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PEARL MILLET, THE HOPE OF FOOD SECURITY IN MARGINAL ARID TROPICS: IMPLICATIONS FOR DIVERSIFYING LIMITED CROPPING SYSTEMS

Ademe Mihiretu✉, Netsanet Assefa, Adane Wubet

Sekota Dry-Land Agricultural Research Center, Ethiopia

Abstract. Pearl millet has great potential to withstand climate-related risks in marginal areas. However, much remains unknown as to how it contributes to income and food security at the smallholder level. As a result, this study assessed the contributions of pearl millet to the farmers' income and food security, its production constraints, and connections between stakeholders in the marginal arid tropics of Northeast Amhara. The technology was promoted for five (2015–2019) production years, and data from 223 samples were analyzed. The new pearl millet technology provided better yield (1420 $kg \cdot ha^{-1}$) and net return (42328 ETB ha^{-1}) than sorghum, even in difficult climatic conditions. Despite the higher cost of production, its additional returns (31638) and effective gains (28838) were higher across the years. The results of the sensory evaluation revealed that "Enjera", "Tella", Bread, and Porridge were the farmers' 1st, 2nd, 3rd, and 4th food type choices of pearl millet, respectively. The trend towards acceptance of the technology made up a large number of the farmers, as 79.5% of those who participated applied the full technology package. Those who did not apply the full package did so due to labor shortages, technological complexity, and insufficient practical training. Therefore, climate-smart pearl millet crop technology is recommended for better and consistent production in marginal arid-tropical areas.

Keywords: climate change, food security, pearl millet technology, stakeholder connections

INTRODUCTION

Farmers in arid and semi-arid regions have been badly affected by climate change, but most of them continue to derive their livelihood from farming using different drought-resistant crop varieties (Choudhary et al., 2021). In this context, climate-smart small millets such as pearl millet (*Pennisetum glaucum* (L.) R. Br.) can play a critical role in addressing water scarcity and high temperatures as they can endure drought and other extreme conditions (Heuzé and Tran, 2015). They also benefit resource-poor and rain-fed farmers by reducing the crop duration and water requirement by almost 30 days and 75%, respectively (Zhang et al., 2021). Pearl millets are cereals grown globally in dry, semi-arid, and sub-humid drought-prone agroecosystems. Millets have been common food staples in human history, particularly in the semi-arid tropics of Africa. They are major sources of energy and protein for about 130 million people in sub-Saharan Africa (Alexandratos, 2009). Therefore, to recognize the benefits of millets for better production and nutrition, a better environment and life in the face of climate change, the United Nations General Assembly declared 2023 to be the 'International Year of Millets' (http://www.fao.org/millets-2023).

Worldwide, there are nine types of pearl millet varieties, of which six are available in Africa (Shivhare and Lata, 2019). The area where pearl millet is important

✉Ademe Mihiretu, Sekota Dry-Land Agricultural Research Center, Sekota, Ethiopia, e-mail: ademe78@yahoo.com.sg; https://orcid.org/0000-0002-2861-5694

falls within low agricultural potential, low market access, and low population density production domains in Eastern and Central Africa. These include, among others, the lowland areas of Eritrea, Ethiopia, and western and northern Sudan (Jukanti et al., 2016). In the arid lowlands of Eastern Amhara, where goats and sorghum are the main source of livelihoods, crop production has deteriorated over time due to the short and erratic rainy season and distribution (Mihiretu et al., 2019b). Pearl millet also provides the opportunity for reliable harvest, food, and nutrition under erratic and scanty rainfall with low soil fertility (Jaiswal et al., 2018). Upgrading production, storage, and utilization of pearl millet may significantly contribute to household food security in the area. The substantial importance of pearl millet in agricultural extension and rural development efforts is due to its better adaptability to marginal areas with narrow livelihood options (Faye et al., 2019).

In Ethiopia, only one pearl millet variety, named 'Kola-1', has been released for production in marginal dryland parts of the country (Saba et al., 2015). Even in the fragile climatic conditions of Eastern Amhara, where sorghum is not productive, pearl millet bids yield within 60–70 maturity days on average. Having all these vital traits of pearl millet, the Sekota Dry Land Agricultural Research Center stretched the adaptability of the nationally released variety to its parched lowland mandate areas and found it to be successful. The study was carried out mainly to promote pearl millet technology as an alternative to sorghum-based cropping systems in the marginal arid tropics of Northeast Ethiopia. The specific objectives were to:

a) Introduce and promote the contributions of pearl millet technology[1] to smallholder farmers' income and food security in marginal dryland areas,
b) Identify the major constraints in pearl millet production and technology demand creation,
c) Assess the trend lines and stakeholders' connections in technology multiplication and diffusion.

[1] In this study, "Pearl millet technology" stands for planting/sowing improved pearl millet (Kola-1) variety in a row, using recommended fertilizer (100/50 kg ha^{-1} DAP/UREA) and seed (10 kg·ha^{-1}) rates, as well as optimum (3×) tillage and proper weed management (2×) (Mihiretu et al., 2019b).

MATERIALS AND METHODS

Description of the study area

About 23 districts in the Tekeze lowland sorghum and goat livelihood zone are classified as arid agro-pastoral (AAP[2]) farming systems and vulnerable to severe water stress and drought (Mihiretu et al., 2019a). Two districts that represent the AAP farming system in Northeast Ethiopia were selected for the study. Abergelle district is located at 13° 01′ 37.50″ N latitude and 38° 58' 36.50" E longitude, having an altitude range of 1150-1500 meters above sea level (m.a.s.l) (Mihiretu et al., 2021). Its annual mean rainfall ranges between 250-750 mm, while its average temperature varies between 23-43°C annually. Ziquala district is located at 13° 09' 60.00" N latitude and 38° 29' 59.99" E longitude, with an altitude of 1462 m.a.s.l. The annual average rainfall and temperature of the district were 255 mm and 42°C, respectively (Mihiretu et al., 2021). The districts' annual rainfall is bimodal, short, and erratic, with two months duration usually from the end of June to mid-August (Mihiretu et al., 2019a). Crop farming in these areas is limited to the cultivation of some drought-resistant sorghum and lowland pulse crops (Mihiretu et al., 2020).

Design and sampling procedure

The study adopted a mixed research approach. The first phase of the study was demonstrating the contributions of pearl millet to smallholder farmers' income, food, and nutritional security as an alternative crop to sorghum. Two districts in the AAP farming system, i.e., Abergelle and Ziquala, were selected purposively based on adaptation trial results in Northeast Ethiopia. The promotion was launched for five production years (2015–2019) involving 750 farmers who had farmlands in a cluster. The average farm size allocated per farmer was between 0.25-0.5 ha, to reach a large number with the new pearl millet technology. Training was given to participant farmers to create awareness about the crop and its production packages. Planting and other agronomic management practices were done as per the recommendations (Mihiretu et al., 2019b).

[2] AAP system is characterized by a dry and hot climate with annual precipitation ranging from 300 to 750mm with average daily minimum and maximum temperatures of 21 and 41°C, respectively (Dudhate et al., 2018).

The second phase of the study was focused on wider technology demand creation, major production constraint documentation, and potential stakeholder identification and connection building, which are likely to aid the subsequent up-scaling and diffusion of pearl millet. A familiarization workshop was organized to share duties and responsibilities among the key stakeholders, who signed a memorandum of understanding (MoU) (Mihiretu, 2019). The main stakeholders were agricultural development experts, researchers, and Non-governmental Organizations (NGOs) working for rural development in the area. The study was hence not only designed to increase the farmers' knowledge but also to improve stakeholders' connections and sense of duty in the technology promotion process. Using systematic sampling, about 223 (30%) farmers were selected using an approximate sampling interval of 3 (Eq. 1) from the total 750 pearl millet-producing population.

$$K = \frac{N}{n} \tag{1}$$

Where: K – sampling interval, N – total pearl millet producing population, n – sample size.

Data collection and analysis

The quantitative data, such as the socioeconomic characteristics of the studied farmers, farm management practices, grain, and biomass yield, as well as the benefits and costs of pearl millet technology were collected using a semi-structured questionnaire. The qualitative data, i.e., perception and demand of pearl millet technology, sensory preference of food items, technology application and constraints as well as stakeholder connections in the promotion were collected. Field days were also organized per year to promote the technology to the wider community. The collected quantitative data were analyzed in descriptive statistics, percentage yield increase (Eq. 2), technology gap (Eq. 3), extension gap (Eq. 4), and technology index (Eq. 5) using the formula of Mihiretu et al. (2019b). In this study, the technological index was operationally defined as the technical feasibility attained due to the implementation of full production package components.

$$YI\ (\%) = \left\{ \frac{Y_{pearl} - Y_{sorg}}{Y_{sorg}} \right\} \times 100 \tag{2}$$

$$TG = Py - Dy \tag{3}$$

$$EG = Dy - P_r y \tag{4}$$

$$TI = \left\{ \frac{Py - Dy}{Py} \right\} \times 100 \tag{5}$$

Where: Py – potential yield, Dy – demonstration yield, Y_{pearl} – yield of pearl millet in farmers' field, Y_{sorg} – yield of sorghum in farmers' field, YI (%) – percentage yield increase, TG – technology gap, EG – extension gap, TI – technology index.

To assess the profitability of pearl millet technology, total variable cost (TVC), gross return (GR), net return (NB), benefit-cost ratio (BCR), additional cost (AC), additional returns (AR), effective gain (EG), and sensitivity analysis were calculated (Meena and Singh, 2017). The prevailing farm gate price was used to value the costs and returns of production on a hectare basis. TVC is the sum of input costs that vary, while GR is the product of total yield by the farm gate selling price. NR is the difference between GR and TVC. BCR is the ratio of GR to TVC, and if the ratio is less than 1, the technology is not profitable. AC is the production cost difference between sorghum and pearl millet, but AR is the change in GR between them. The EG is the variation of AR and AC (Meena and Singh, 2017). As well as this, farmers' perceptions and demands were assessed using descriptive statistics and Likert scale to calculate the sum of the scores (Eq. 6) and average scores[3] (Eq. 7) of different items (Mihiretu, 2019). The Cronbach's alpha was checked for internal consistency among Likert-type questions (Table 5b). The sensory preference of different pearl millet food items was evaluated using the pair-wise ranking method (Mihiretu et al., 2019b). The major constraints of pearl millet technology application were ranked according to their severity and converted into percentage positions using Garrett's ranking method (Garret and Woodworth, 1969). The position (Eq. 8) of each rank is converted into a score and referenced with Garrett's table (Table 6b). The positive and negative sides of the stakeholders involved in pearl millet promotion were assessed via SWOT (strengths, weaknesses, opportunities, threats) analysis (Mishra et al.,

[3] If the average score is greater than 3.51, the farmers have a good perception of the technology. If the average score is 2.51–3.50, the farmers have no confidence in the technology. If the average score is below 2.50, the farmers do not have a good perception of the technology (Mishra et al., 2018).

2018). The qualitative field day data were explained in thematic-oriented narration.

$$SS = \sum_{i=1}^{S} SD, D, NAD, A, SA \tag{6}$$

Where: SS – sum of scores, SD – strongly disagree, D – disagree, NAD – neither agree nor disagree, A – agree, SA – strongly agree

$$\text{Average score} = \frac{\text{Sum of score}}{\text{Sample size}} \tag{7}$$

$$\text{Percent position} = \frac{100\left(R_{ij} - 0.5\right)}{N_j} \tag{8}$$

Where: R_{ij} – rank given for i^{th} constraint by j^{th} individual, N_j – number of constraints ranked by j^{th} individual.

RESULTS AND DISCUSSION

Socioeconomic features and agronomic practices of farmers

The socioeconomic characteristics of farmers are described in Table 1. The average age and farm experience of the farmers were 43 and 19.3 years, respectively. Most of them were married, and the majority of the households were male-headed, while the rest (16.8%) were female-headed (Table 1). The family size per household was 5.6 on average, which indicates that there was sufficient labor per household for the technology package application. The educational status of farmers defines their technology application habits. 29% of the farmers were illiterate but the rest were literate, with knowledge ranging from reading and writing to primary education, but the literate farmers' role in the community is only limited to religious involvement.

All the farmers who participated in pearl millet promotion got training, but 21.3% of them agreed that the training provided was not adequate to apply the technology (Table 1). The agronomic literature suggested that 'three times tillage is an optimum level' for pearl millet production (Saba et al., 2015). Therefore, 81.2% of the farmers tilled at a sufficient level (3x), while the remaining ones tilled below and above the optimum level.

Yield performance and gaps in pearl millet technology

The mean yield of pearl millet (1420 kg ha^{-1}) had a 102.9% yield advantage over the existing sorghum yield (700 kg ha^{-1}) in similar production years. The stalk

Table 1. Household and farm characteristics of participant farmers, *n* = 223

	Variables	Freq.	%	Mean
Socioeconomic characteristics	Age (years)	–	–	43
	Farming experience (years)	–	–	19.3
	Family size (numbers)	–	–	5.6
	Female headed households	38	16.8	
	Educational status			
	· Literate	158	71	
	· Illiterate	65	29	
	Community participation			
	· Religious positions	67	41.3	
	· Political positions	9	5.8	
	· No participation	82	52.9	
	Farmers who got training	223	100	
	Was it sufficient for practice			
	· Yes	176	78.7	
	· No	47	21.3	
Agronomic practices	Farmland tillage frequency/status			
	· Poor	9	4.9	
	· Enough	180	81.2	
	· More than enough	31	13.9	
	Planting time			
	· On time	191	85.8	
	· Late	32	14.2	
	Weed management			
	· Weed problem	12	7.7	
	· Good management	211	92.3	
	Full technology package usage			
	· Yes	177	79.5	
	· No	46	20.5	
	Constraints in package application			
	· Yes	155	69.5	
	· No	68	30.5	
Technology demand	Interest to use by next years			
	· Yes	192	85.9	
	· No	31	14.1	
	Suggested for neighbours to use			
	· Yes	201	90	
	· No	22	10	

Source: own elaboration

Table 2. Likert item statements' reliability test statistics

Cronbach's alpha	Cronbach's alpha based on standardized items	Number of items
0.735	0.788	11

Source: own elaboration

yield of pearl millet was also comparable to sorghum stalk yield (Table 1). The increase in pearl millet yield over sorghum was because the former is better resistant to water scarcity and higher temperatures than sorghum in the study areas. Singh et al. (2018) similarly stated that the yield increase of new pearl millet technology over the usual crop might be due to better adaptability or being quite environmentally friendly. The yield of pearl millet was compared with the potential yield and demonstration yield in frontline farmers' fields to estimate the technology gap, extension gap, and technology index.

Technology gap: The results (Table 3) revealed that the technology gap was on average 400 $kg \cdot ha^{-1}$. The technology gap may be attributed to variations in soil fertility status, inconsistent weather conditions, and the management practices used for specific crop cultivars under trial and demonstration fields. This result was found to be similar to the findings of Mishra et al. (2018), who identified that location-specific recommendations appear to be necessary to bridge gaps.

Extension gap: The extension gap between the frontline demonstration plots and the farmers' land was recorded at 180kg ha^{-1} on average (Table 3). The extension gap in this study indicates that there is a need to motivate farmers to adopt all of the recommended pearl millet production technologies. Improvement in local farmers' practices for the adoption of area-specific farm technology is an option for scientists for enhanced crop productivity (Mihiretu et al., 2019b). Extension yield gaps are indicators of a lack of awareness of the adoption of improved farm technologies by farmers. This result is similar to Yadav et al. (2021), who reported that location-specific mediations may have a massive effect on crop productivity improvement.

Technology index: The 20% technology index demonstrates the gap between technologies developed and demonstrated in frontline farmers' fields (Table 3). It depicts the possibility of increasing pearl millet yield through full-package technology promotion in the future. The higher technological index revealed that there is still room for improving the pearl millet yield through intensive package application. The social environment, in terms of irrational attitudes, illiteracy, and impassive behaviors toward the adoption of new technologies, is a major limiting factor to improving agricultural productivity (Yadav et al., 2021).

Economic analysis and profitability

The benefit-cost analysis shows that the gross return (50328 ETB ha^{-1}), and net return (42328 ETB ha^{-1}) of pearl millet technology were higher than those from existing sorghum production. The increased returns of pearl millet might be due to its better adaptability to marginal areas, as well as the use of improved management practices. These findings are in line with Singh et al. (2017), who described that farmers who did not adopt new production technologies and/or were unable to afford the input costs ended up with low yield returns and financial benefits. Despite pearl millet technology having a higher average additional cost, it also had higher additional returns and effective gains compared to sorghum production (Table 4). The greater additional

Table 3. Productivity, technology gap, extension gap, and technology index of pearl millet

Pearl millet	Range yield index ($kg \cdot ha^{-1}$)	Mean yield ($kg \cdot ha^{-1}$)	SD	Yield index (%)	Technology gap ($kg \cdot ha^{-1}$)	Extension gap ($kg \cdot ha^{-1}$)	Technology index (%)
Grain	980-1700	1 420	1.787	102.9	400	180	20
Stalk	1300-2150	1 570	6.233	–7.6	500	430	25

Note: Farmers' grain (stalk) yield of sorghum = 700 (1700) kg ha^{-1}.
Potential grain (stalk) yield of pearl millet = 2000 (2500) kg ha^{-1}.
Demonstration grain (stalk) yield of pearl millet = 1600 (2000) kg ha^{-1}.
SD – standard deviation.
Source: own elaboration.

Table 4. Profitability and benefit-cost analysis of pearl millet technology

Cost-benefit items	Pearl millet (ETB ha^{-1})	Sorghum (ETB ha^{-1})
Cost of seed	400	300
Cost of fertilizers	2 500	2 500
Cost of package application	5 100	2 400
Total variable cost (TVC)	8 000	5 200
The selling price of grain yield	35	25
Selling price of stalk yield	0.4	0.7
Gross return (GR)	50 328	18 690
Net return (NR)	42 328	13 490
Benefit-cost ratio (BCR)	6.3	2.6
Additional cost (ETB ha^{-1})	2 800	
Additional return(ETB ha^{-1})	31 638	
Effective gain (ETB ha^{-1})	28 838	
1 Dollar = 45 ETB on average in the study years		
ETB = Ethiopian Birr.		

Source: own elaboration.

returns and effective gains of pearl millet may have been attained due to the application of improved technology, i.e., the use of ideal crop varieties and the timely operations of the required crop management practices.

Farmers' perceptions of and demand for pearl millet

Most of the farmers had a positive view and good perception of pearl millet technology in most parameters (Table 5). However, a large number of the farmers had no confidence in its pest resistance capacity since it is very susceptible to bird attacks, especially during the ripening stage. Still, a large number of the farmers remained neutral in their views on its disease resistance capacity because there is no disease record on the variety.

As displayed in Table 6 below, the average score of the responses is 4.24, which implies that the farmers perceived and accepted the technology with full confidence. Cronbach's alpha reliability analysis was carried out to test internal consistency among Likert scale items (Mihiretu, 2019).

The alpha coefficient ($\alpha = 0.78$) demonstrated that the questions used were consistent and reliable (Table 1).

Table 5. Farmers' perception of pearl millet technology, $n = 223$

Parameters	SD	D	NAD	A	SA	SS	MS
Germination performance of the crop is good	–	–	4.5	43.2	52.3	694	4.48
The vegetative performance of the crop is good	–	–	–	26.5	73.5	734	4.74
Seed setting performance of the crop is good	–	16.1	–	27.1	56.8	658	4.23
The crop is resistant to diseases	–	7.7	77.4	11.0	3.9	482	3.46
The crop is resistant to different pests	14.8	46.5	21.9	16.8	–	399	2.87
The crop is early maturing	–	–	–	24.5	75.5	737	4.76
The crop is adaptable to marginal areas	–	–	2.5	12.0	85.5	742	4.82
The grain productivity of the crop is good	–	–	–	54.8	45.2	690	4.45
Stalk productivity of the crop is good	–	–	24.2	58.0	25.8	436	3.20
The palatability of the stalk is good	13.6	36.4	20.2	20.0	9.8	364	2.78
The food quality of the crop is good	–	–	12.9	28.4	58.7	691	4.49
Average score = 4.24							
Cronbach's 'α' coefficient = 0.78							

Note: values are in percentage points (%); SD – strongly disagree, D – disagree, NAD – neither agree nor disagree, A – agree, SA – strongly agree, SS – sum of scores, MS – mean of scores.
Source: own elaboration.

Table 6. Sensory evaluation and ranking of food items prepared from pearl millet

Food types	Enjera	Bread	Porridge	Tella	Scores	Ranks
Enjera		Enjera	Enjera	Enjera	3	1
Bread			Bread	Tella	1	3
Porridge				Tella	0	4
Tella					2	2

Note: "Enjera" is a common stable food in the daily food dishes, while "Tella" is a local alcoholic beverage in Ethiopia, and the study area in particular.
Source: Mihiretu, 2019.

Thus, 85.9% of the farmers were highly interested in adapting pearl millet technology in the future, and most of them (90%) convinced their neighbouring farmers to use the technology (Table 2).

In addition, field days involving farmers, agricultural experts, and journalists were held. After attending these field days, farmers' opinions about the new pearl millet technology was summarized as follows:

> The pearl millet technology is very adaptive to our moisture deficit area and can give yield even in warm and low moisture situations. At germination, a single seed would have up to 20 tillers of good performance; as a result, we termed it the "crop of the poor". As an agro-pastoral community, we negate the variety for its low stalk palatability, because in this area livestock forage is worth as much as grain yield. Some of the positive aspects of the variety are that it is resistant to drought and early maturing, resistant to Striga and with better production, a good source of house roofing and household fuel wood, and a quality staple food. However, they negatively described that the variety has a higher lodging problem and needs tying at maturing. In addition, the stalk has low palatability to livestock and is susceptible to bird attacks at the maturity stage. Clustering as an approach was also appreciated for creating competition in farm management among farmers, reducing the risk of pest damage, and having "eye-catching" power to impress individuals.

Since pearl millet is a new crop to the community, food recipe demonstration is required, thus different food items were prepared in the form of staple foods and local beverages, then tasted by a set of panellists, i.e., farmers and experts. The results of the sensory taste evaluation revealed that "Enjera", "Tella", Bread, and Porridge were the panellists' first, second, third, and fourth food choices, respectively (Table 7).

Technology application and constraints

Among other factors, applicability plays a significant role in new technology adoption, hence with expert follow-up, 79.5% of the farmers applied the full package (Table 1). Despite better package application, 69.5% of the studied farmers identified constraints in package application and ranked them according to their severity. The percentage position of each rank is converted into scores using Garrett's table (Table 7b). The mean scores of all constraints are arranged to make the final rankings, thus attributes with the highest mean score are considered the most influencing factors. The results (Table 7a) showed that shortage of labor in the household, the complexity of the technology, and inadequate practical training were the top three challenges experienced by farmers when attempting to apply the full technology package of pearl millet in the study areas.

Stakeholder connections and technology exchange

Sharing duties among stakeholders would consolidate the triple connection of farmers-extension-research, and that is in turn vital to sustainable technology promotion. Therefore, in this study, all participant farmers hand over the technology to interested fellow farmers. The agricultural experts at different levels were also handling tasks to facilitate technology dissemination via continuous follow-up and consultation. Being innovative stakeholders, different NGOs were involved in technology dissemination to other target areas using earlier farmers

Table 7a. Constraint of pearl millet technology production and package application

Constraints	Ranks						Total sample	Total score	Total mean	Rank
	1	2	3	4	5	6				
Complexity of the technology	42	68	26	6	5	8	155	9 661	62.3	2
Inadequate practical training	59	46	14	12	16	8	155	9 585	61.8	3
Lack of experience (skill gap)	72	18	24	21	5	15	155	9 512	61.4	4
Shortage of labour	95	31	16	7	4	2	155	1 069	69.0	1
Shortage of finance	39	46	15	10	30	15	155	8 687	56.1	5
Pessimist about technology	7	10	7	20	23	88	155	5 359	34.6	6

Source: own elaboration.

Table 7b. Percentage positions and their corresponding Garett's table values

Ranks	Percentage position		Garrett table value
1	100 (1–0.5)/6	8.3	77
2	100 (2–0.5)/6	25	64
3	100 (3–0.5)/6	41.7	55
4	100 (4–0.5)/6	58.3	46
5	100 (5–0.5)/6	75	37
6	100 (6–0.5)/6	91.7	23

Source: own elaboration.

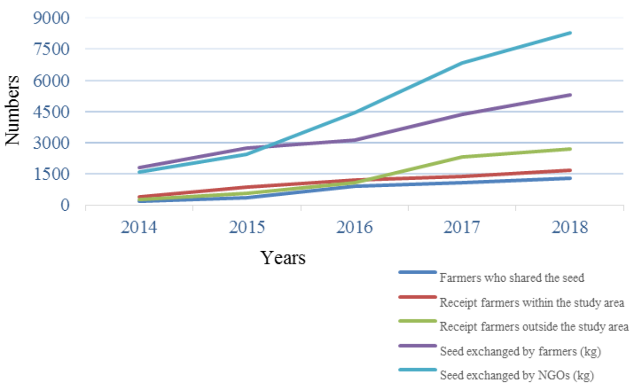

Fig. 1. The diffusion and exchange trends of pearl millet technology
Source: own elaboration.

as a source. The cooperation among those involved in and affected by the promotion increased compared to previous years, and the strengths, weaknesses, opportunities, and threats in the process are described below (Table 8). Moreover, the solid seed exchange system takes the front line in the diffusion of improved varieties (Mihiretu, 2019), hence the number of farmers who delivered the variety to interested fellow farmers in different arrangements showed an increasing trend in the study years. The amount of seed disseminated to interested farmers in/outside the study areas by participant farmers and NGOs also showed a consistently increasing trend across the years (Fig. 1).

CONCLUSION AND RECOMMENDATIONS

Conclusion

The global food system faces many complex challenges, including climate change, depletion of natural resources, and hunger. However, an ever-growing population needs sufficient and healthy food. In the face of climate change, when other crops are at risk, pearl millet ensures better yield and income for resource-poor farmers. Pearl millet can thus become a key crop with the potential to improve the livelihood and nutrition of smallholder farmers in the marginal areas of Northeast Ethiopia. Therefore, the results of the current study revealed that the average yield of pearl millet had a 102.9% yield advantage over the yield of the dominant crop grown in the area, i.e., sorghum. Its stalk yield was also comparable with that of sorghum in similar production years. Financially, the gross and net returns of pearl millet technology were far higher than

Table 8. SWOT analysis of stakeholders' linkage in pearl millet promotion and diffusion

Strengths	Weaknesses	Opportunities	Threats
Farmers • Being optimist and high technology demand • Good contact with other stakeholders throughout the promotion process • Sowing in a cluster and used as a seed source Experts • Good contact in the promotion process • Including NGOs in the process • Inviting media for broadcasting Researchers • Good contact in the promotion process • Involving NGOs in the process • Avail inputs and training on time • Collect and analyse the data on time	Farmers • Gap in full technology package application • Problem of maintaining the seed quality Experts • Insufficient follow-up by the nearby actors • Stumpy technical backup to farmers Researchers • Stumpy technical backup to farmers	• Presence of NGOs working on technology upscaling • Technology usage suits the government's focus on rising production • Farmers have good information and experience with pearl millet • Existence of seed exchange culture in the community via local arrangements, i.e. cash, kind, free for non-eligible	• Being arid with low and erratic rainfall with high temperature • High-risk experience of drought within 3-4 years of occurrence • Low willingness to pay for inputs due to the expensive price • Increasing dependency on relief food aids

Source: own elaboration.

sorghum from an equal land size. Despite higher average additional costs, the pearl millet technology had better additional returns and effective gains than sorghum. Technological acceptance was high, thus 79.5% of the farmers applied the all of the technology. Those who did not apply the technology fully did so due to labor shortages, technological complexity, and inadequate practical training. Durable technology demand was also created for stakeholders working on food security and agricultural development in the areas. Moreover, different food types of pearl millet were prepared and tasted by farmers, the sensory comparison revealing that the panellists' preferred "Enjera", "Tella", Bread, and Porridge as their 1st, 2nd, 3rd, and 4th choices, respectively. Agricultural extension experts at different levels handle tasks to facilitate technology dissemination. The cooperation among those involved in and affected by the promotion increased compared to the preceding years. The number of farmers who delivered a variety to interested fellow farmers in different arrangements showed an increasing trend in the five years of the study years. The amount of seed disseminated to interested farmers in/outside the study areas showed a consistently increasing trend across the years.

Recommendations

The authors safely recommend the introduced pearl millet technology for further up-scaling to similar agroecologies to diversify sorghum-based cropping systems. Since the crop is suitable for marginal areas, further adaptation and breeding studies are required to offer technology options in the future. The stalk is ineffective as a livestock feed in agro-pastoral communities, thus undertaking thorough research in this area is compulsory to resolve the palatability problem. Finally, organizing workshops to connect stakeholders is worthwhile to devise ways to forward the technology to the wider community in a sustainable manner. In this regard, farmers are advised to use the prevailing 1:5 extension networking to hand over the technology to fellow farmers easily. Seed-producing and marketing cooperatives should work together to make pearl millet technology multiplication and transfer viable.

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