Innovations in Agriculture 2023, 6:01-08
www.innovationsagriculture.com
ISSN: 2617-1295
DOI: https://doi.org/10.25081/ia.2023-08

Research Article

Constraints, interventions and prospects for improving pearl millet (*Pennisetum glaucum* L.) production in the state of Eritrea - A review

Okumu, Oliver Otieno[1*], Wendot Kibet, Philip[1], Tesfa Michael A., N.[2]

[1]*Department of Plant Health, Hamelmalo Agricultural College, P. O Box 397, Keren, Eritrea*

[2]*Department of Agronomy, Hamelmalo Agricultural College, P. O Box 397, Keren, Eritrea*

*Corresponding Author, Email: oliverotieno182@gmail.com

ARTICLE INFO

Received: July 20, 2023
Revised: August 27, 2023
Accepted: August 31, 2023
Published: September 1, 2023

Keywords:

Abiotic and biotic constraints, landrace, pearl millet, *Pennisetum glaucum* L., pests and diseases, varieties

ABSTRACT

Pearl millet (*Pennisetum glaucum* L.) is the second most important cereal grown in Eritrea after sorghum (*Sorghum bicolor* L.) grown under low input systems by small scale farmers. The crop utilizes soil moisture efficiently and has ability to tolerate soil toxicity and extreme temperatures than other cereals. It is a sustenance and food security crop important for its nutritive and cultural value and provides dietary energy and nutrition. However, despite the positive attributes and qualities of pearl millets for the present and future agriculture, production has been low. We attribute this to inadequate rainfall distribution, poor crop management by poorly resourced farmers, unavailability and high prices of farm inputs such as fertilizer and pesticides and low adoption of improved varieties by the farmers. This review outlines the constraints, interventions the government/ farmers have and can implement and the prospects of actions that can improve pearl millet production. As much as there have been efforts by the government and stakeholders to address these challenges and improve productivity of pearl millet, more needs to be done to meet the increasing demand of the increasing populations. This will enable farmers to intensify and diversify their agricultural systems and improve food security situation in the country. Unless a combined effort in soil fertility improvement, policies to promote use of modern varieties and conservation of and promotion of this crop biodiversity, the potential of this crop as famine and poverty alleviation among the rural poor will not be realized.

INTRODUCTION

Agriculture is one of the most important sectors of the Eritrean economy, contributing up to 17% of the gross domestic product (GDP) [1, 46]. The agricultural production levels are low with average yield per ha being the lowest when compared to other African nations. The contribution of the sector to the export is also low with most of the export gains coming from livestock [1]. The suboptimal performance is attributable to factors such as over reliance on rainfed agriculture in an environment of low and erratic rains, land degradation coupled with poor soil fertility, limited access to agricultural inputs, and inadequate agricultural skills among the farmers [46]. The sector is dominated by small scale farmers, who cultivate from one to three hectares depending on the availability of land [2]. Agriculture production occurs in various agro-ecological zones of the country in a mixed production system. The production system comprises of cereal/pulse base cultivation which includes trees such as coffee in the highlands, annual crops such as wheat, maize, sorghum, barley and millets as well as different pulses (chick pea, faba bean, field pea, lentil, grass pea), oil seeds (linseed, sesame, groundnut), spices, medicinal plants, fruits and vegetables. In the lower zones citrus, bananas, vegetables and cereals are common [3]. Among the most important cereals, sorghum, barley, wheat, taff and millets are common. Millets represent a diverse group of cereal crops that typically produce small seeds [4] and critically a food security crop among millions of farmers in Eritrea. In particular pearl millet and finger millets have a superior adaptation to drought and poor soils that is common in this country.

Pearl millet (*Pennisetum glaucum* L.) is the most important crop among small millets, accounting for 60-70% of total small millet production area worldwide [49]. It is the sixth most important cereal and it is a fundamental in the dry lands of the Sub-Saharan Africa including the Sahel region [4, 5]. The Sahel region is semi-arid grassland and transition zone extending from Senegal to Eritrea and is located between Sahara desert to the North and tropical Savannas to the South [6]. In Eritrea, as depicted in figure 1, pearl millet is the second most important cereal crop after sorghum (*Sorghum bicolor* L.) by crop coverage, however, by production it is fifth after sorghum, wheat, taff and barley [7, 8]. The crop is a sustenance and food security crop that is important for its nutritive, cultural value and provides dietary energy (360k cal/kg) for the Eritreans. It is highly nutritious and a rich source of protein, and minerals such as calcium, phosphorus, potassium, zinc, and iron [50]. Pearl millet grain also contains fairly large amounts of thiamine, riboflavin and niacin [9, 10]. As an animal feed, it provides good quality fodder to cattle in the arid and semi-arid tropical regions and recognized as valuable forage crop because of its vigorous and fast growing habit [11]. This is because the crop stover remains green till harvest and therefore has high nutritional value than many of the cereal residues and its stalk is used for fuel and thatching [12, 13]. In a survey done in Eritrea, farmers listed various reasons as to why they plant pearl millet: high water absorbance making it easy to make more Injera (traditional meal), good taste, drought tolerant, early maturing, more energy, longer storage, and its porridge is good for lactating mothers and children as some of the reasons they plant crop [14]. Farmers also indicated that it is a good rotation crop and has stover with higher protein content, its thatch is more durable and commands fair market prices than other cereals.

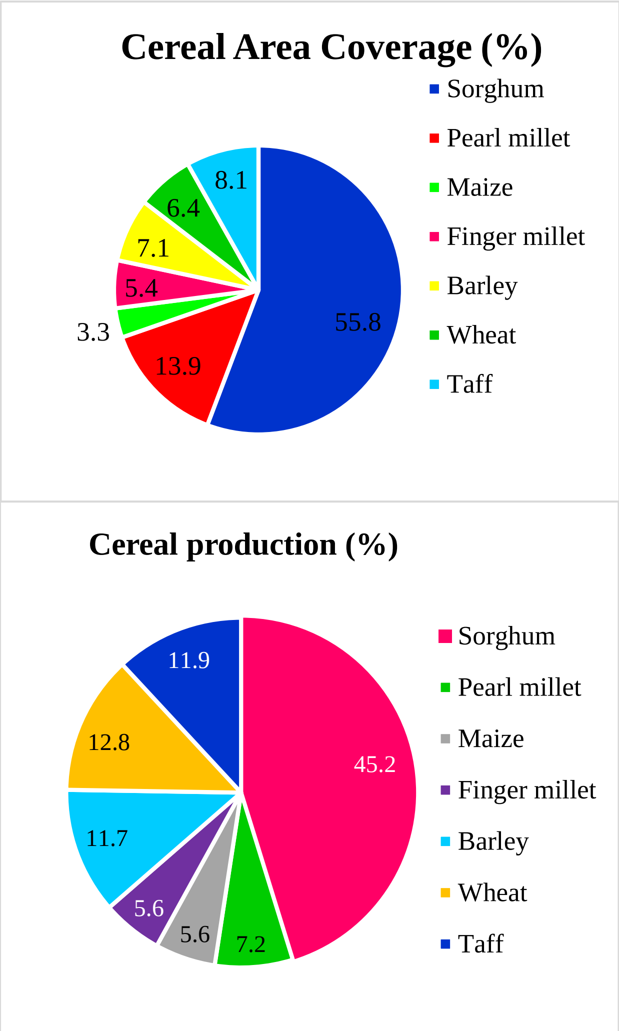

Fig. 1. Crop area coverage and production contribution in Eritrea [7,8].

The crop is grown under low input systems by small scale farmers [2, 15] in areas with less favourable environments where rainfall is variable and low averaging 250 – 300mm [14, 15] in steep escarpments and mountains that have dissected plateau, ridges, valleys and rolling hills [13, 15]. Pearl millet is more efficient in utilizing soil moisture, and has ability to tolerate soil toxicity and extreme temperatures than other cereals. This is because of their inborn ability to tolerate water stress and supra-optimal temperatures due to their morpho-physiological, molecular and biochemical characteristics that confer them with better tolerance [16-18]. Even with better environmental advantages over other cereals, peal millet has not received the scientific and political backing it needs and has been neglected both nationally and internationally. We attribute this neglect largely to socio-ecological conditions as it is a crop considered to be associated with resource poor farmers in marginal agricultural areas. This has led to massive decline in production in many countries including Eritrea, however, Drabo et al. [19] attributed the low yield to low adoption of improved varieties by the farmers. The goal of this review is to provide comprehensive look at the constraints and prospect for improving production of this neglected crop. Research citations from other African countries and India are also included. It is however, important to point out that research citations for the crop in the Eritrean context are very limited. From the information gathered, interventions for and policy needs are suggested in order to improve production.

2. Origin and distribution

Millets are recognized among the most ancient food grains to be domesticated for food and dates back to 3,000 BC. Africa is the centre of origin, diversity and cultivation of millets and constitutes both an exceptional ecological heritage and a critical food security factor among the many small-scale farmers cultivated throughout the Sub-Saharan Africa especially in the Sahel region. Pearl millet is cultivated in about 32m ha in more than 30 countries in the world and is ranked as the sixth most important cereal crop in the world [20, 5]. In Africa, the crop is cultivated in 14m ha and in about 12m ha in Asia with India contributing the highest tons of production [21]. The top producing countries are India, Niger, Sudan, Nigeria, Mali, Burkina Faso and Chad. The crop has a superior ability to adapt to drought and poor soils, producing a constant yield in these conditions, growing where no other crops can, requiring little maintenance, and offering a rich source of nutrients. Since pearl millet has been farmed for a very long time in Eritrea [22], the farmers there have access to a wide genetic variety of landraces. It is grown in arid highlands, and arid lowlands occasioned by low and variable rainfall averaging 250-300mm and in soils characterized by sandy textures, low organic matter and nutrient levels and high soil temperatures (Table 1).

3. Varieties and varietal selection

Pearl millet varieties comprise the short oasis types that mature early (two months) and those that are highly photoperiod–sensitive types that grow up to 4.5m tall with a five month cycle [5]. In Eritrea, traditional cultivars of pearl millet are widely used by the farmers (Table 2). Farmers grow landraces that they select exchange and conserve over the past generations [15]. Farmers conserve and cultivate innumerable cultivars, even though low yielding, have wider and better adaptation and tolerance to adverse environmental conditions that is why it is commonly grown in many parts of Eritrea. However, because of the cross-pollinated nature of the crop, some of the desirable traits may not be available in the existing landrace populations [17]. These traits may also have undesirable traits such as susceptibility to pests and diseases. Yield potential, maturity classification, water use efficiency, pest and disease tolerance are important variety selection criteria that farmers use.

To enhance the native landraces that were already available, the National Agricultural Research Institute (NARI) launched the pearl millet program in 2000. This was accomplished by combining the native landraces with recently introduced cultivars that have features like early maturity, disease resistance, and enhanced plant or panicle type. [14]. Through this, varieties such as ICMV221 (Kona) (ICRISAT variety), Hagaz which is a cross between Kona and a local Eritrean landrace (Tokroray) were released. The Kona variety was first released in 2000 while the Hagaz variety in 2004. The use of these two varieties increased due to their positive attributes such high yielding, early maturity, and resistance to diseases such as downy mildew. Other commonly grown varieties are the local landraces Tokroray, baryay and Zibedi. In a farmer appraisal work in Eritrea, Kona and Hagaz varieties were rated as high yielding than the local varieties [14]. Kona for instance, has been reported to maintain high yields in both good and poor soils in contrast to Zibedi, Tokroray and Hagaz. The launch of this initiative exemplifies a crucial aspect of government efforts to ensure food security by quickly responding to farmers' demands.

Table 1. Characteristics/ Agro-ecological zone of selected areas in Eritrea where pearl millet is grown.

Agro-ecological Zone (AEZ)	Dominant crop	Altitude (m.asl)	Rainfall (mm)	Temperature (°C)
Arid highland	Sorghum, pearl millet, barley	1600-2600	200-500	15-21
Moist lowland	Sorghum, pearl millet, sesame, cotton, Finger millet, maize	500-1600	500-800	21-28
Arid lowland	Sorghum, pearl millet	400-1600	200-500	21-29

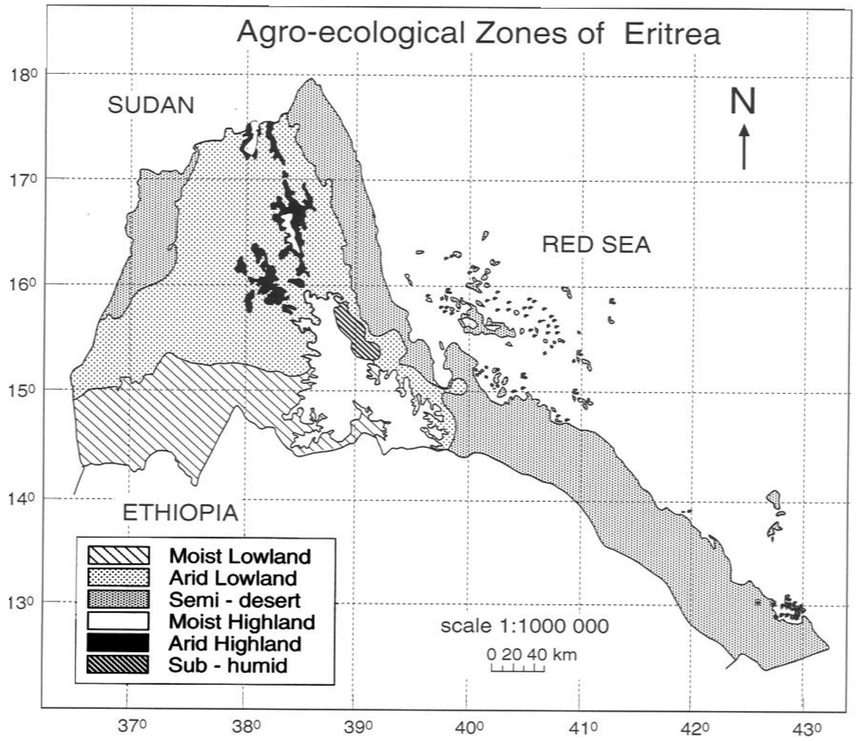

Figure 2. Map showing AEZ in Eritrea - Pearl millet is grown in – Moist low lands, arid highland and arid lowlands.

Table 2. Common pearl millet varieties and their characteristics among the farmers in Eritrea.

Variety/ Landrace	Preferred characteristics	Drawbacks	References
Dukun (Landrace)	Very high tillering capacity. When panicles are removed, new branches are produced by shoots. tall, with a strong resistance to odor and ear head bugs,	Susceptible to downy mildew, low yields	[23, 14, 15]
Kona (ICMV221) (Improved variety)	High yielding (2.0 – 2.8t/ha) compared to the local varieties, early maturity (70-75 days), short to medium in height, drought tolerant, Resistant to downy mildew, long durability.	Susceptible to bird damage	[14, 15, 23]
Hagaz (Improved variety)	High yielding (2.2 – 3.0 t/ha, intermediate maturity (75-85 days), medium plant height (200 -230 cm), drought tolerant, Fairly resistant to downy mildew	Susceptible to bird damage	[14]
Tokroray (Landrace)	When panicles are removed, very high tillering ability shoots create new branches.	Late maturing, Susceptible to downy mildew, low yields	[14, 15]
Zibedi (Landrace)	Very high tillering capacity	late maturity, high water demand, Susceptible to downy mildew, low yielding	[14, 15, 23]
Baryay (Landrace)	Adapted to the local environmental conditions, has good taste with good marketability,	Susceptible to downy mildew	[15]
Bultug (Landrace)	Long durability	Susceptible to downy mildew, late maturity (90-110 days),	[14, 15, 23]

4. Production of pearl millet

Pearl millet production in Eritrea is mostly done by small scale farmers growing mainly traditional varieties. As a result, the yields are low averaging 8 quintal/ha, however, the demand for the crop can be easily met if new improved varieties are grown. The crop is grown throughout the country in midlands and low lands characterized by low rainfall and high temperatures. The production output of these farmers is limited by myriad of constraints that lead to low agronomic productivity [15]. Numerous constraints limit the yield potential and productivity of pearl millet in the country. These limiting factors are broadly classified as either abiotic and/or biotic stresses and even institutional and they have had colossal effect on the overall productivity and output of the small-scale farmers. Statistical documentation for pearl millet is generally poor and fragmented in the country; therefore, accurate figures on pearl millet production were not obtained.

4.1 Production constraints and interventions

4.1.1 Abiotic constraints

Owing to pearl millet cultivation in rainfed agricultural systems, the production is affected by abiotic stresses. These include drought, and high temperatures which is as a result of erratic and low rainfall distribution. For example, an increase in air temperature and soil temperatures during germinations in the Eritrean arid zones leads to disturbed plant stand. Low water level adversely affects pearl millet growth at all developmental stages, impairing morphology and the biochemical processes of the crop while heat stress negatively affects the vigour and reduces germination rates, seedling emergence and growth [25]. In fact, years of poor rainfall amount and variable distribution across the country have led to severe droughts that have affected 60-70% of the country [45]. These extreme droughts have become frequent affecting moist low lands, arid highlands and arid lowlands thus crops lack necessary moisture to complete their growth cycle and properly fill the grain. Drought stress impairs cell division, elongation, and functioning of vital enzymes, this resulting in yield decline as crucial stage (tillering) of moisture supply is adversely affected. According to Suganthi et al. [49] drought stress decreases protein content that has an effect on the rate of biosynthesis and increased breakdown of proteins. Soils in the regions where pearl millet is grown are sandy and infertile as they contain low organic matter because of low vegetation cover, coarse texture, with prevailing high temperatures [26]. These soils are also low in phosphorus, and farmers rarely use organic manure resulting in extremely nutrient depleted soils [27]. Continuous cultivation clears the soil leaving the soil surface bare, in cases of heavy rains as experienced in July of every year, the soil suffers structural deterioration. Eritrea is severely affected by land degradation and desertification. The country experiences increased deterioration of soil quality and vegetation cover which has led to loss of soil productive capacity.

Crop improvement in pearl millet is usually difficult than in most other crops such as maize. This is largely attributed to the environment in which they are produced. Other restrictions include the need for traditional low yielding varieties because improved varieties are not readily available and farmers adopt them at very low rates, the lack of improved seeds and fertilizers, subpar seed production and distribution, subpar agronomic practices, subpar technology transfer, subpar research extension to farmer links, and susceptibility to biotic restrictions [15].

4.1.2 Biotic constraints

Pearl millet suffers from various pests and diseases. The disease that significantly lowers yields among the diseases is downy mildew (*Sclerospora graminicola*). Other illnesses include blast (*Pyricularia grisea*), smut (*Moesziomyces penicillariae*), rust (*Puccinia substriata* var. indica), and ergot (*Claviceps fusiformis*) [13]. In 2000, it was reported that more than 50% of pearl millet farms surveyed in Anseba and Gash Barka were found to be infected with downy mildew [28]. As a result, there was massive yield reductions estimated at 30% in Anseba region alone. In a survey conducted in 2016 downy mildew was reported to be the most economically important disease contributing to significant losses to pearl millet production [15]. Once a field has been infected, the disease has survival mechanisms that can re-infect succeeding crops for up to 15 years, making management highly challenging. One of the most common foliar diseases of pearl millet in Eritrea has also been identified as rust disease [15]. On pearl millet, the fungus' macrocyclic uredinial, telial, and basidial stages can be found. The spermagonial and aecial stages survive on alternate hosts such as *Solanum melongena* (eggplant). The environment, which is characterized by high temperatures and occasionally high humidity, is favorable for the growth and occurrence of pests and diseases like downy mildew (*Sclerospora graminicola*), smut (*Moesziomyces penicillariae*), rust (*Puccinia substriata* var. indica), blast (*Pyricularia grisea*), ergot (*Claviceps fusiformis*), millet leaf

Production of pearl millet is further hampered by weeds including Abebela (Corchorus olitorius), Elawa (Coleome gynandra), Dodota (Cassia obtusifalia), Alama (Convolvulus sagittatus), Afenfena (Setaria pumila), Weynaka (Striga hermonthica), Arkubeshukufa (Amaranthus sp. [14]. However, pearl millet here is not constrained by striga witch weed and therefore does not lead to yield losses (Personal communication). In other countries like Burkina Faso, however, losses of up to 80% have been reported [29]. It has been claimed that striga can cause poor seed germination, leaf chlorosis, stunted development, and even death in other crops like maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L. Moench), and finger millet with heavy infestation. [29]. The parasitic weed has a wide range of hosts it is therefore difficult to be controlled using the available strategies [47]. The availability of striga in these farms is a demonstration of the deteriorating state of soil fertility in major peal millet and other cereals in growing areas in Eritrea. This occurrence is likely due to overexploitation of farmlands coupled with no conservation practices. The high prevalence of the striga is common in areas with nitrogen and phosphorus deficiencies [30]. The profusion of striga in these farms is because of its capability to produce many seeds that remain viable for many years even in harsh environmental conditions [31]. Striga weed has also been reported as one of the factors limiting pearl millet production across the different countries in Africa; Nigeria, [32], Burkina Faso [33, 29], and Tanzania [48] just to mention a few. According to Abdella et al. [15] there is constant food shortage and the households cannot feed their families. As a result, it was determined that the majority of households are vulnerable since a sizable amount of their average income is spent on food consumption.

Insects are also a problem in pearl millet production. Some of the major insects' pests that have been implicated in reducing yields include millet leaf miner (*Heliocheilus albipunctella*), stem borer (*Coniesta ignesfusalis*), armyworms (*Spodoptera exempta*) and grasshoppers. Farmers indicated in a survey that the loss due to insects' occurrence is estimated at 25%, however, for insect pests such as locusts, stinkbug, aphids and stem borers the losses may increase up to 80% or even 100%. Birds are also a major problem for pearl millet in Eritrea. The varieties planted are not like sorghum, pearl millet grains do not have tannins, and thus bird tolerance is unavailable.

4.2 Interventions adopted by farmers, the government and way forward

Farmers, in a bid to manage some of these constraints have employed various strategies. For example, they have adopted cultural interventions such as crop rotation, intercropping, and terracing to improve emergence, manage weed, and conserve water to optimize pearl millet yields in drought prone areas. For striga management, farmers have employed practices such as hand weeding, weeding, and application of organic manures, which have had unpredictable success rates depending on the level of infestation. Most farmers have few options other than to use family labor for manual weeding and hoeing since they lack the equipment or financial means to buy herbicides.

Cropping failure due to low rainfall is common and this has forced farmers to come up with mechanisms to handle water unavailability. For example, at the beginning of a cropping season, farmers will plant a late pearl millet variety and if it fails due to over flooding or shortage of water, the crop is replaced by an early maturing variety [24]. If crop failure occurs often, a drought-tolerant pearl millet type is planted, although not for crop production but rather for the production of animal feed for their cattle.

Farmers understand the importance of preserving high-quality seed for the upcoming planting season. They select panicles from the best plants that are vigorous, healthy and have bigger panicles and large size seeds [14]. After gathering the seeds, they smoke-dry them to help keep them free of rodents and other pests like moths. Farmers also utilize a conventional seed-treatment technique in which the seed is treated in cow urine for 24 hours before being dried and sown. This lessens the likelihood of pests and diseases infesting the soil.

Due to the comparatively short growing period requirements for a two crop system and the crop's ability to mature in up to 20 to 25 days less time than the first crop, crop ratooning is often used by farmers. Ratoon yields, however, are significantly lower and more unpredictable than the first crop, particularly when pest and disease carryover is an issue. High ratooning capability pearl millet types are grown by farmers. In the ratooning procedure, the main crop's stalk is cut at ground level, laid out between the rows, and left there for three to five days to encourage plant regrowth and preserve soil moisture. After less than a week, the plant begins to grow, and from one plant, more than 4 tillers are generated.

Downy mildew disease has been managed by farmers through adoption of the National Agricultural Research Institute (NARI) released varieties while the insect pests have been culturally managed by practicing crop rotation, intercropping, adjusting planting time and date, and field selection. However, insect problem increases with production intensification. Crop rotation can reduce problems associated with insect pests that have limited number of hosts and are not mobile while intercropping reduces infestation by increasing diversity in the field. For the birds, farmers' plant similar maturing varieties at the same time, as earlier or late maturing varieties suffer more damage.

The national Agricultural research Institute (NARI) initiated a Pearl millet Programme in 2000 to introduce new varieties with better attributes. This was done through crossing between the local landraces and the newly introduced varieties with traits such as disease resistance, early maturity, and improved plant or panicle type. Through these efforts, new varieties such as Kona and Hagaz were released. Kona variety was released in 2000 which is introduced and adopted to Eritrean condition from ICRISAT pearl millet program. Originally this variety was known as "ICMV 221" and became Kona after farmers agreed to give it a local name after the village called Kona. These varieties have positive attributes such as high yielding, early maturity, and resistance to diseases such as downy mildew. The adoption of these two varieties has increased overtime.

The ministry agriculture (MoA) of the state of Eritrea is committed to improve agriculture and highlights agriculture and land management as the priorities for both mitigating and adapting to climate change [45]. The ministry came up with the agriculture sector policy which aimed at promoting equal opportunities, market liberalization, and support services to the smallholder farmers. This policy was designed to rehabilitate and maintain natural resources, and realize food security for the Eritreans.

4.3 Way forward for pearl millet production

Even though attempts have been made to address these issues and increase pearl millet output, more must be done to satisfy the population's growing need. Support from the stakeholders and the government is necessary to enable improvement and reinforcement of the pearl millet development process, seed production, and seed distribution systems for enhanced varieties. Through instruction in integrated soil fertility management and crop livestock management systems, farmers must be given the tools they need to manage their natural resource base sustainably. Cropping strategies including crop rotation, minimal or conservation tillage, speeding up the expansion of new pearl millet varieties, and access to agricultural inputs and markets can all help achieve this.

Adoption of different cropping systems has been shown to improve production as has been practiced in West Africa; bush fallow system can improve soil organic matter and nutrient levels at low cost to farmers. This system follows production of crops for a particular number of years then fallow years to enable soil to replenish itself [5]. During fallowing, vegetation is allowed to grow and at the end of a rainy they are worked on by macro soil fauna and buried into the soil, thus increasing organic matter which in turn increases structural stability of the soil [34]. However, due to increased population growth, economic development, this system may not meet the current crop nutrient needs as population pressure have led to shortened fallow periods which has caused a decline in soil fertility. Intercropping to take advantage of beneficial effect of legumes can also be practiced. This can be done as it has been in Niger, where a tall, late-maturing cowpea variety is planted two to six weeks after the last of the pearl millet is planted [5], depending on how quickly the pearl millet is sown. In this cropping system, the production of cowpea grain or stover is of secondary importance since pearl millet is allowed to dominate over cowpeas for sunshine, water, and nutrients. Additionally, according to reports, the productivity of the pearl millet and groundnut intercropping system can be increased by selecting the right crop kinds and changing the planting dates and spacing. Shorter early-maturing pearl millet cultivars coupled with indeterminate, spreading cowpea, claim the authors [35]. Crop rotation system can reduce pest infestations [36], improve soil chemical and physical characteristics, increase occurrence of beneficial arbuscular mycorrhizae, and promote nutrient cycling in the soil and increase productivity of pearl millet [5]

Farmers can be trained to practice agroforestry by deliberately using trees in association with crops, pasture and livestock. The production of pearl millet can be integrated into an agroforestry system with deep-rooted leguminous trees that exhibit reverse phenology, meaning that their leaves appear during the dry season and fall off during the growing season [37]. Agroforestry techniques that use nitrogen-fixing trees enrich the soil with nitrogen. Organic matter will enhance the physical characteristics of the soil, including its structure, aeration, and drainage. By lessening the effect of wind and raindrops on the soil, the combination of a tree canopy, a mulch layer made of leaf litter, and tree cuts reduces soil erosion. [38]. Productivity can be increased through expansion of land area. In fact, yield increase of up to 169% in agroforestry system with *F. albida* trees have been reported [39]. Higher soil nutrient levels, more readily available water, an improved microclimate, and better soil physical qualities were all cited as contributing factors.

Research on crop improvement programs that are mainly addressing adaptation to drought and that possess better morphological characteristics should be done. There is need to continue the breeding efforts that corresponds to farmer's preferences and that responds to the prevailing production environment, and to seek to strengthen the national research institutions in the use of modern breeding platforms and methodologies. There is need for inclusion of farmers through participatory plant breeding programs where farmers are mobilized and their technical knowledge is integrated during the cultivar development in order to develop cultivars/ varieties that are attractive [40]. This technique should be embraced by plant breeders locally to ensure adoption of newly bred cultivars by farmers. According to Mulatu and Belete [41] this approach has worked and enhanced adoption by farmers and helped breeders identify constraints and farmer preferred trait. Participatory plant breeding has been conducted with numerous success stories. For instance, in West Africa in a participatory varietal selection, farmers indicated they preferred cultivars with high grain yield and taste [42]. In Niger, during participatory rural appraisal (PRA) farmers preferred pearl millet with traits such as resistance to pests and diseases, and adaptation to abiotic stresses [43]. By encouraging enhanced operating procedures, the adoption of contemporary breeding techniques, and significantly improved information management methods, the implementation of these initiatives will result in fundamental improvements in efficiency. This will require government commitment to increase research funds and to encourage collaboration with international research organizations for better results. Given that they can preserve their good agronomic traits for a longer period of time than adapted alien varieties, the advantages of collecting indigenous genetic resources are of particular importance and consideration. Through this screening and evaluation, germplasm can be developed and tested for their reaction to various diseases.

The government should expedite access to inputs and markets for the farmers. When these technologies are available, and made accessible even the resource poor farmers will adopt improved pearl millet technologies. Farmers should be given access to the inputs required for production as well as the markets for disposing of excess farm output. There is need for revamp of the national institutions charged with the responsibility of spearheading agricultural development in Eritrea. This includes research, extension service, and value chain operators. The government efforts have been noticed, however, more needs to be done especially in the areas of extension and research. Research institutions should be equipped with current research tools.

The soils in Eritrea are severely deteriorated and lacking in organic matter. Crop rotation can play a significant role in these systems in terms of residual Phosphorus (P) and Nitrogen (N) for the legume and cereal crops, as well as minimum or conservation tillage systems. Farmers must be given the tools necessary to manage their natural resource base in a sustainable manner. Extension systems are required so that farmers can continuously acquire new techniques for carrying out both existing and new activities in order to enhance productivity while protecting the environment and the land's potential for yield. The ridge furrow cultivation system is an approach that can be used in environments such as one experienced in Eritrea. According to reports, using this technique changes the soil's moisture environment by improving aeration in the ridges and holding moisture in the furrows. In fact, increase in yield of pearl millet in drought stricken areas of Namibia has been reported by implementing a combination of ridge furrow tillage and manure application [44]. Because ridge plants produce more in flooded years and furrow plants produce more in drought years, the ridge furrow system provides protection from flooding. Ridge-furrow tillage is an effective way of allotting risk in areas experiencing extreme droughts such as Eritrea.

We can borrow the "seed village" concept of India which involves multiplication of specific cultivars in particular Eritrean villages to undertake seed production program in non-traditional areas [21]. Seed production by small scale farmers under contractual arrangement by the government will improve farmers' commitment to pearl millet production. This will also lead to improved seed processing period, reducing the time from harvesting to delivery of seed to the target regions

Multiple agronomic researches should be conducted at various research stations and farmer fields with respect to e planting time, seed rate, weed management, fertilizer application including biofertilization, cropping systems and moisture conservation [21]. Management research can include intensive management for regions where moisture is generally adequate and low-input management in areas where moisture is the major production constraint. Intensive management focused on increased plant population by following differential crop geometry. Fertilizer doses should be worked out using soil-test-crop response approach and this can include average recommendations in the range of 40-80 kg/ha in various agro-climatic zones as was done in India. With significant changes in climate change, normal strategies towards pest and disease management need certain changes. Strategies such as managing host stress in ways that are safe to the environment can be adopted [51]. Strategies that positively influence biodiversity, cropping systems and uncultivated biota, and natural enemies can all influence positively pest management [52]. Integrated Pest Management (IPM) therefore, can be adopted as a strategy to minimize the effect of pests and diseases on yield. The IPM strategies to be adopted then should include host plant resistance, ecology and evolutionary pest biology, knowledge of the local agro-ecosystem, and available efficient control techniques, notably natural enemies.

5. Potential research areas

The objective of pearl millet research should be to improve the yield and quality of pearl millet varieties and their production environment. Specifically, the objectives of this research should be:

- To develop improved varieties of pearl millet through germplasm evaluation and breeding
- To develop early maturing pearl millet varieties that are resistant to drought, downy mildew diseases
- To determine what factors, make pearl millet immune to striga infestation in Eritrea
- To improve and develop the production environment through adoption of integrated drought management initiatives to ensure better production environment.

- To promote pearl millet production through integrated agronomic management technologies among the farmers

CONCLUSION

Pearl millet has great contribution to make towards food security and economy in Eritrea. Improvement of the environment of production through irrigation set up initiatives, expansion of land under pearl millet cultivation, breeding on new varieties that are drought tolerant and disease resistant will go a long way to boost production. This will enable farmers to intensify and diversify their agricultural systems. Wide dissemination of pearl millet technologies will create awareness about the importance of the crop among the Eritreans. Promotion of the consumption of pearl millet in diverse new uses such as bread, cakes, and biscuits will be another strategic plan for wide utilization of the crop.

ACKNOWLEDGEMENT

We thank the insightful exchange of ideas on the topic of this article with the members of the Departments of Plant Health and Agronomy at Hamelamalo Agricultural College, Eritrea.

AUTHOR CONTRIBUTIONS

OO designed the review, gathered the information and wrote this document while WP, TAN reviewed and gave insightful comments. All authors read and approved the final manuscript.

FUNDING

No funding.

AVAILABILITY OF DATA AND MATERIALS

Not applicable.

DECLARATIONS

Ethics approval and consent to participate

We approve and consent.

CONSENT FOR PUBLICATION

Authors consent to the publication of this document.

COMPETING INTERESTS

Authors declare no competing interests.

REFERENCES

1. Sati V, Danish P, Naqvi S. Prevalence of economically important fungal diseases at different phenological stages of peanut (*Arachis hypogaea* L.), pearl millet (*Pennisetum glaucum* L.) and sorghum (*Sorghum bicolor* L.) in Sub-zone Hamelmalo. African J Food Agric Nutr Dev. 2008;8(2):237–45.
2. Danish S, Naqvi Y. Prevalence of economically important fungal diseases at different phenological stages of peanut (*Arachis hypogaea* L.), pearl millet (*Pennisetum glaucum* L.) and sorghum (*Sorghum bicolor* L.) in Sub-zone Hamelmalo. J Agric Econ Dev. 2013(2):237–45.
3. Ministry of Agriculture. Country report to the FAO international technical conference on plant genetic resources. Ministry of Agriculture, Eritrea. 1996.
4. Gari AJ. Review of the African millet diversity Paper for the International workshop on fonio, food security and livelihood among the rural poor in West Africa. Bamako, Mali; 2001.
5. Mason SC, Maman N, Palé S. Pearl millet production practices in semi-arid West Africa: A review. Exp Agric. 2015;51(4):501–21. http://dx.doi.org/10.1017/s0014479714000441
6. United Nations Environmental Program. Sahel Atlas of Changing Landscapes: Tracing trends and variations in vegetation cover and soil condition. United Nations Environment Programme. Nairobi. 2012.
7. Abraha N, Roden P. Farmer experience with productivity enhancing technology uptake: A case study of pearl millet in Eritrea. In: Integrated sorghum and millet sector for increased economic growth and improved livelihoods in Eastern and Central Africa Proceedings of the ECARSAM Stakeholders Conference. Dar es Salaam; Tanzania; 2006.
8. Ministry of Agriculture. Country report to the FAO international technical conference on plant genetic resources. Ministry of Agriculture, Eritrea. 2021.
9. Dayakar-Rao B, Bhaskarachary K, Christina A, Devi S, Tonapi G. Nutritional and health benefits of millets. ICAR-Indian Institute of Millets Research. Vol. 104. Hyderabad, India, New Delhi, India; 2017.
10. Nithiyanantham S, Kalaiselvi P, Mahomoodally MF, Zengin G, Abirami A, Srinivasan G. Nutritional and functional roles of millets-A review. J Food Biochem. 2019;43(7):e12859. http://dx.doi.org/10.1111/jfbc.12859
11. Kanfany G, Diack O, Kane NA, Gangashetty PI, Sy O, Fofana A, et al. Implications of farmer perceived production constraints and varietal preferences to pearl millet breeding in Senegal. Afr Crop Sci J. 1970;28(3):411–20. http://dx.doi.org/10.4314/acsj.v28i3.6
12. International Crops Research Institute for the Semi-Arid Tropics. The world sorghum and millet economies: Facts, trends and outlook. A joint study by the Basic Foodstuffs Service FAO Commodities and Trade Division and the Socioeconomics and Policy Division. International Crops Research Institute for the Semi-Arid Tropics. Rome Italy; 1996.
13. Yadav HP, Gupta SK, Rajpurohit BS, Pareek N. Broadening the genetic base of grain cereals. 2016;205–24.
14. Roden P, Negusse A, Merhawit D, Menghistab G, Haile B, Thomas K. Farmers's appraisal of pearl millet varieties in Eritrea. In: SLM Eritrea; National Agricultural Research Institute (NARI), and Ministry of Agriculture, Eritrea; Syngenta Foundation for Sustainable Agriculture (SFSA), and Centre for Development and Environment (CDE). Bern; 2007.
15. Abdella O, Shemendi G, Naqvi SY, Jamo LM. Yield and Yield constraints Assessment of Pearl millet (*Pennisetum glaucum* (L.) in Sub Zoba-Hamelmalo. Pharmacology and Life Sciences. 2021;10(10):174–80.
16. Yadav OP, Rai KN, Gupta SK. Pearl millet: Genetic improvement in tolerance to abiotic stresses. In: Improving Crop Productivity in Sustainable Agriculture. Weinheim, Germany: Wiley-VCH Verlag GmbH & Co. KGaA; 2012. p. 261–88.
17. Gupta SM, Arora S, Mirza N, Pande A, Lata C, Puranik S, et al. Finger millet: A "certain" crop for an "uncertain" future and a solution to food insecurity and hidden hunger under stressful environments. Front Plant Sci. 2017;8:643. http://dx.doi.org/10.3389/fpls.2017.00643
18. Vries D, Griffiths FT, Knight RI, Williams NO. Harnessing rhizosphere microbiomes for drought-resilient crop production. Science. 2020;368:270–4.
19. Drabo I, Zangre RG, Dangquah YE, Ofori K, Witcombe JR, Hash T. Identifying farmer's preferences and constraints to pearl millet production in the Sahel and North Sudan Zones of Burkina Faso. Exp Agric. 2019;55(5):765–75.

20. FAOSTAT. Choice (Middletown). 2011;48(05):48-2430-48–2430. http://faostat.fao.org/site/5676/DesktopDefault.aspx.
21. Promoting millet production, value addition and consumption. National Academy of Agricultural Sciences. 2022;24(114).
22. Water and Environment. The 4th national report to the convention on biological diversity. The State of Eritrea Ministry of Land. 2010.
23. Natarajan M. Strengthening the agricultural research and extension in Eritrea, GCP/ERI/001/ITA. Report of the consultation on Production/Farming Systems Agronomy. State of Eritrea Ministry of Agriculture, Department of Agricultural Research and Human Resources Development and FAO. 1999.
24. Ogba-Michael B. Agronomy in spate irrigated areas of Eritrea. Ministry of Agriculture. The State of Eritrea. 2003.
25. Hatzig S, Nuppenau JN, Snowdom RJ, Schiel SV. Drought stresshas transgenerational effect on seeds and seedlings in winter oilseed rape (*Brassicae napus* L). BMC Plant Biol. 2018;8.
26. Kumar P, Tarafder JC, Painuli DK, Raina P, Singh MP, Beniwal RK, et al. Variability in arid soils characteristics. In: Kar A, Garg BK, Singh MP, Kathju S, editors. Trends in arid zone research in India. Jodhpur; 2009. p. 78–112.
27. Bationo A, Kihara J, Waswa B, Ouattara B, Vanlauwe B. Management of Tropical Sandy soils for sustainable agricultura. A holistic approach for sustainable development of problematic soils in the tropics. FAO Regional Office for Asia and the Pacific. Bangkok. 2014;414–29.
28. Bhasker R, Bidinger AG, Panduranga F, Rao V, Negusse A. Report of a survey of downy mildew incidence in farmers' fields in Anseba and Gash Barka Regions and an evaluation of the pearl millet breeding trials and nurseries at the Hagaz Research Station. ICRISAT, Patancheru, India, and ARHRD, Ministry of Agriculture. Eritrea. 2000;121–8.
29. Roumba A, Shimelis H, Drabo I, Laing M, Gangashetty P, Isack M, et al. Constraints to Pearl Millet (*Pennisetum glaucum*) Production and Farmers' Approaches to Striga hermonthica Management in Burkina Faso. Sustainability. 2021;13.
30. Jamil M, Kanampiu FK, Karaya H, Charnikhova T, Bouwmeester HJ. *Striga hermonthica* parasitism in maize in response to N and P fertilizers. Field Crops Res. 2012;134:1–10.
31. Yoneyama K, Awad AA, Xie X, Yoneyama K, Takeuchi Y. Strigolactones as germination stimulants for root parasitic plants. Plant Cell Physiol. 2010;51(7):1095–103. http://dx.doi.org/10.1093/pcp/pcq055
32. Dawud MA, Tongoona AII, Ofori PB, Eleblu K, Ifie JS. Farmers' production constraints, knowledge of striga and preferred traits of pearl millet in Jigawa State, Nigeria. Nigeria Global J Sci Front Res. 2017;17:1–7.
33. Ouedraogo N, Sanou J, Kam H, Traore H, Adam M, Gracen V, et al. Farmers' perception on impact of drought and their preference for sorghum cultivars in Burkina Faso. Agric Sci Res J. 2017;7:277–84.
34. Rouw A. Long-term topsoil changes under pearl millet production in the Sahel. in management of tropical sandy soils for sustainable agriculture. A holistic approach for sustainable development of problems soils in the tropics. In: Proceedings held on the. Khon Kaen, Thailand; 2005.
35. Reddy KC, van der Ploeg J, Maga I. Genotype effects in millet/Cowpea intercropping in the semi-arid tropics of Niger. Exp Agric. 1990;26(4):387–96. http://dx.doi.org/10.1017/s0014479700001319
36. Abdou A, Koala S, Bationo AB, Kihara I, Adolwa B, Vanlauwe K. Long term soil fertility trials in Niger, West Africa. In lessons learned from long term soil fertility management experiments in Africa, 105-120(EdsB). Dordrecht: Springer; 2012.
37. Roupsard O, Ferhi A, Granier A, Pallo F, Depommier D, Mallet B, et al. Reverse phenology and dry-season water uptake by *Faidherbia albida* (Del.) A. Chev. in an agroforestry parkland of Sudanese West Africa. Functional Ecol. 1999;13:460–72.
38. Doso SJ. Land degradation and agriculture in the Sahel of Africa: causes, impacts and recommendations. J Agric Sci App. 2014;3(3):67–73.
39. Mokgolodi NC, Setshogo MP, Shi L-L, Liu Y-J, Ma C. Achieving food and nutritional security through agroforestry: a case of *Faidherbia albida* in sub-Saharan Africa. For Stud China. 2011;13(2):123–31. http://dx.doi.org/10.1007/s11632-011-0202-y
40. Weltzien E, Whitaker ML, Rattunde HF, Dhamotharan M, Anders MM. Participatory approaches in pearl millet breeding.
41. Mulatu E, Belete K. Participatory varietal selection in lowlands sorghum in Eastern Ethiopia: Impact on adoption and genetic diversity. Exp Agric. 2001;37(2):211–29.
42. Omanya GO, Weltzien-Rattunde E, Sogodogo D, Sanogo M, Hanssens N, Guero Y, et al. Participatory varietal selection with improved pearl millet in west Africa. Exp Agric. 2007;43(1):5–19. http://dx.doi.org/10.1017/s0014479706004248
43. Issaka A. Development of downy mildew resistant F1 pearl millet hybrids in Niger. Ghana; 2012.
44. Hirooka Y, Awala SK, Hove K, Nanhapo PI, Iijima M. Effects of cultivation management on pearl millet yield and growth differed with rainfall conditions in a seasonal wetland of sub-Saharan Africa. Agronomy. 2021;11(9):1767. http://dx.doi.org/10.3390/agronomy11091767
45. Eritrea interim country strategy paper (I-CSP) 2017-2019. African Development Bank. 2017.
46. State of Eritrea: Country Strategic Opportunities Programme 2020-2025. 2020.
47. Tesso T, Ejeta G. Integrating multiple control options enhances Striga management and sorghum yield on heavily infested soils. Agron J. 2011;103:1464–71.
48. Mrema E, Shimelis H, Laing M, Bucheyeki T. Farmers' perceptions of sorghum production constraints and Striga control practices in semi-arid areas of Tanzania. Int J Pest Manag. 2017;63(2):146–56. http://dx.doi.org/10.1080/09670874.2016.1238115
49. Sugnathi S, Sivagami KG, Maheswari C, Manivannan P. Effect of drought stress on biochemical contents and proline metabolizing enzymes of *Pennisetum glaucum* L. Innovations in Agriculture. 2021;4:2–4. http://dx.doi.org/10.25081/ia.2021.v4.2797
50. Shobana S, Krishnaswamy K, Sudha V, Malleshi NG, Anjana RM, Palaniappan L. Pearl millet (Ragi, *Eleusine coracana* L.): a review of its nutritional properties, processing, and plausible health benefits. Adv Food Nutr Res. 2013;69:1–39.
51. Peterson RKD, Higley LG, Pedigo LP. Whatever happened to IPM? Am Entomol. 2018;64(3):146–50. http://dx.doi.org/10.1093/ae/tmy049
52. Brévault T, Clouvel P. Pest management: Reconciling farming practices and natural regulations. Crop Prot. 2019;115:1–6. http://dx.doi.org/10.1016/j.cropro.2018.09.003
53.