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Review

Constraints, Interventions and Prospects for Improving Pearl Millet (*Pennisetum glaucum* L) Production in the State of Eritrea - A review

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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.

Keywords: Abiotic and biotic constraints; landrace; pearl millet; *Pennisetum glaucum* L; pests and diseases; varieties

1. 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 with 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 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 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. 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.

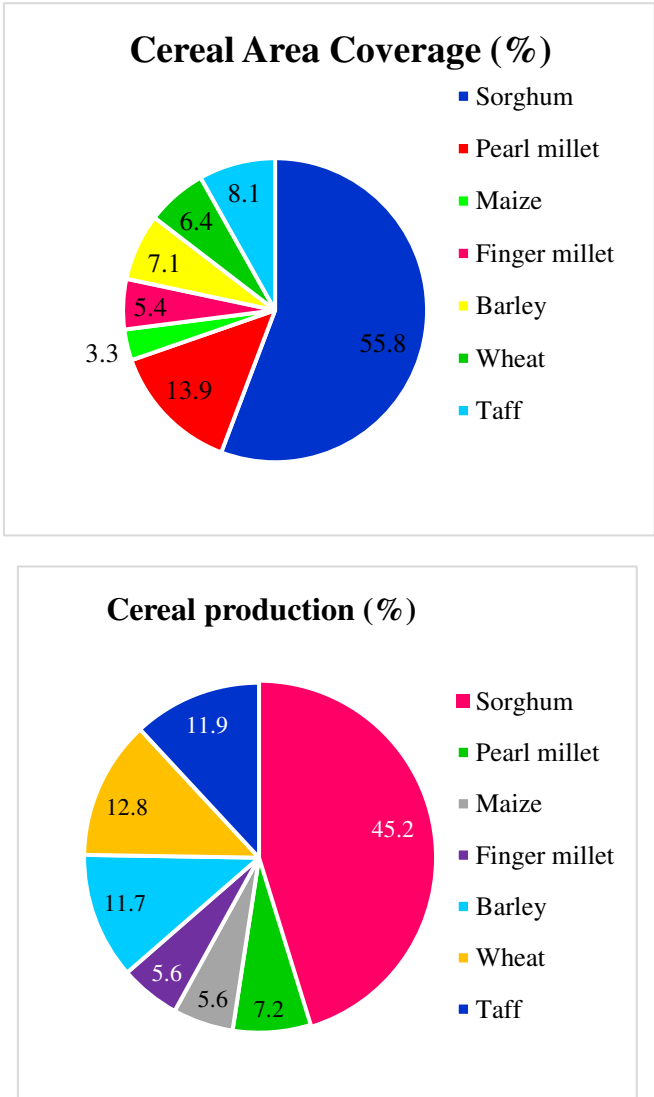


Figure 1. Crop area coverage and production contribution in Eritrea (MoA, 2021).

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, pearl 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 [5,20]. 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 adaptation to drought and poor soils, providing a consistent harvest under such conditions, growing where no other crops succeed, requiring minimal inputs, and providing good nutritional sources. In Eritrea Pearl millet has been cultivated for a long time [22] and the farmers have an extensive genetic variability of pearl millet 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).

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

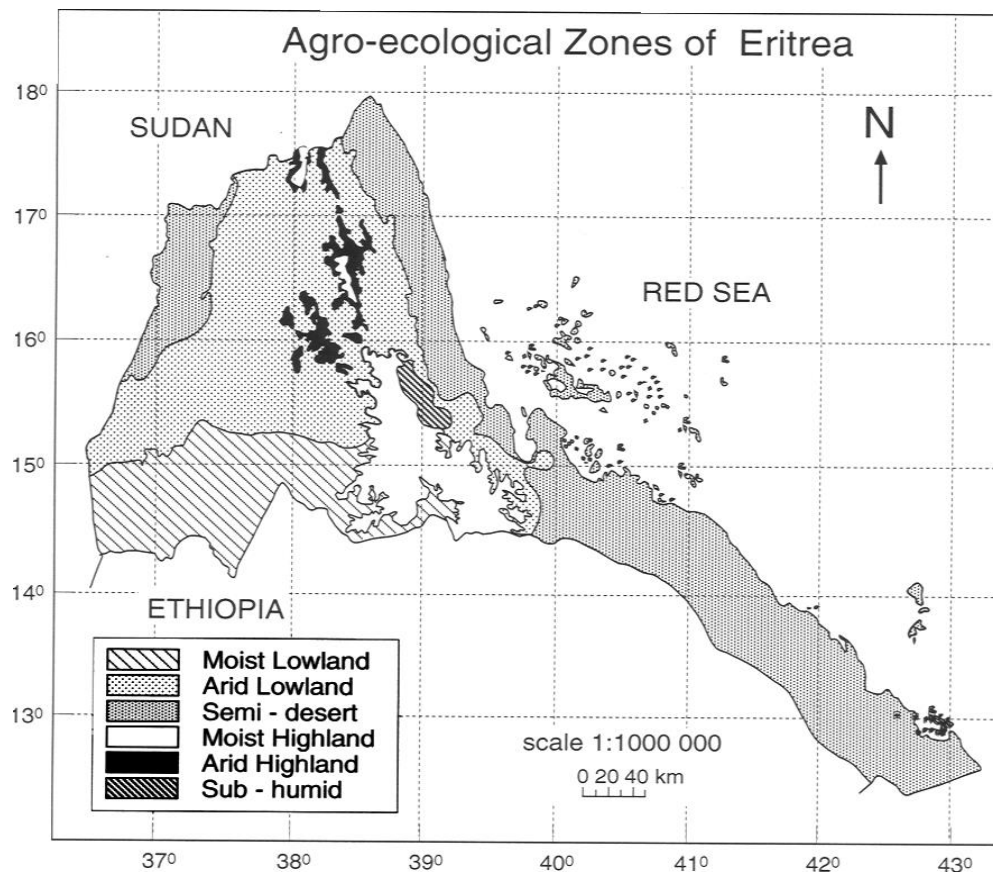


Figure 2. Map showing AEZ in Eritrea - Pearl millet is grown in – Moist low lands, arid highland and arid lowlands.

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.

In 2000 the pearl millet Programme was initiated by the National Agricultural Research Institute (NARI) in order to improve the local available landraces. This was achieved through crossing of the local landraces and the newly introduced varieties with traits such as disease resistance, early maturity, and improved 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 introduction of this initiative demonstrates an important part of the governments' food security efforts, in addressing the needs of the farmers with relatively quick impact.

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

Variety/Landrace	Preferred characteristics	Drawbacks	References
<i>Dukun</i> (Landrace)	Very high tillering capacity. Shoots produce new branches when panicles are removed. Tall statured and resistant to stink and ear head bug,	Susceptible to downy mildew, low yields	[14,15,23]
<i>Kona</i> (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]
<i>Hagaz</i> (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]
<i>Tokroray</i> (Landrace)	Very high tillering capacity shoots produce new branches when panicles are removed.	Late maturing, Susceptible to downy mildew, low yields	[14,15]
<i>Zibedi</i> (Landrace)	Very high tillering capacity	late maturity, high water demand, Susceptible to downy mildew, low yielding	[14,15,23]
<i>Baryay</i> (Landrace)	Adapted to the local environmental conditions, has good taste with good marketability,	Susceptible to downy mildew	[15]
<i>Bultug</i> (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 affect 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. Soils in 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, 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 constraints include use of traditional low yielding varieties due to unavailability and very low adoption rate of improved varieties by farmers, unavailability of improved seeds & fertilizers, poor seed production and distribution, poor agronomic practices, poor technology transfer, poor research extension to farmer linkages, susceptibility to biotic constraints [15].

4.1.2. Biotic constraints

Pearl millet suffers from various pests and diseases. Among the diseases, downy mildew (*Sclerospora graminicola*) is the most important disease which causes significant yield reductions. Other diseases include smut (*Moesziomyces penicillariae*), rust (*Puccinia substriata* var. *indica*), blast (*Pyricularia grisea*) and ergot (*Claviceps fusiformis*) [13]. In 2000, it was reported 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]. The disease has survival structures which can re-infect subsequent crops for up to 15 years once a field is infested making it very difficult to manage. Rust disease has also been reported as one of the major foliar diseases of pearl millet in Eritrea [15]. The fungus is macrocyclic, and uredinal, telial, and basidial stages occur on pearl millet. The spermatogonial and aecial stages survive on alternate hosts such as *Solanum melongena* (eggplant). The climate characterized by high temperatures and sometimes high humidity that favour development and occurrence of these pests and diseases.

Weeds such as Abebela (*Corchorus olitorius*), Elawa (*Coleome gynandra*), Dodota (*Cassia obtusifolia*), Alama (*Convolvulus sagittatus*), Afenfena (*Setaria pumila*), Weynaka (*Striga hermonthica*), Arkubeshukufa (*Amaranthus* sp.) and Legogata (*Tribulus terrestris*) also constraint pearl millet production [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]. In other crops such as maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L. Moench), and finger millet striga has been reported to contribute to poor seed germination, leaf chlorosis, stunted growth, and even death under heavy infestation [29]. The parasitic weed has a wide range of hosts it difficult to be controlled [47]. The availability of striga in these farms is a demonstration of the deteriorating state of soil fertility in major pearl 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 [29,33], 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 such the majority of the households were found to be vulnerable since large proportion of their average income is used 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 lack resources such as equipment or financial means to acquire pesticides, which leaves them with minimal options but to use hand weeding and hoeing through family labour.

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 a an early maturing variety [24]. If crop failure is repeated a number of times, drought tolerant pearl millet variety is planted mainly for the production of animal feed for their livestock but not for crop production.

Farmers are aware of the need to maintain good quality seed for the next planting season. They select panicles from the best plants that are vigorous, healthy and have bigger panicles and large size seeds [14]. Once they collect the seeds, they smoke dry to help protect the seed from pests such as moths, and rodents. Farmers also use traditional method of seed treatment where the seed is soaked in cattle urine for 24 hours and then dried before sowing. This helps to reduce pests and disease infestation in the soil

Crop ratooning is highly practiced by farmers because it has relatively short growing period requirement for a two crop system and can crop can mature in up to 20 to 25 days less than the first crop. However, ratoon yields are much lower and more variable than the first crop, especially when pest and disease carry over is a problem. Farmers grow varieties of pearl millet that have high ratooning capacity. In ratooning system, the stalk of the main crop is cut at ground level, the cut material is placed on the ground between the rows and is left there for three to five days to promote regrowth of the plant and to conserve soil moisture. The development of the plant starts after less than a week and more than 4 tillers are produced from one plant.

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 increase 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

As much as there have been efforts to address these challenges for improved productivity of pearl millet, more needs to be done to meet the increasing demand of the ever increasing populations. To enable improvement and strengthening of the pearl millet development process, seed production and seed delivery systems for improved varieties support from the stakeholders and the government is required. Farmers needs to be empowered to enable them manage their natural resource base in a sustainable manner through trainings on integrated soil fertility management and crop livestock management systems. This can be achieved through cropping systems such as crop rotations, practicing minimum or conservation tillage, and expedite the scaling up of new pearl millet varieties, and access to agricultural inputs and markets.

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 practiced as has been done in Niger where a tall late maturing pearl millet variety is planted following the first rain of the season while photoperiod, indeterminate cowpea varieties are planted two to six weeks later depending on the completion of pearl millet planting [5]. Since the main crop is pearl millet, it is allowed to dominate over cowpeas for sunlight, water, and nutrients in this cropping system while cowpea grain or stover production is of secondary importance. It has also been reported that pearl millet and groundnut intercropping system productivity can be improved by choosing appropriate varieties for crops, adjusting the planting dates, and spacing. According to the authors [35] shorter early maturing pearl millet varieties combined with indeterminate, spreading cowpea genotypes result in the highest yields and land use ratios. 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. Pearl millet production can fit in the agroforestry system with deep rooted leguminous trees with reverse phenology where the leaves are present during the dry season then drop the leaves during the growing season [37]. The inclusion of nitrogen fixing trees in agroforestry technologies adds nitrogen into the soil. Organic matter will improve soil physical properties, such as soil structure, soil aeration, and drainage. Tree canopy plus mulch layer of leaf litter and tree cuttings reduce soil erosion by reducing the impact of wind and rain drops on the soil [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]. This was attributed to higher soil nutrient levels, higher water availability, improved microclimate, and better soil physical properties

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 [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]. Implementation of these programs will lead to fundamental improvements in efficiency by promoting improved operational practices and the uptake of modern breeding approaches, as well as much improved information management practices. This will require government commitment to increase research funds and to encourage collaboration with international research organizations for better results. The benefits derived from local genetic resources collection are of particular importance and consideration, since contrary to the adapted exotic variety, they are capable of maintaining their good agronomic qualities for long period. 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. Efforts should be made to enable farmers' access the inputs needed for production, and the markets for disposing of surplus farm produce. 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

In Eritrea, soils are widely degraded and depleted of organic matter. There is need to empower farmers to enable them manage their natural resource base in a sustainable manner using integrated soil fertility and crop-livestock systems management, crop rotation can play an important role in these systems in terms of residual Phosphorus (P) and Nitrogen (N) for the legume and cereal crops, minimum or conservation tillage systems. There is need for extension systems that enable farmers to continuously learn new ways of performing old tasks, as well as new tasks, to increase their production while sustaining the environment and their lands productive capacity. The ridge furrow cultivation system is an approach that can be used in environments such as one experienced in Eritrea. This method has been reported to modify the soil-moisture environment by increasing aeration in the ridges and retaining 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]. The ridge furrow system offers protection from flooding because the ridge plants produce better in flooded years while furrow plants produce better in drought years. 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.

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

6. 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.

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