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Research Article

Rice Seed System: Current Practices to Strengthen Early Generation Seed of Climate Resilient Rice Varieties in Ethiopia

Yilikal Melak Assaye*, Ayele Tesfahun Gashu, Esuyawkal Demis Tenaw

Ethiopian Institute of Agricultural Research, Fogera National Rice Research and Training Center, Bahir Dar, Ethiopia

Abstract

The availability of quality rice seed is a critical factor in boosting rice productivity and production in Ethiopia. This study assessed the current practices of early generation and community-based rice seed multiplication and quality control to strengthen the rice seed system in Fogera district, Ethiopia. Community-based seed production and marketing groups played a significant role in rice seed multiplication and distribution, but faced challenges related to limited access to breeder and foundation seed, inadequate technical and financial support, and weak seed quality control mechanisms. Strengthening the capacity of seed producers, enhancing the availability of early generation seed, and improving seed quality assurance systems are recommended to enhance the effectiveness of the rice seed system in the study area. Intervention of large scale demonstration of the early generation rice seed is one of the practical and effective techniques in the rice seed system, which can enhance the better rice seed accessibility. Large scale demonstration of early generation rice seed is also useful for participatory learning on the rice seed production procedures, and rice seed quality management activities in the community. The findings provide insights for policymakers and development practitioners to design and implement interventions that can strengthen community-based rice seed systems in Ethiopia.

Keywords

Rice, Seed System, Early Generation Seed, Community-Based Seed Production, Seed Quality Control, Large Scale Demonstration, Ethiopia

1. Introduction

Rice production was first described in Gambella (1973), the Fogera Plain (early 1980s), and Pawe (1985) [5]. The estimated potential area of rice production in Ethiopia is approximately 30 million ha for rain-fed rice production. There is an irrigation potential of 11 million hectares [6]. Rice is suitable for growing in many parts of Ethiopia: Fogera, Gonder Zuria, Dembia, Takusa and Achefer; the northwestern lowland areas of the Amhara and Benshangul Regions, particularly Jawi, Pawi, Metema and Dangur; the Gameblla regional states of Abobo and Etang Woredas; the southwestern lowlands of the SNNPR region, which encompasses Omorate, Gura Ferda and Menit; and the western highlands of the Oromia Region, which comprises the Illuababora, Wellega and Jimma Zones [5].

*Corresponding author: yilikalmelak9@gmail.com (Yilikal Melak Assaye)

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Rice, which is a relatively new crop in Ethiopia, is recognized as a "millennium crop". The first National Rice Research and Development Strategy of Ethiopia (NRRDS, 2009-2019) was developed to address the challenges in the subsector. Following this, the second National Rice Development II strategy (NRDS-II, 2019-2030) was developed with the objective of enabling stakeholders to coordinate their efforts toward rice sector development [5].

The cultivation of rice is increasing in terms of both area coverage and production, which is due to the existence of interventions in new potential wetland and upland areas. However, the use of imported rice has increased over time in Ethiopia. In addition, 56% of local rice consumption is covered by imported rice (FOSTAT, 2021), which resulted in a considerable decline in the rate of self-sufficiency from 60% in 2008 to 20% in 2016 [5]. Most rice farmers in Ethiopia are smallholders who are producing for household consumption and sell their surplus to village or district markets.

Rice is a staple food for millions in Ethiopa, yet the seed system faces significant challenges. Recent innovations in technology and institutional frameworks offer potential pathways for enhancing seed quality and availability [1]. One of the challenges in the rice seed system is limited capacity of early generation rice seed multiplication in research centers [5]. Rice seed system in Ethiopia is limited by accessing rice seed from unreliable seed sources, ineffective delivery systems, weak linkage among rice seed value chain actors, and other associated challenges (Mulugeta et al., unpublished). [27] demonstrated that weak linkages among seed system actors are related to limited collaboration among the seed actors and due to weak management capacity, limited engagement of the private sector and seed associations during the development of regulatory measures, substantial mismatch in the supply and demand of certified seeds of available crop varieties, inefficient seed dissemination and marketing mechanisms, weak variety release, and a poor seed quality assurance system.

2. Methods

2.1. Seed Source and Variety Selection

The pre-basic seed for rice production could be sourced from the breeder seed maintained under local conditions. These breeder seeds were obtained from foreign institutions such as the International Rice Research Institute (IRRI) and the Japan Germplasm Conservation Center (JGCC) ([13, 15]). The rice varieties commonly multiplied in the region were Fogera-1, NERICA-4, Shaga, and Selam [5].

Pre-basic Seed Production Protocol

The pre-basic seed production followed a well-established genetic and agronomic protocol [17]. The key steps in the genetic seed production protocol included:

1. Maintaining isolation distance
2. Rouging of off-types
3. Field inspections at critical growth stages
4. Seed certification procedures

The agronomic management steps involved:

1. Variety and seed selection
2. Land preparation and farm machinery operation
3. Synchronized planting
4. Water and pest management
5. Harvest and post-harvest handling

Field Inspections and Seed Quality Testing

Two field inspections were conducted, one at the onset of flowering and the other during grain filling [14]. Regular field observations were carried out to ensure timely inspections. After harvest, the seeds underwent processing, laboratory inspection, certification, and packaging. During the laboratory inspection, a representative sample of 50 grams was drawn from the seed lot using a seed divider [10]. The percentage of pure seed was assessed, and the moisture content was determined. Germination tests were conducted on 100 randomly selected seeds from the working sample, with four replications. The average percentage of normally germinated seedlings was recorded as the standard germination percentage [10]. For external inspections, the seed was manually cleaned to remove extraneous materials and empty hulls before the laboratory evaluations.

2.2. Seed Moisture Content

Seed moisture content determination was started during crop cut for post-harvest yield estimation using a 1m by 1m quadrant using a portable seed moisture tester. This parameter was also determined in the laboratory using an oven drying method [9].

2.3. Physiological Quality Test

Germination test was carried out in four replicates of 100 seeds from each sample in pleated paper. After planting, seeds were placed in a germination room maintained at 20 ℃ for 14 days according to ISTA Rules [14]. Normal and abnormal seedlings, un-germinated, and dead seeds were recorded, and the average germination was calculated on the basis of the final count. Seedling vigour index I and II were calculated using shoot and root length and seedling dry weight [2].

3. Results

3.1. Status of Early Generation Rice Seed Production

The pre-basic seed production status of the last five years (2017/18-2021/22) is presented in Figure 1. In all the production seasons the rice pre-basic seed produced more than the quantity of seed demanded every year. A lot of rice was released but, a few varieties had the highest indent among them due to some varieties having better yield and preferable by farmers. Ediget, Shaga, Wanzaye, Fogera-1, Erib, Adet, Abay, NERICA-4, and Selam were produced in the last five years from 2017/18-2021/22. Among these varieties, Shaga, Wanzaye, Fogera-1, and NERICA-4 were produced in all production years. It indicated that these varieties were preferred and had better demand in all production years. Erib, Adet, and Abay produced till 2019/20 for three years (2017/18 to 2019/20) and Ediget produced until 2018/19 for two years (2017/18-2018/19). These indicate that Ediget, Erib, Adet, and Abay rice varieties are dominated by other varieties because the potential varieties were produced in all production years. Selam rice variety was started in the production years 20201/22 which indicated that recently released varieties (Figure 1).

A total of 1496.33 quintals of quality pre-basic rice early-generation seeds were produced in the 2017/18 to 2021/22 cropping seasons (Figure 1), which was an average of 299.266 quintals per year. The highest share of 261.5 and 148 quintals of rice seeds were produced from the variety Shaga in 2020/21, and 2019/20 cropping years respectively. Next to this rice variety, the highest share of early-generation seeds of rice was produced from the Ediget variety (131.63 quintals) in the 2017/18 production year followed by, NERICA-4 (90 quintals), Shaga (78 quintals), and Selam (71 quintals) in the production year of 2021/22. The lowest share of early generation seeds of rice was produced from Abay, Adet, and Erib rice varieties which were 1.11, 2.14, and 5.88 quintals quality pre-basic class of rice seeds produced respectively in the 2017/18 cropping year (Figure 1).

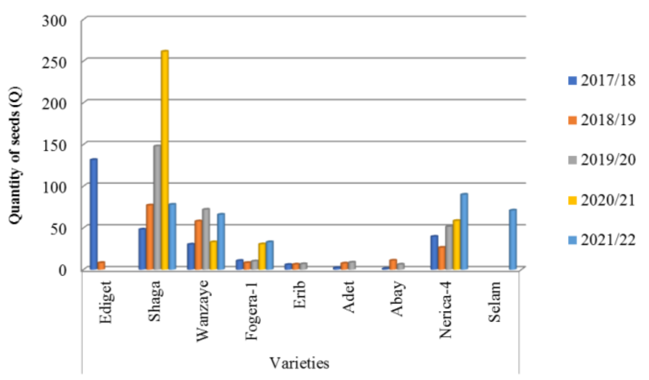


Figure 1. *Early generation rice seed produced (Q) in Fogera during 2017/18-2021/22.*

Seed is the most vital input for crop production and productivity [27]. Rice crop productivity and the quality of production primarily depend upon the quality of seed. So availability of high-quality seeds of high-yielding varieties is essential for crop productivity [5]. Newly released rice varieties need to be rapidly multiplied and made readily available to farmers so they can access and benefit from the genetic improvements. The early-generation seed production, which includes maintaining the improved variety and regularly multiplying small quantities of breeder, pre-basic, and basic seed, is crucial for getting these new varieties into the hands of seed producers as quickly as possible for large-scale seed production. Rice crop cultivation in Ethiopia especially in Fogera has been increasing. This could be elucidated as a result of rice seed producers gradually seeing the great importance of rice seed production. This finding suggests that the increase in rice seed production is a result of the intensification of quality early-generation rice seed production used for large-scale certified seed production. It was indicated that early-generation seed production is important to fulfill the demand of early generation seed and it is important to maintain the genetic potential and identity of a variety and provide a regular supply of high-quality breeder seed, which is the basis for subsequent seed production [16]. Seeds are an essential component and valuable commodity in agriculture, sustained increase in crop production and productivity, and the pillars of farmer's livelihood and food security [24].

3.2. Rice Seed Quality Analysis

Ensuring high seed quality is paramount for successful rice cultivation. Seed vigor significantly impacts crop establishment and yield [1]. The Ethiopian Standards Authority has established specifications for seed quality, providing essential guidelines for producers to follow [2]. Furthermore, the International Seed Testing Association outlines standardized protocols for seed testing that can enhance the quality of seeds in Ethiopia [3]. Research indicates that the vigor and viability of seeds, such as soybean and rice, are influenced by storage conditions and seed handling practices [2]. In Ethiopia, the use of traditional storage methods often compromises seed quality, leading to reduced germination rates [3]. Regular assessment of seed viability is critical, with studies indicating that proper storage conditions can extend seed life significantly, reducing losses and ensuring better yields [4]. To combat these issues, modern seed storage techniques are being encouraged to enhance seed longevity and viability. Furthermore, [17] emphasizes the importance of building capacity in seed quality assurance, highlighting that developing countries need robust frameworks to ensure seed quality across all levels of production.

Maintaining seed quality is important if any seed lot is to meet the expectations of end users. Seed quality assurance is a systematic and planned process for ensuring the genetic, physical, and physiological integrity of the seeds delivered to farmers [26]. Early-generation seeds are expected to meet a high standard of varietal purity and seed quality attributes prescribed by national seed regulations [14]. The seed samples of the officially approved or notified varieties are being sent to the seed testing laboratory for analysis of moisture content, purity, and germination. So the major attributes of the early-generation seed quality status of rice considered in this seed quality analysis were moisture content, physical purity, and germination percentage of the last five consecutive years from 2017/18 - 2021/22.

Moisture content (%)

The average moisture content of early-generation seeds of rice varieties ranged from 9.0-12.5% in the five consecutive years 2017/18- 2021/22 (Figure 2). The maximum moisture content (12.5%) was found in the Shaga variety followed by the Wanzaye variety (12.3%) in the 2021/22 cropping season, whereas the minimum moisture content (9.0%) was recorded from the Abay variety followed by Ediget variety (9.3%) in 2018/19 cropping season (Figure 2). The seed moisture contents in all the production seasons of the five consecutive years meet the seed moisture standard of rice. All rice varieties had moisture content within the acceptable range of 9.0-13.0% and they fulfilled the national standards which are the moisture content of all rice varieties is below the maximum standard of 13.0% (Figure 2).

The result of moisture content indicates that the moisture content of early-generation rice seed meets the standard which is not prone to quality deterioration of seed. If the moisture content is above the standard or higher moisture content in the seed enhances seed deterioration, which reduces the quality of the seed [24]. According to [14] rice seed should be stored below 14.0% moisture content of seed for short-term storage. However, it is better to keep the moisture content of seed below 12% for short-term storage (maximum 9 months), below 11% for intermediate-term (18 to 24 months) storage, and below 10% for long-term storage (3 to 10 years) of rice seed with 30°C and 50% relative humidity [12]. Forever, for quality seed production of rice, it should meet the recommended level of moisture content.

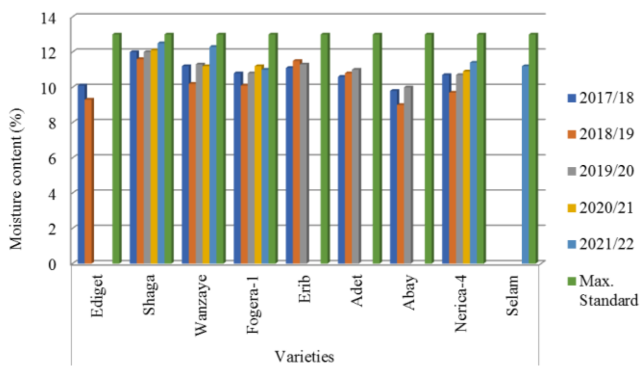


Figure 2. *Moisture content (%) of rice varieties during (2017/18-2021/22).*

Physical purity (%)

Analytical purity analysis is the major attribute of early-generation seed quality status of rice conducted to determine the constituents in the seed lots. The physical purity analysis of the early generation of rice seeds of the last five consecutive years from 2017/18- 2021/22 is presented in Figure 3. The pure seed rate ranged from 98.4% to 99.6%. The highest seed physical purity was recorded by Shaga (99.6%) in the 2022/21 cropping year followed by Wanzaye, Adet, and Abay with 99.8% in 2021/22, 2019/20, and 2017/18 production years. The lowest seed purity was observed on Erib (98.4%) in the 2018/19 cropping year followed by Erib (98.6%), Fogera-1 (98.7%), Erib (98.8%), and Ediget (98.9%) in 2019/20, 2021/22, 2017/18 and 2018/19 cropping years respectively. All rice varieties fit the minimum national purity standard in all production years which is higher than the recommended level of 98% (Figure 3).

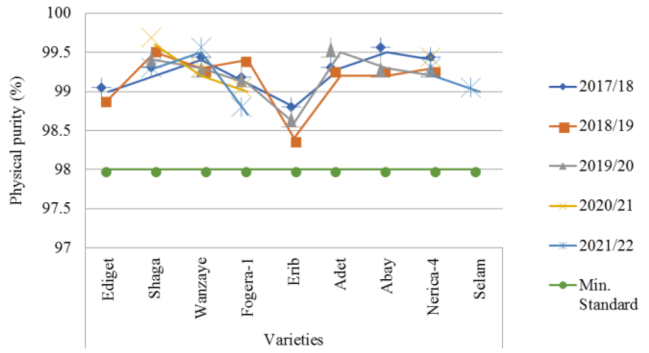


Figure 3. *Physical purity (%) of rice varieties during (2017/18 – 2021/22).*

Generally, early generation rice seed, physical purity or cleanliness appears to be the most important seed quality parameter. If seed lots fail to meet the established analytical purity standards, they are rejected during the quality assurance process. Meeting these purity standards is a requirement for the seed to pass quality checks. So early-generation rice seeds meet the analytical purity standard for next seed production. As a result, early generation seed quality status of wheat and tef in three consecutive years from 2019/20-2021/22, the physical purity percent of all wheat and tef varieties meet the Ethiopian purity minimum standard [10].

Germination (%)

The results of the germination test of early-generation rice seeds are summarized in Figure 4. In the five consecutive years, the germination rate ranged between 96-99%. The maximum seed germination percentage was recorded by the Shaga rice variety (99%) in the 2018/19 cropping year while the minimum seed germination of 96% was observed on Ediget in 2017/18 and 2018/19, Erib in 2017/18, NERICA-4 in 2020/21 and Shaga in 2021/22 cropping years. In all production years from 2017/18- 2021/22, all rice varieties satisfied the national minimum germination standard which is all varieties above the standard rate of 80% (Figure 4).

The high germination rate could be attributed to high-quality management in rice seed production. Germination is the most important function of a seed as an indicator of its viability and worth as a seed [2]. The germination capacity of all rice varieties was recorded above 80%. So the results of the present germination test analysis revealed that the germination percentage of rice seed was found to increase with the application of high-quality management practices in the rice seed production time in all varieties throughout the production years.

Assessment of viability or germinability of commercial seed lots is an essential aspect of seed certification. Viability is the property of the seed that enables it to germinate under conditions favorable for germination in the absence of dormancy [20], while germination reflects the number of seedlings that can produce normal and abnormal seedlings [16]. Seed lot viability is customarily evaluated using a tetrazolium test, while a standard germination test is used to evaluate germination capacity. However, when dormancy is suspected, a common situation for freshly harvested rice, and other crop seeds, a quick biochemical topographical viability test, preferably tetrazolium, is required. Both standard germination and viability tests are conducted following ISTA Rules [14].

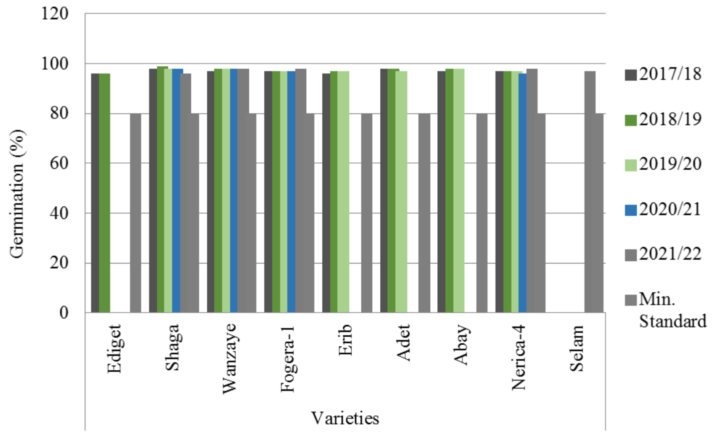


Figure 4. Germination (%) of rice varieties during (2017/18- 2021/22).

3.3. Exploring the Role of Early-Generation Seed Production

Four rice varieties, two upland varieties of New Rice for Africa (NERICA-4) and Fogera-1, were multiplied with the prescribed standards (Table 1) in the required amount for research centers and seed producers, including community-based seed producers. Quality assurance under field conditions and laboratory conditions were conducted both by internal seed inspectors and by external seed inspectors and certified, and then, the rice seeds were distributed to upland rice seed-producing farmer cooperatives and investors in the rice seed system. According to experience, making neighboring farmers land in clusters and producing rice in a synchronous way for all rice seed production practices was effective. However, increasing local market linkages need to be further conducted.

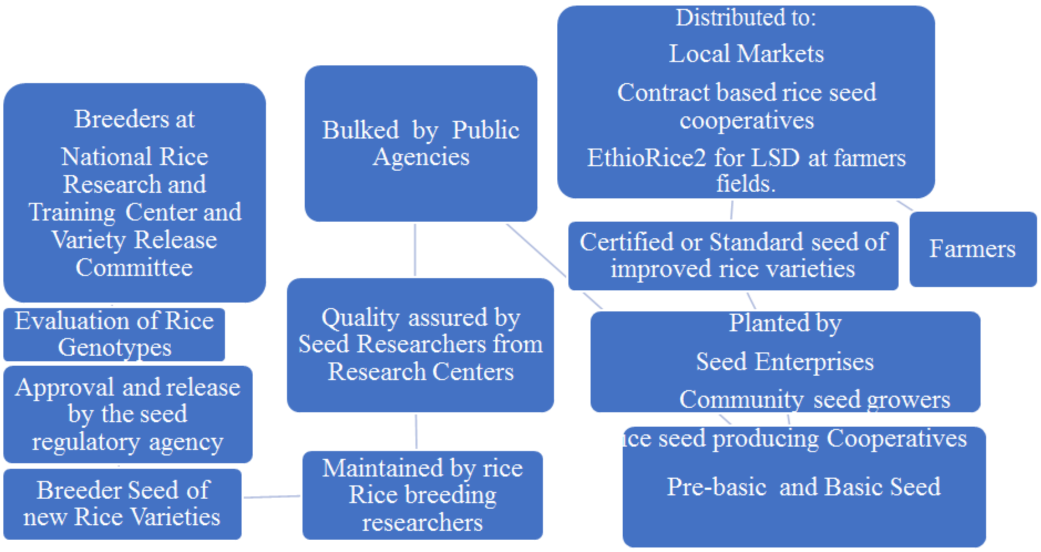


Figure 5. Generic representation of rice EGS and the rice seed system in Ethiopia (own survey).

Results of the External Rice Seed Inspection Laboratory

***Table 1.** Laboratory Analysis of Rice Seed Quality.*

Year	Variety	Lot Size	Purity	Moisture	Germination
2021	N-4	38.5	99.075	11.5	93.75
	Wanzaye	33.28	99.04	12.25	96.75
	Shaga	261.19	99.095	12	96.5
	Fogera-1	22.23	99.1	12.25	94.75
2022	Shaga	78	99.8	11.75	97.25
	Selam	71.78	99.8	12	95.25
	Fogera-1	33	99.45	12	97.25
	Wanzaye	64.7	99.45	12	97.25
	N-4	91	98.28	12	91.07
2023	Selam	88	100	12	94.25
	F-1	21.04	100	11.5	90.75
	Shaga	93	99.85	11.55	97.75
	N-4	51.5	99.87	11.7	84.5
	Wanzaye	18.04	99.82	11.6	89.25

3.4. Seed System in Ethiopia

It is revealed under Figure 6 the three categories in the rice seed system. The informal, intermediate, and formal sectors make up the three divisions of the seed system ([11, 24]). The informal seed system involves farmers choosing, multiplying, storing, using, and distributing seeds through local markets and social seed networks, providing a wide range of crop varieties in large quantities of seeds. This includes both conventional varieties and "obsolete" improved varieties that were previously published by the official system [27]. The formal seed system encompasses both public and private sector organizations involved in plant variety production, variety release, germplasm conservation in gene banks, and other linear activities along the seed value chain [4]. The formal system is still at an early stage of growth and is dominated by public institutions [8]. The intermediate seed system involves business-oriented community-based groups, such as producer cooperatives or unions, that focus on multiplying and distributing non-certified seeds of either modern or local varieties ([7, 16]).

In Ethiopia, the Quality Declared Seed (QDS) scheme requires seed producers to employ robust internal quality assurance and declare the quality of their seed based on limited quality control established by the regulatory authorities (Regional Bureaus of Agriculture), e.g., inspection of 10% of the total seed produced instead of undergoing the full inspection and quality testing procedures [21]. This is intended to reduce the burden on seed regulatory authorities and hasten community-based production and marketing.

Approximately 99% of the rice seed system in Ethiopia falls under the informal category, underscoring the need to strengthen the rice seed system [22]. The absence of a legal seed certification process and the lack of quality control mechanisms pose significant challenges, preventing the assurance of minimum quality standards and adversely affecting productivity [4].

The Maderie rice seed multiplication cooperative has been established and supported in the Fogera district of Ethiopia for the past decade. This cooperative operates within the Guna union. The cooperative has received assistance and support from various entities, including:

1. The Fogera National Rice Research and Training center
2. The Fogera district office of agriculture
3. The MEDA project

The formal seed sector in Ethiopia comprises institutional operations involved in various aspects of seed development, such as creating improved varieties, multiplication, processing, storage, and distribution to farmers. This sector includes:

1. Large private firms
2. Small private seed enterprises
3. Public seed enterprises

4. Research institutions

Research centers play a pivotal role in the multiplication of Early Generation Seeds (EGS), which serve as the foundation for further breeding and development.

Despite being established around six decades ago, the formal seed sector in Ethiopia still faces limitations. It primarily focuses on a small number of major crop varieties developed by agricultural researchers.

This indicates that the formal seed sector's scope and impact are currently confined to a select range of crops, leaving many other varieties and agricultural practices reliant on the informal and intermediate seed systems [18].

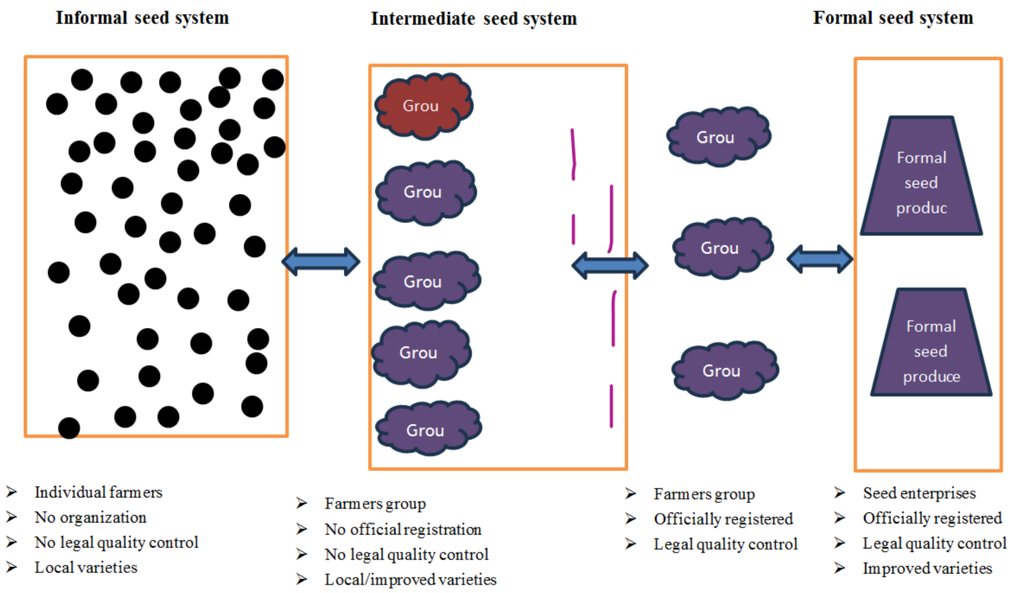
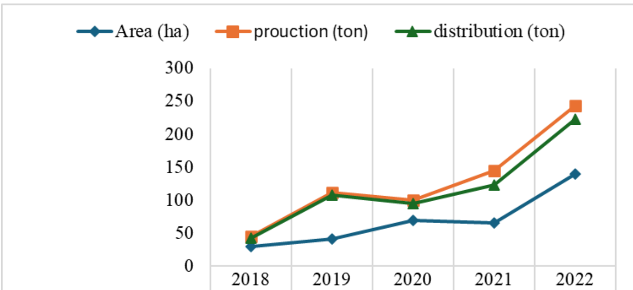


Figure 6. *Continuous movement of seed system, adapted from FAO.*

The Figure 7 shows an increasing trend in the cultivated land area dedicated to rice seed production, indicating growing interest and investment in rice seed cultivation. However, there is no significant increase in rice seed production, suggesting potential limitations in agricultural practices, environmental conditions, or seed production constraints. Similarly, the distribution of rice seeds remains relatively stable, indicating efforts to maintain a consistent supply for farmers.

It is an evident that the formal seed sector, specifically seed enterprises, has limited involvement in rice seed production. However, the Fogera National Rice Research and Training Center, along with farmers' organizations, plays a commendable role in various stages of rice seed production. The Fogera National Rice Research and Training Center is actively involved in the production of Early Generation Seeds (EGS) particularly pre-basic seed in greater amount. Their contribution in these stages is crucial for ensuring the availability of high-quality foundation seeds for further multiplication. Additionally, farmers' organizations are actively engaged in basic and certified seed production. Their involvement in these stages of seed production is commendable, as it helps bridge the gap left by the limited participation of formal seed enterprises. These organizations play a vital role in multiplying and distributing quality seeds to meet the demands of farmers. The five year National Rice Flagship Program indicated that organizing and supporting the rice seed producing cooperatives is crucial to strengthen the rice seed system [21].

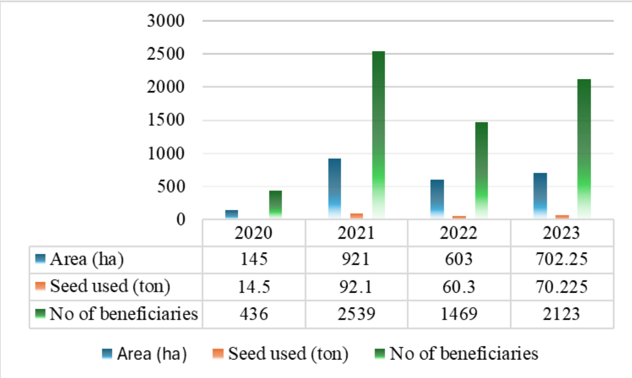


	2018	2019	2020	2021	2022
Area (ha)	29.63	41.308	69.595	65.57	139.043
proution (ton)	44.55	110.8	100.5	144.54	243.865
distribution (ton)	42.9	107.725	94.825	123	222.38

Figure 7. *The role of Guna union in rice seed production.*

The LSD approach has proven to be successful in promoting the adoption of improved rice varieties and strengthening the rice seed system. The graph in Figure 8 illustrates the progress achieved over a four-year period. The area coverage of improved rice varieties has significantly increased, with 145 hectares in 2020, 921 hectares in 2021, 603 hectares in 2022, and 702.25 hectares in the 2023 production season. This expansion in area coverage demonstrates the growing acceptance and adoption of modern rice technologies among farmers. Furthermore, the graph also indicates the number of beneficiaries who have benefited from the LSD approach. The number of beneficiaries increased steadily over the four years, with 436 in the first year, 2549 in the second year, 1469 in the third year, and 2123 in the fourth year. This indicates the successful dissemination and adoption of improved rice varieties among a growing number of farmers. The dominance of the Shaga variety in terms of area coverage highlights its popularity and suitability for the local rice production context. The LSD approach has played a crucial role in promoting the adoption of this variety and strengthening the overall rice seed system.

Overall, the LSD approach has effectively contributed to the dissemination of rice technologies to the informal seed system, leading to improved productivity and agricultural outcomes in the rice sector. The significant increase in area coverage and the growing number of beneficiaries are clear indicators of strengthening the informal seed system.



	2020	2021	2022	2023
Area (ha)	145	921	603	702.25
Seed used (ton)	14.5	92.1	60.3	70.225
No of beneficiaries	436	2539	1469	2123

Figure 8. *Rice LSD in Fogera plain and new rice producing areas.*

Bottlenecks

1) Inadequate access to suitable land for multiplying rice early generation seed (EGS) for newly released lowland rice varieties.
2) Poor rice seed marketing channels to encourage private investment.
3) Lack of availability of sufficient pre-basic seed from research centers.
4) Lack of financial resources to multiply rice EGS.
5) Lack of technical know-how and mechanized equipment and facilities to maintain EGS.

Proposed Solutions

1) Inadequate access to suitable land for multiplying rice EGS:
   a. Establish partnerships between research institutes, government, and private sector to identify and allocate suitable land for EGS multiplication [27].
   b. Provide incentives and subsidies to farmers and landowners to make their land available for EGS production [27].
   c. Explore the use of community-owned or public land for EGS multiplication [27].
2) Poor rice seed marketing channels to encourage private investment:
   a. Improve seed distribution and marketing infrastructure, such as establishing seed hubs, cooperatives, and private agro-dealer networks [27].
   b. Provide market information and linkages between seed producers and potential buyers [25].
   c. Offer financial incentives and credit facilities to encourage private sector investment in rice seed production and distribution [25].
3) Lack of availability of sufficient pre-basic seed from research centers:
   a. Strengthen the capacity of research centers to produce and maintain adequate quantities of pre-basic seed [27].
   b. Establish seed multiplication contracts between research centers and private/public seed producers to ensure a steady supply of pre-basic seed [27].
   c. Invest in the infrastructure and equipment needed for pre-basic seed production at research centers [27].
4) Lack of financial resources to multiply rice EGS:
   a. Establish public-private partnerships to share the costs and risks of EGS multiplication [27].
   b. Provide low-interest loans, subsidies, or other financial support mechanisms to seed producers for EGS multiplication [27].
   c. Explore alternative financing models, such as crowdfunding or community-based seed funds [27].
5) Lack of technical know-how and mechanized equipment and facilities to maintain EGS:
   a. Provide training and capacity-building programs for seed producers on best practices in EGS multiplication and maintenance [27].
   b. Facilitate the acquisition of appropriate equipment and infrastructure (e.g., seed processing units, storage facilities) through subsidies or leasing programs [27].
   c. Encourage knowledge-sharing and collaboration between experienced seed producers and newer entrants to the industry [25].

Access to Quality Seed: Many smallholder farmers struggle to access quality seeds, which limits their ability to adopt improved varieties [12]. The disparity in seed availability can hinder efforts to enhance overall food security.

Infrastructure and Storage: Poor infrastructure and inadequate storage facilities lead to significant seed losses. [13] underscore the importance of proper storage conditions in extending seed viability, yet many farmers lack access to these facilities.

Policy Constraints: Existing policies may not adequately support the diversification and resilience of seed systems. [14] discuss the need for policy reforms that align with the realities faced by smallholder farmers, ensuring that they can benefit from advancements in seed technology and practices.

Coordination Among Stakeholders: Effective coordination among various stakeholders, including government agencies, research institutions, and farmers, is critical for a sustainable seed system. Kifle et al. [25] analyze the roles, responsibilities, and linkages of seed system actors in Central Ethiopia, highlighting the need for better collaboration to improve seed accessibility and quality.

3.5. Current Practices in the Rice Seed System

3.5.1. Seed Quality Assurance

Ensuring high seed quality is paramount for successful rice cultivation. Seed vigor significantly impacts crop establishment and yield [1]. The Ethiopian Standards Authority has established specifications for seed quality, providing essential guidelines for producers to follow [2]. Furthermore, the International Seed Testing Association outlines standardized protocols for seed testing that can enhance the quality of seeds in Ethiopia [3]. Regular assessment of seed viability is also critical, with studies indicating that proper storage conditions can extend seed life significantly, reducing losses and ensuring better yields [4].

3.5.2. Technological and Institutional Innovations

Innovations in seed production and distribution systems are essential for improving access to quality seeds. The importance of technological advancements and institutional reforms in supporting marginalized farmers, particularly in enhancing their access to improved seed varieties [5]. Ethiopia’s seed policies and institutional frameworks are pivotal in shaping the rice seed system. The National Seed Policy emphasizes the importance of quality seed production and distribution as a means to improve agricultural produc tivity [22]. Furthermore, the Ethiopian Agricultural Transformation Agency (ATA) has introduced strategies aimed at systemic challenges within the seed sector, enhancing market access and seed availability [6]. This includes prioritizing interventions that facilitate increased production of high-quality seeds and improving the infrastructure necessary for seed distribution. [18] propose an integrated seed sector development framework that aligns practices, programs, and policies, which can be instrumental in creating coherence within Ethiopia's seed systems.

3.5.3. Farmer Seed Networks

Farmer seed networks have been identified as critical components of the seed system, providing informal channels for the exchange of seeds among smallholders. However, misconceptions about their contributions often undermine their potential [8]. Strengthening these networks can enhance access to diverse rice varieties, including climate-resilient options.

3.5.4. Community-Based Seed Networks

Farmer seed networks can significantly enhance local seed availability and diversity, fostering resilience against climatic shocks. In Ethiopia, these networks can serve as vital conduits for integrating traditional knowledge and practices into modern seed systems [7]. The political economy of seed systems in Ethiopia, noting the necessity for decentralized governance to empower local farmers. By strengthening community-based networks, farmers can better access climate-resilient varieties and share best practices for cultivation [8]. This approach is supported by [20], who note that understanding the seed systems smallholder farmers use is critical for improving agricultural productivity.

3.5.5. Climate Resilience and Early Generation Seed Production

The Ministry of Agriculture has initiated programs aimed at promoting climate-resilient rice varieties to address food insecurity exacerbated by climate change [21]. [23] provide insights into the status of early generation seed production at research centers, identifying both challenges and opportunities for scaling these practices. Integrating climate-smart agricultural practices into seed production is crucial for enhancing resilience, as these practices can help mitigate the effects of climate variability on rice yield [22]. [19] discuss the principles and practices of seed production, emphasizing the necessity of robust production systems for maintaining quality and variety in seed supply.

4. Conclusion

The strengthening of early generation seed systems is crucial to ensure the widespread adoption of climate-resilient rice varieties in Ethiopia. This study has outlined the current practices and key achievements in this regard, highlighting the critical role played by quality evaluation and large-scale demonstration activities.

The quality control protocols and procedures established have been instrumental in maintaining high standards throughout the early generation seed production process. Regular quality checks and the implementation of best practices for storage and handling have ensured that the seed distributed to farmers meets the necessary quality requirements. This, in turn, has built trust and confidence in the new climate-resilient varieties among farmers and other stakeholders.

The large-scale demonstration plots have been equally impactful, allowing farmers and extension agents to witness firsthand the superior performance of the climate-resilient rice varieties. The data collected from these demonstrations has provided tangible evidence of the varieties' advantages, such as higher yields, improved disease resistance, and enhanced resilience to climate stresses. This information has been crucial in convincing farmers to adopt the new varieties and integrate them into their farming systems.

Moving forward, it will be important to sustain and scale up these efforts to strengthen the early generation seed system.

Continued investment in quality control measures, expansion of demonstration plots, and strengthening of the linkages between research institutions, seed producers, and farmers will be crucial to ensure the widespread availability and adoption of climate-resilient rice varieties in Ethiopia. By doing so, the country can enhance its food security, improve the livelihoods of smallholder farmers, and build resilience to the impacts of climate change.

Abbreviations

LSD	Large Scale Demonstration
MoA	Ministry of Agriculture
SNNPR	South Nations Nationalities and Peoples Representative

Author Contributions

Yilikal Melak Assaye: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Writing – original draft

Ayele Tesfahun Gashu: Formal Analysis, Writing – review & editing

Esuyawkal Demis Tenaw: Methodology, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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