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Rice Breeding Achievements, Potential and Challenges in Ethiopia

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Abstract: *The introduction of rice to Ethiopia is associated with the mission to address different challenges mainly targeting insuring food security for settlers in the beginning of 1960s. Formal research on rice has started in 1986.Since then multi-environment breeding trials were conducted with major objective of identifyinghigh yielding, stable, early maturing and major disease resistant rice varieties. In the past three decades a total of 35 varieties were released-registered nationally. Under research station, the productivity of released lowland rice variety increased from 3.0 tonha^{-1} (1998) to 4.6 tonha^{-1} (2016),raised by 34.8 % and 1.9 % of an annual yield increment. For lowland rice, productivity increased from 3.8 tonha^{-1}(1999)to 6.8 tonha^{-}1 (2017), raised by 44.1 % and 2.5 % annually. Although a number of varieties have been released, only a few are adopted by farmers because of lack of extension service, lack of mechanization, lack of grain quality trait and lack of rice utilization. This suggested the introgression of important traits to the elite varieties is critical. Considering product based variety development, consisting of all the important traits preferred by the end users would help to increase the adoption of released varieties.*

Keywords: *Rice, "Injera", Productivity*

1. Introduction

Rice (Oryza sativa L.) which was originated from the tropics and subtropics is widely cultivated in diverse environments. The tremendous growth of human population worldwide has increased the demand for rice production [1], requiring an improvement of 50% by the year 2025[2].

Rice is 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 two 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 [3].Most of the species are diploid, having 12 pairs of chromosomes. Seven species are tetraploid (2n =4 x = 48). The chromosomesofricespeciesaresmallanddeficientinmorphologic markers, rendering them difficult to discern and identify [3].

Rice is a universal food, feeding more than half of the world's populations [4]. It is the most important foodgrain 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 costs6.4 billion USD annually [5]. For instance, in 2015, 36 % of consumed rice was imported [5].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 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. According to the report of [6], National Rice Research and Development Strategy of Ethiopia (NRRDSE) revealed that the rainfed rice cultivation potential isabout 30 million ha (5 million ha highly suitable and 25 million ha suitable).Moreover, 3.9 million ha are suitable for irrigated rice production.

The first rice variety released in 1998 by Pawe research center and with the name of Pawe-1 (M-55). From the start of rice breeding to recent years, traits like high yielding, major disease resistance and early maturing were the major traits for the breeding objectives. Now, instead of trait-based breeding approach product-based breeding approach is highly demanded because of different stalk holder preferences.

Rice research and development in Ethiopia recognized following the considerable expansion of small scale rice production, recognition of the potential of production in the country and the huge increase in the amount of imports over time [7]. The Ethiopian government considered rice as a millennium crop for the fact that the demonstrated an increasing productivity and the potential to alleviate food security issues in the country. In line with the increasing production rice consumptions in Ethiopia has increased and also contributing for increasing farmers income, creating employment opportunity, as well as sources of animal feed have been well recognized[8]. There is an increasing trend in area coverage and volume of production of rice in the country [9]. However, an increasing trend of importing rice is practicing which proved that demand of rice is quite higher than the domestic production. For instance domestic production increased from 11,244.3 tones (2007) to 126,806.4 tones (2016) [10].However importing of rice from abroad increased from 22,500 tones (2008) to 311, 827 tones (2016, which chargedthe country more than 170 million USD [11]. 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 tones ha^{-1}) of Ethiopia is quite low compared to the global average productivity (4.4 tones ha^{-1}) even though 6 tones ha^{-1} has been reported on research fields [12]. 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 [6].

Therefore, this review paper presents what has been done so far rice variety development to enhance production and productivity in the national research system of the country.

2. ACHIEVEMENTS

The achievements of this paper present a historical analysis of rice variety development process so far in Ethiopia.

2.1. Germplasmacquisition

As rice isan exotic crop to Ethiopia, the source of germplasmuntil now is through introduction. Since the inception of rice research, a number of germplasm 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 serious of evaluation stages for variety release.

Table1. *List of germplasms introduction (2007-2018) to Ethiopia from different sources*

No	Origin	Ecosystem	No. Of germplasm	Year of introduction
1	IRRI	Irrigated	72	2007
2	Africa Rice	Irrigated	39	2009
3	IRRI	Irrigated	162	2010
4	Africa Rice	Lowland-Cold tolerant	132	2011
5	Africa Rice	Lowland	99	2011
6	Africa Rice	Irrigated	78	2012
7	IRRI Tanzania	Lowland	122	2012
8	IRRI	Irrigated	107	2013
9	IRRI-ESA-Burundi	Lowland	107	2014

10	Africa Rice	Lowland-Cold tolerant	33	2013
11	IRRI- Tanzania	lowland	84	2013
12	Africa Rice (Tanzania)	Upland	72	2013
13	Africa Rice (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	Africa Rice	Upland MET	102	2014
20	Africa Rice Tanzania	Lowland-Cold tolerant	60	2014
21	IRRI-GSR	Lowland	65	2015
22	China (CAAS)	Lowland-Cold tolerant	8	2015
23	Africa Rice (Bennie)	Lowland and Upland	11	2015
24	Africa Rice	Upland PET	32	2015
25	IRRI, Egypt	Irrigated	111	2015
26	Africa Rice (KAFACI)	Lowland	99	2016
27	Africa rice	Lowland	59	2016
28	Tanzania- PRiDe	Lowland	17	2016
29	Africa Rice	Upland	70	2016
30	Africa Rice Nigeria	Lowland	100	2016
31	Africa Rice	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	Africa Rice- 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	Africa rice-Madagascar	Lowland –ColdTolerant	45	2018
50	IRRI-ESA- Burundi	Lowland	34	2018
	Total		**3336**	

2.2. Variety Development

Before the start of formal rice breeding in Ethiopia, adaptation trials were started in 1980sthroughTanaBeles project for the upland rice ecosystemin 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 Paweand similar agro-ecologies.

The variety evaluation starts from quarantine for one year 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 a variety, a total of five years 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 (Fig. 1). For agronomic and morphological data collection, the standard evaluation system [13] is adopted. Through these stages, different type of data analysis tools/management systems has been used. SAS, Gen stat and R are the major statistical software we used for data analysis.

In the varietal development, high yielding, early maturing, white caryopsis, resistance against key biotic (Blast, sheath rot, brown spot)and abiotic (cold, drought, salinity) stress and high are the major traits taken into consideration. Until to date, 15rainfedupland, 11rainfedlowland 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 Gumarain the lowland rainfed ecologies are under production and brought some impact in improving livelihood of thousands of farmers.

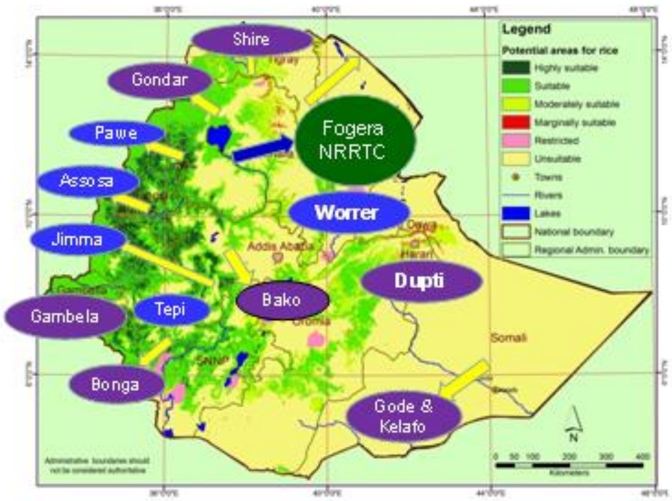


Figure1. *Rice variety testing sites targeting the different growing environments in Ethiopia*

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 [12, 14, 15, and 16]. The G x E interaction may arise when specified genotypes are grown in diverse environments [17, 18]. 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 [19]. Multi-environment variety trials have been conducted to select high yielding varieties with wider adaptation with major disease resistance and early maturing characters [12, 20]. 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).

Table2. *List and description of released rice varieties*

SN	Variety Name	Year of release	Growing ecosystem	Days to maturity	Grain yield (tha^{-1})		Released by (Research center)
					Farmers field	Research station	
1	Shaga (Scrid017-1-4-4-4-1)	2017	Lowland	110-120	3.9-5.0	4.9-6.8	Fogera/EIAR
2	Wanzaye (Scrid006-3-2-3-2)	2017	Lowland	120-130	3.5-3.9	4.5-6.5	Fogera/EIAR
3	Erib (WAB880-1-32-1-2-P1-HB)	2017	lowland	115-125	3.0-4.1	4.7-5.3	Fogera/EIAR
4	Abaye (ARCC16Bar-21-5-12-3-1-2-1)	2017	Lowland	130-145	3.5-4.0	4.4-5.3	Fogera/EIAR
5	Fogera 1(ART15-7-16-30-2-B-B)	2016	Upland	105-120	3.2-3.9	4.2-5.0	Fogera/EIAR
6	Fogera 2 (KOMBOKA)	2016	Lowland	131-139	3.7-4.9	4.2-6.1	Fogera/EIAR

7	Adet (WAB450-1-B-P-462-HB)	2014	Upland	112-120	2.4	4.2	Fogera/EIAR
8	NERICA 13	2014	Upland	104	3.3	3.8	Maitsebri/TARI
9	NERICA 12 (WAB880-1-38-2-17-P1-HB)	2013	Upland	101-132	2.3-3.4	3.5-4.1	Adet/ARARI
10	Hiber (IRGA370-38-1-1F-B1-1)	2013	Lowland	105-141	2.6-3.6	3.4-4.7	Adet/ARARI
11	Chewaqa (YIN LU20)	2013	Upland	160	3.3	4.2	Bako/ORARI
12	Hidassie(WAB515-B-16A1-2)	2012	Upland	100-130	2.2-3.2	3.0-4.2	Adet/ARARI
13	Ediget (WAB189-B-B-B-HB)	2011	Lowland	132.8	3.2	5.2	Adet/ARARI
14	NERICA-15	2011	Irrigated	80-91	5.0	6.2	Dolla/SOPARI
15	NERICA-6	2011	Irrigated	90-110	5.5	6.3	Dolla/SOPARI
16	NERICA-14	2010	Irrigated	80-90	5.0	6.2	Gode/SOPARI
17	Kallafo-1(FOFIFA3737)	2010	Irrigated	90-100	5.0	6.5	Gode/SOPARI
18	Getachew (AD01)	2007	Upland	97-125	2.1	3.0	Adet/ARARI
19	Andassa (AD012)	2007	Upland	111-135	2.5	3.8	Adet/ARARI
20	Tana (AD048)	2007	Upland	109-135	2.4	4.4	Adet/ARARI
21	NERICA-1	2007	uplandirrig.	80-90	3-4	4.7	Gode/SOPARI
22	NERICA-2	2007	uplandirrig.	80-90	3.5	5.5	Gode/SOPARI
23	Shebele(IR688059-76-3-3-3-2)	2007	uplandirrig.	120-135	4.5	5.9	Gode/SOPARI
24	GODE-1(BG-90-2)	2007	uplandirrig.	120-135	4.3	5.7	Gode/SOPARI
25	HODEN (MTU-1001)	2007	uplandirrig.	120-135	4.0	4.7	Gode/SOPARI
26	NERICA-3(WAB-450-IB-P-28-HB	2006	Upland	110	2.9	4.5	Pawe/EIAR
27	NERICA-4(49WAB-450-IB-P-9/1)	2006	Upland	110	3.0	4.8	Pawe/EIAR
28	SUPERICA-1(WAB-4507)	2006	Upland	115	2.3	5.1	Pawe/EIAR
29	Gumara(IAC-164)	1999	Lowland	130	3.0	3.8	Adet/ARARI
30	Tigabe(IREM-194)	1999	Upland	90-97	3.2	3.7	Adet/ARARI
31	Kokit(IRAT-209)-	1999	Upland	90-97	2.8	3.6	Adet/ARARI
32	Pawe-1(M-55)	1998	Upland	125-135	2.0	3.0	Pawe/EIAR
33	VRH 606	2013	Lowland	121		6-7	ViBHA Seeds Eth.(PLC)
34	VRH 640	2013	Lowland	119-121		6-6.8	ViBHA Seeds Eth.(PLC)
35	VRH 654	2013	Lowland	130-135		7.5-8.6	ViBHA Seeds Eth.(PLC)

EIAR: Ethiopian Institute of Agricultural Research; ARARI: Amhara Regional Agricultural Research Institute; ORARI: Oromia Regional Agricultural Research Institute; SOPARI: Somali Pastoral and Agro-pastoral Research Institute; TARI: Tigray Agricultural Research Institute

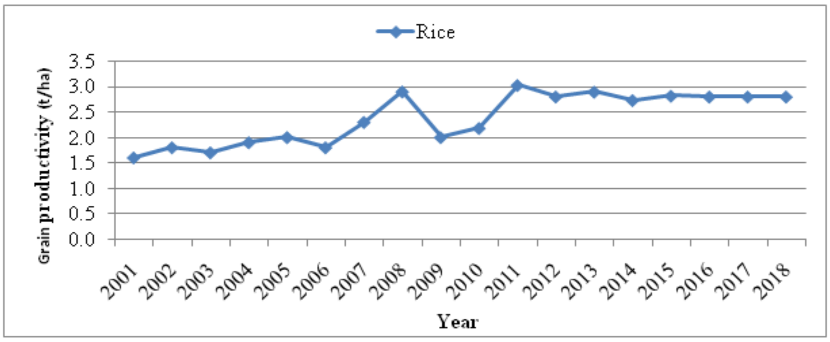
Of the 35 released varieties, 20 (12 upland and 8 lowland) werereleased nationally; 12 varieties under regional research centers (1 upland variety by OARI/Bako research center, 2 Upland varieties by TARI/Shire research center and 9 irrigated varieties by SOPARI/Gode research center). The other 3 lowland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

2.3. Productivity trend in Ethiopia

The overall national mean grain yield productivity of rice in Ethiopia showed a constant increase from 2001 (1.6tones ha^{-1}) till 2008 (2.9tonesha^{-1}) 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 overallrice grain yield productivity increased from 1.6tones ha^{-1} in 2001 to 2.8 tones ha^{-1}in 2017 which was increased by 42.9 %, with 2.5% annual productivity gain the last seventeen years (Fig. 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 tones per hectare the productivity is less than by half (Fig. 4).

The productivity ofrainfed upland rice variety under research station confirmed constant increase from 1998 (3.0 tonesha^{-1}, Pawe-1) until 2016 (4.6 tonesha^{-1}, 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 $tonesha^{-1}$, Gumara) until 2017 (6.8$tonesha^{-1}$, Shaga), 44.1 % yield increase and 2.5 % annually (Fig. 4). Similarly, there is also an increment on grain productivity on irrigated rice varieties from 2007 (4.7 $tonesha^{-1}$, HODEN-1) to 2011 (6.5 $tonesha^{-1}$, 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.



Source: *CSA (2001-2018)*

Figure2. *Mean grain yield productivity of rice in Ethiopia*

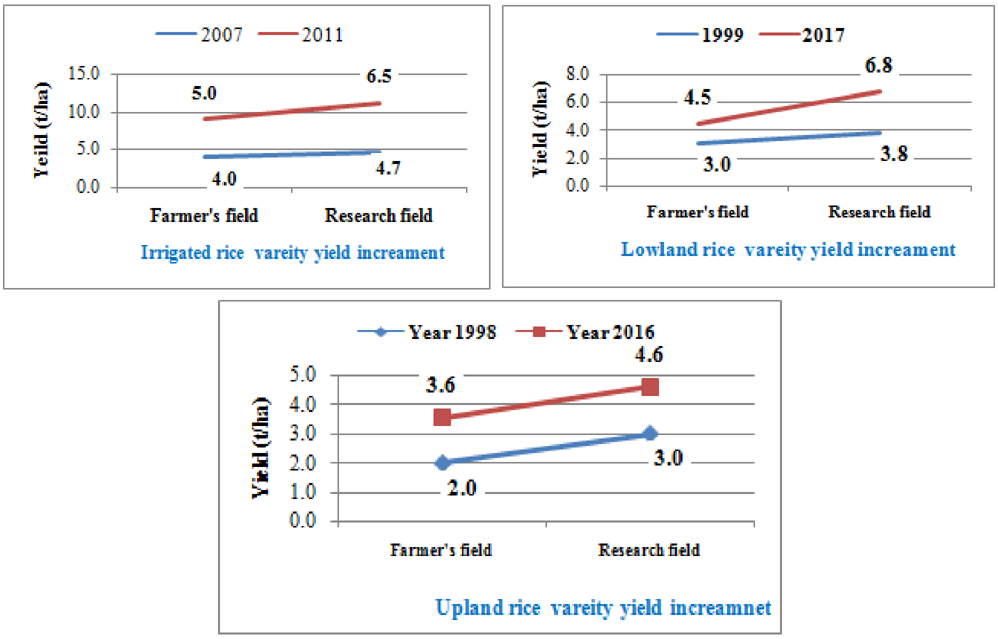


Figure4. *Release rice variety productivity trend for the three ecosystems in Ethiopia*

In comparison to other major cereal crops in Ethiopia, the productivity of rice is second after maize since 2001 (Fig. 5). This scenario revealed that rice can be a potential crop for Ethiopia not only for self-sufficiency but also for export purpose [6]. It will be a good opportunity to Ethiopia to export rice to African countries as all are importer of rice.

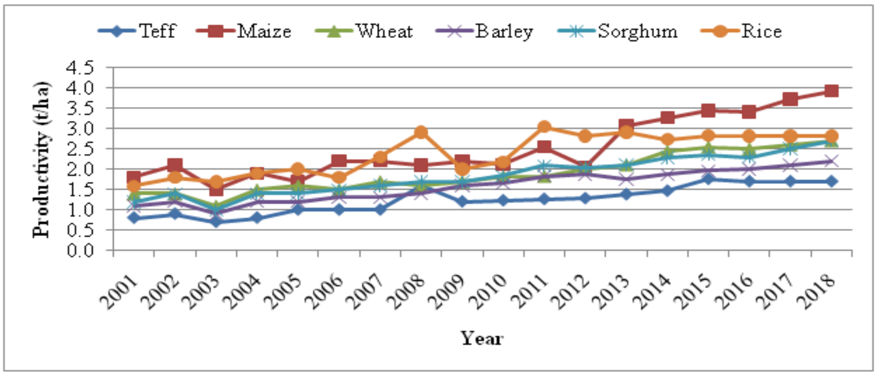


Figure5. *Mean grain yield productivity of major cereal crops (2001- 2018) in Ethiopia*

3. Current Status of Rice Breeding

Rice breeding research in Ethiopia is at its early of development in terms of facilities, human resources and research approach. There are a number of improved technologies and information generated since the start of the rice research. However, the statuses of adoption of these technologies are at slow motion. These may be because of the poor extension service on improved technologies, lack of seed system, and lack of mechanization and absence of irrigation facilities especially for irrigated rice ecosystem.

So far, the rice breeding program entirely relies by introduction of germplasms and passes through serious of evaluation/selection stage. To release a variety, a total of five years can take from introduction to release. Incomplete block design like augmented and alpha lattice designs are commonly used at early evaluation stage (observation and preliminary variety selection). For the national variety trial, complete block design (randomized completely block design) is usually used. The major traits which considered at different stages includes grain yield, disease resistance (blast, sheath rot, brown spot), 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 the quality of the data.

The revenue getting from rice farming is quite 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.

4. 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 got 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 germplasms 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 laboratories (Biotechnology, pathology, entomology, physiology, food science and others), screening facilities for biotic and abiotic stresses, and green house for off season crossing activities. Besides the limited research support is considered as a challenge to advance the research endeavors of the program.

5. Conclusion

Although a number of varieties have been released, only a few are adopted by farmers. Many reasons may be mentioned for that. For example, in South Gondar, where a large contiguous area is used for rice production, farmers prefer to cultivate the variety called X-Jigna. It is a japonica type and introduced from North Korea, and farmers prefer it for the reason that it has good *injera* making quality, a premium price in the market because of its white caryopsis and higher biomass. This suggests that *injera* making quality is an important quality trait to be included in the rice variety development. Although introducing already developed lines elsewhere required less investment and reducing time to release varieties, it is not always recommended. To modernize the rice breeding program for the betterment of the genetic gain and inclusion of costumer preference traits, product-based breeding approach which is market-oriented product design should be apply. Understanding the client needs is the first step followed by market-driven product profile contracts, well designed breeding program and well-designed product testing and delivery. This breeding approach is undertaking under Africa rice and International Rice Research Institute (IRRI). And benchmarking of these two potential institutes can speed up the success of product-based rice breeding approach in Ethiopia.

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