively low amounting to about 2.8 t ha-1 for rice in 2016 (CSA, 2017). This, amongst others, is due to the widespread use of low yielding varieties coupled with unimproved traditional practices that ultimately contribute to the low national average yield of major cereal in the country.

Diseases: Several pests (weeds, diseases, and insect and other pests) are constraining cereal production and productivity in different parts of Ethiopia. The impact of these biotic factors on the general performance, yield and

Table 1. Important diseases of major cereals in Ethiopia

Crop	Major Diseases
Barley	Scald (Rhynchosporium secalis)), net blotch (Helminthosporium spp.), stripe rusts (Puccinia spp.) powdery mildew(Erysiphae graminis),head blight (Fusarium hetrosporium), covered smut (Ustilago hordei), barley yellow dwarf virus(BYDB)
Maize	Turcicum leaf blight ((Exserohilum turcicum), gray leaf spot (Carpospora zea-maydis), common leaf rust (Puccinia sorghi),maize streak virus (MSV), Maize Lethal Necrosis Disease (MLND)
Rice	Rice blast (Pyricularia oryzae), brown spot (Cochliobolus miyabenus), Sheath rot (Sarocladium oryzea) and sheath blight(Thanatephorus cucumeris).
Sorghum	Anthracnose (Colletotrichum sublineolum), grain mold (Fusarium spp, Alternaria spp., Helminthosporium spp., Curvularia spp.), gray leaf spot (Cercospora sorghi), rust (Puccinia purpurea), smut (Sphacelotheca spp), ergot (Claviceps sorghi), downy mildew (Peronosclerospora sorghi) and leaf blight (Helminthosporium turccium
Teff	Teff rust (Uromyces eragrostidis Tracy), head smudge (Helminthosporium miyakei Nisikado), leaf spot (Helminthosperiumspp.), damping-off (Drechslera spp., and Epicoccum nigrum Link.)
Wheat	yellow/stripe rust (Puccinia striiformis Westrnd), stem/black rust (P. graminis fsp. tritici) leaf/brown rust (P. ricondite fsp.tritici), Septoria tritici (Microsphearelia graminicola)
Finger millet	Finger millet blast (Pyricularia grisea)

Table 2. Important insect pests of major cereals in Ethiopia

Crop	Major insect pests
Barley	Barley Barley shootfly, (Delia arambourgi Seguy, D. flavibasis Stein.), Russian aphid (Diuraphis noxia Mordvilko),,chafer grub (Melolontha spp.)
Maize	Stalk borer (Busseola fusca), Spoted stalk borer (Chile partellus), termites (Macrotermes and Microtermis spp) Maize, weevels (Sitotroga zeamias) Large grain borer (Postephanus turncatus)
Rice	Termites, stem borer (Pyraliae), stalked-eyed flies (Diopsis thoracica)
Sorghum	Stak borer (Chilo partellus), shootfly (Atherigona soccata), midge (Contarinia sorghicola), weevil
Tef	Shoot fly (Atherigonia spp.), red tef worm (Mentaxya ignicollis Walker), Wello bush cricket (Decticoidesbrevipennis Ragge.), black tef beetle (Erlagerius niger Weise), grasshoppers (Ailopus spp. and Eyprepocnemisspp.)
Wheat	Shoot fly D. steiniella Emden, , Russian aphids (Diuraphis noxia Mordvilko)

grain quality varies depending upon the genetic, environmental, management condition and the interactions of these factors. Diseases are amongst the most important constraints in cereal production in Ethiopia (Table 1). The magnitude of yield loss associated with various diseases varies with varieties, location, season and planting date.

Insect Pests: Large numbers of insect pests attacking cereals under field and storage conditions have been identified (Table 2). Depending on the incidence and damage, some insect pests have been known to be economically important in Ethiopia.

Abiotic Constraints

Abiotic stresses including drought, high and low temperatures, salinity, submergence, and oxidative stress contribute significantly to reduce crop yield. More than 50% crop damage has been reported due to these stresses worldwide (Bray *et al*., 2000). They are often interlinked and cause similar cellular as well as physiological damage. Moreover, they also activate similar cell-signaling pathways (Nakashima *et al.,*2009). Several proteins, antioxidants, and compatible solutes are produced in response to stress conditions. Many crop plants have been developed by over expression of genes responsible for these compounds and evaluated for various abiotic stresses under laboratory and field conditions (Luo *et al.,* 2010).Tolerance to water shortage and salt stress are the most damaging factors that inhibit yield in rice crops.GM technology is one of the available options to increase abiotic stress tolerance in crop plants (Flowers, 2004).

Relatively low productivity

The national average grain yield of rice in Ethiopia is relatively low amounting to about 2.8 t ha-1 for rice in 2016 (CSA, 2017). This is due to the widespread use of low yielding varieties coupled with unimproved traditional practices that ultimately contribute to the low national average yield of major cereal in the country.

Opportunities to Increase Rice Production

Food price hike and government actions

The food prices hike in 2007-2008 was the biggest spike on world food markets. The price hike was mainly for three of the world's major cereals (rice, wheat, and maize) the price of a ton of wheat climbed from $105 in January 2000, to $167 in January 2006, to $481 in March 2008).The crises were leading to substantial effects on the poor in countries where rice is the staple food for consumers. As FAO (2010) estimated that the poor people often spend as much as 40% of their incomes on staple foods. Governments of Ethiopia in collaboration with other actors responded to the crises by taking the following actions: recognize rice as one of the millennium crops, promotion of private sector investment in rice production (e.g. land allocation for private investors) promotion of improved rice technologies, irrigation development increase area of rice production due to high rice price.

Market demand and availability of rural labor

According to Dawit (2015) higher cost value of rice grains over other cereals; increased rice consumption habit of consumers along with income increase and urbanization (demand increase); integration of rice value chain through improved processing (promotion of quality machineries) and integration of value chain actors (ensuring service provision by private sector). The above demand factors have driven Ethiopian smallholder farmers to start rice production and this shift of cropping was enabled also by the abundant and low-cost rural labor, as the rice crop is labor intensive.

Technology, inputs and research

Availability and the use of high yielding and adaptable rice varieties; introduction and utilization of improved farm mechanization technologies; adoption of various promotion approaches, such as community based seed multiplication, pre-scaling up of technologies and on-farm demonstration (Dawit, 2015).

Suitability related factors

Ethiopia has the existence of huge unexploited lands and diverse ecosystems such as the uplands, rain-fed lands and flashes flood prone areas (during the rainy seasons).Long shelf life and acceptance of rice amongst rural population due to the possibility of using rice to a range of traditional food recipes. Relatively higher productivity as compared to other main staple crops Possibility of using in a range of traditional food recipes Provide by-products such as straws and husks that shall be fed to livestock and/or used as an alternate source of fuel (Dawit, 2015).

Achievements and Impacts of Rice in Ethiopia

Released varieties

Over the years of research on cereals, commendable achievements have been made in the generation of technologies and information useful for boosting the productivity and production of cereals in Ethiopia. As one of the components of the package of improved technologies, to-date a total of 35 improved rice varieties have been released for the three rice ecosystems (15 for rainfed upland, 11 for rainfed lowland and 9 for irrigated). The initiation and expansion of upland rice production in Ethiopia correlates strongly with the implementation of research into the commodity. The varieties tested and disseminated by the research organizations are bringing farmers higher yields (Table 3).

Genetic/productivity gain in rice

The overall national mean grain yield productivity of rice in Ethiopia showed a constant increase except a sharp drop in 2003. However from 2004 till 2017 a constant and progressive increase was recorded. It indicated that the overall rice grain yield productivity increased by 100 %.

SUMMARY AND CONCLUSION

Rice is currently considered as a strategic food security crop and its use as a food crop, income source, employment opportunity and animal feed has been well recognized in Ethiopia. Various breeding methods for increasing the rice yield potential like; conventional hybridization, ideotype breeding, heterosis breeding, male sterility, wide hybridization, genetic engineering and molecular marker assisted breeding were applied in rice improvement strategies. The impact of biotic (pests) and abiotic factors on the rice general performance, yield and grain quality varies depending upon the genetic,

Table 3: Yield potential of recently released rice varieties in different ecological zones

Name of the variety	Year of release	Appropriate ecology	Yield (t/ha) at	
			Farmers Field	Research Field
Shaga	2017	Lowland	5.0	6.8
Wanzaye	2017	Lowland	3.9	6.5
Erib	2017	Lowland	4.1	5.3
Abay	2017	Lowland	4.0	5.3
Fogera-1	2016	Upland	3.2	4.2
Maitsebri-2	2016	Upland	3.8	4.5
Fogera-2	2016	Lowland	4.9	6.1
Adet	2014	Upland	2.4	4.2
Nerica-13	2006	Upland	3.3	3.8
Nerica-12	2013	Upland	3.4	4.1
Hibir	2013	Lowland	3.6	4.7
Chewaka	2013	Upland	3.3	4.2
Ediget	2011	Lowland	3.2	5.2

environmental, management condition and the interactions of these factors. Opportunities like food price hike and government actions; market demand and availability of rural labor; technology, inputs and research; Suitability related factors coupled with released 35 improved rice varieties for each of the three rice ecosystems leads to the current status of rice production in Ethiopia. Generally detail works expected from different research teams in order to exploit the potentials of rice production and productivity to achieve the food security in Ethiopia.

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