Pearl Millet as a Sustainable Alternative Cereal for Novel Value-added Products in Sub-Saharan Africa: A Review

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ABSTRACT
Pearl millet [Pennisetum glaucum (L.) R. Br.] is an underutilized small grain, nutrient-rich cereal crop cultivated in the arid and semi-arid tropics of Asia and Africa. However, several barriers exist that preclude the full exploitation of the crop such as low yield, inadequate processing technologies, lack of extension support and limited productive varieties. Furthermore, anti-nutritional factors in the grain such as polyphenols reduce digestibility, palatability and bio-availability of other nutrients. Reduction or elimination of these anti-nutritional factors through pre-treatments like boiling, cooking, roasting, soaking improves the nutritional quality of the grain. Underutilized pearl millet genetic resources and processing has the potential to contribute towards sustainable agriculture particularly in drought prone and marginal areas of Africa. This review focuses on nutritional value, pearl millet cultivation and utilization challenges, processing and value addition interventions to improve crop adoption and productivity in sub-Saharan Africa.

Key words: Orphan crop, Pennisetum glaucum, Small grain.

Pearl millet [Pennisetum glaucum (L.) R. Br.] is a widely cultivated crop grown mainly for its grain and fodder. It is projected that by 2050, a 70-100% increase in cereal food supply will be required to feed the predicted world population growth of 9.8 billion people (Wang et al., 2018). Accordingly, more needs to be done by developing countries particularly in sub-Saharan Africa (SSA) to ensure crop productivity and food security for this projected population growth. A boost in pearl millet is an alternative solution to this increasing food and nutritional demands (Serba et al., 2017). Pearl millet is a hardy crop with a relatively short growth period compared to maize (Zea mays L.), wheat (Triticum aestivum) and rice (Oryza sativa L.) that are widely grown in Africa. It can be grown in regions characterized by persistent low rainfall due to its ability to tolerate and survive under variable drought weather conditions associated with increased temperatures and high soil salinity (Varshney et al., 2017). Pearl millet performs relatively well in low-fertile soils and with lower inputs of water and fertilizers in semi-arid regions (Jiri et al., 2017; Embashu and Nantanga, 2019). This cereal crop has the potential and desirable attributes to adapt to the harsh conditions when compared to other major crops (e.g., wheat, paddy and maize).

Being a C3 plant, pearl millet has a higher water use efficiency compared to maize and sorghum that are widely grown in SSA (Singh et al., 2012). This characteristic makes pearl millet a relevant crop to water scarce situation in the semi-arid regions. Moreover, pearl millet germplasm is genetically diverse with great plasticity to adapt to erratic environments (Tadele, 2018). The crop is heat and drought tolerant with several genotypes reported to survive at temperatures as high as 62°C. Furthermore, the crop is the second most saline tolerant crop to barley which is a positive attribute in marginal and reclaimed areas. Developmental plasticity through primary and secondary tillering allows pearl millet to compensate for any crop failures (Tadele et al., 2013). This is coupled with a comparatively large germ proportion than cereals such as sorghum which contributes to its higher nutritive value

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The essential amino acids include higher content of leucine, isoleucine and lysine comparable to wheat and rye (Hulse et al., 1980; Rana and Dahiya, 2019). Furthermore, the crop is gluten-free, high in calcium, iron, zinc, vitamin A, riboflavin compared to other cereals (Table 1). Accordingly, incorporating millet into diets can be a sustainable way to curb nutrition related disorders (Datir et al., 2018).

Polyphenolic compounds, tannin, phytic acid, goitrogens and oxalic acid are some anti-nutritional components found in pearl millet grain (Ndiaye, 2018; Embashu and Nantanga, 2019). The crop bran specifically contains high concentration of polyphenols and tannin compounds. The concentration of these anti-nutritional attributes contributes towards protein indigestion (Gopalan et al., 2016).

Pearl millet is considered a healthy cereal food crop due to low gluten proportions in the grain (Dudeja and Singh, 2017). In wheat and other cereal grains gluten causes celiac diseases and allergies (Gopalan et al., 1987). Pearl millet has a potential to prevent cancerous effects due to proliferative properties associated with the presence of phenolic extracts (Upadhyaya and Vetriventhan, 2018). It is an anti-diabetic cereal grain crop compared to rice, wheat and sorghum (Krishnan and Meera, 2018). This is due to its low glycemic index and slow digestive ability caused by its raised fibre content (Jiri et al., 2017).

African challenges in pearl millet cultivation and utilization

Despite the numerous benefits that pearl millet has to offer, SSA has not ripped maximum benefits from the crop. The major production constraints emanate from unreliable rainfall, poor crop management and limited extension education. Currently, crop yields range between 500 and 1500 kg/ha, but can further decrease to 150 kg/ha due to poor farming systems. During the growing season quelea birds are difficult to manage without additional labour to scare them. Inadequate processing technologies in pearl millet to address niche markets demands has a limiting effect in the crop utilization for its biobased products. Furthermore, at household level food product preparation from pearl millet is cumbersome. Post-harvest processing practices with no low-cost technologies such as threshers makes farmers shun the crop. These barriers to the wider use of this neglected poor man’s crops expose the region into food insecurity and malnutrition. In most SSA countries, agricultural research, education and extension in agriculture have failed to collaborate to support and promote pearl millet productivity. Success in genetic enhancements of pearl millet which depends on the availability of genetic resources which is also a major constraint (Serba and Yadav, 2016) to enhancing productivity in Africa.

Pearl millet processing methods and end use

Knowledge and availability of pearl millet post-harvest processing technologies is limited in Africa. The products from the crop are primarily porridges and fermented beverages. Yet pearl millet can be processed into flour, roasted, popped, sprouted, salted into ready-to-eat grains for thick and thin porridges and confectionery. Processing pearl millet improves taste, nutritional value and overall product range (Singh et al., 2017; Ramashia et al., 2019).

Table 1: Pearl millet nutritive value compared to major cereal crops /100g edible portion, 12% moisture.

| Constituent     | Pearl millet | Sorghum | Maize | Finger millet | Wheat | Rice |
|-----------------|--------------|---------|-------|---------------|-------|------|
| Protein (g)     | 11.6         | 10.4    | 4.7   | 7.7           | 11.8  | 6.8  |
| Fat (g)         | 5.0          | 1.9     | 0.9   | 1.5           | 1.5   | 0.5  |
| Crude fibre (g) | 1.2          | 1.6     | 1.9   | 3.6           | 1.2   | 0.2  |
| Carbohydrates (g) | 67.5   | 72.6    | 24.6  | 72.6          | 71.2  | 78.2 |
| Minerals (mg)   | 2.3          | 1.6     | 0.8   | 2.7           | 1.5   | 0.6  |
| Calcium (mg)    | 42           | 25      | 9     | 35            | 41    | 10   |
| Phosphorous (mg)| 296          | 222     | 121   | 350           | 306   | 160  |
| Iron (mg)       | 8            | 4.1     | 1.1   | 3.9           | 5.3   | 0.7  |
| Zinc (mg)       | 3.1          | 1.6     | 0     | 2.3           | 2.7   | 1.4  |
| Sodium (mg)     | 10.9         | 7.3     | 51.7  | 49.0          | 17.1  | 0    |
| Magnesium (mg)  | 137          | 171     | 40    | 78-201        | 138   | 90   |
| Vitamin A (mg)  | 132          | 47      | 32    | 64            | 0     |      |
| Thiamine (mg)   | 0.33         | 0.37    | 0.11  | 0.42          | 0.45  | 0.06 |
| Riboflavin (mg) | 0.25         | 0.13    | 0.17  | 0.19          | 0.17  | 0.06 |
| Niacin (mg)     | 2.3          | 3.1     | 0.6   | 1.1           | 5.5   | 1.9  |
| Folic Acid (mg) | 45.5         | 20      | 0     | 0             | 36.6  | 8    |
| Vitamin C (mg)  | 0            | 0       | 0     | 0             | 0     | 6    |

Source: Saleh et al., 2013 Gopalan et al., 2016; Hulse et al., 1980.
Furthermore, processing reduces anti-nutritional factors and enhances bioavailability and digestibility of more nutrients. Caution needs to be exercised when processing using other methods since they reduce shelf-life of pearl millet due to its high fat content. In this section focus is on low-cost technologies that households can undertake to improve food security and nourishment.

**Dehulling**

This is the removal of the outer layer of the grain (hull and pericarp) by hand pounding, abrasive mill or disks with mechanical dehullers (Rani et al., 2018). For long term storage of pearl millet kernels can be kept intact and only dehulled for immediate use.

**Milling**

The processing method is meant for the production of fine flour which is done by reducing the size the grain by crushing. Pearl millet can be milled using a hammer and roller mill producing flour for porridge, baked and steamed food products. However, this process reduces the shelf-life of the flour due to oxidation of released fatty acids (Santakar et al., 2020). The greatest benefit of milling is the reduction of antioxidants in the bran (Sridevi et al., 2010).

**Fermentation**

Fermentation is achieved through malting and souring with mixed cultures of yeast and Lactobacilli (Dias-Martins et al., 2018). Pearl millet starch and soluble sugars are degraded from the grain and fermenting media by enzymes. The benefit of fermentation is the reduction of phytic acid and increase in phosphorus content (Wang et al., 2018). Non-alcoholic beverages such as ontaku, mahewu, obushera widely brewed in several African countries can diversify the product portfolio of pearl millet (Embashu and Nantanga, 2019; Santakar et al., 2020).

**Blanching**

This enhances the shelf life of pearl millet flour through enzyme activity reduction without compromising nutritional value (Rani et al., 2018). Blanching is achieved through submerging the pearl millet grain in hot water for a specified short period and drying (Dias-Martins et al., 2018). High blanching temperatures reduces fat acidity, acid value and percentage free fatty acid profile levels in a pearl millet meal. Polyphenols and phytic acid contents are reduced when the pearl millet grain is exposed to dry heat treatment above 90°C (Ndiaye, 2018). Furthermore, increased heat treatment slows the lipase activity and reduces decomposition of the lipids at storage.

**Acid treatment**

This treatment technique involves soaking grain in an acid such as hydrochloric acid. Use of acid treatment is important in the production of pearl millet food products that have low anti-nutritional content; high mineral bioavailability and better coloration. Lighter colour enhances food utilization and acceptance (Suma and Urooj, 2017).

**Heat treatment**

Better keeping quality in pearl millet flour emanates from dry heat treatment of grain prior to milling which limits lipase activity (Vinoth and Ravindhran, 2017). Dry heat reduces fat acidity, free fatty acid and lipase activity of pearl millet flour which causes bitterness and odour (Dias-Martins et al., 2018).

**Opportunities and proposed direction for developing countries**

Pearl millet has a potential to be utilized as a grain and fodder crop to support integrated crop-livestock systems that typify most of SSA. The large genetic variability in the germplasm can support and supply several quality traits (Gwamba et al., 2019). Biobased food products and downstream commercial industries can be developed from the crop through improved crop adoption systems. Reduction in the production cost from these novel value-added products and supportive government policies are the prerequisites for commercialization of pearl millet crop. Farmer centric approaches through research, education and extension interaction will help improve and disseminate pearl millet production technologies that will help and upgrade the farming systems resulting in improved yields per unit area cultivated. In future breeding pearl millet varieties for increased grain yield without regard to quality will be a major mistake that will affect the crop acceptance in the production chain. Ultimately, Consultative Group for International Agricultural Research (CGIAR) and the National Agricultural Research System (NARS) should not only focus entirely on pearl millet grain yield and include specialty types. This continued, focused, fundamental and applied research will stimulate demand by various stakeholders in the pearl millet production cycle. Promotional campaigns to increase public awareness of alternative products from pearl millet and available processing techniques for the diverse pearl millet germplasm should be launched. Furthermore, smallholder farmers should participate in value chain activities to
empower them with reliable and quality planting material, production skills and link them to profitable market.

CONCLUSION
Pearl millet has the potential to contribute globally towards adequate food security and alleviate malnutrition challenges. It is a suitable alternative crop to mitigate the effects of climate change to maintain food security in Africa. High priority should be on the genetic improvement of pearl millet genotypes and their utilization for commercial exploitation and use as feed and food crops.

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REFERENCES
Datir, R.P., Adil, S. and Sahare, A.S. (2018). Pearl millet: boon in mineral deficiency: A review. Agricultural Reviews. 39: 327-332.

Dias-Martins, A.M., Pessanha, K.L.F., Pacheco, S., Rodrigues, J.A.S. and Carvalho, C.W.P. (2018). Potential use of pearl millet [Pennisetum glaucum (L.) R. Br.] in Brazil: Food security, processing, health benefits and nutritional products. Food Research International. 109: 175-186. https://doi.org/10.1016/j.foodres.2018.04.023.

Dudeja, P. and Singh, A. (2017). Food safety in modern society-changing trends of food production and consumption. Food Safety in the 21st Century: Public Health Perspective. 83-88. https://doi.org/10.1016/B978-0-12-801773-9.00007-8.

Embashu, W. and Nantanga, K.M.M. (2019). Pearlmillet grain: A mini-review of the milling, fermentation and brewing of ontaku, a non-alcoholic traditional beverage in Namibia. Transactions of the Royal Society of South Africa. 74: 276-282.

Gopalani, C., Rama Shastri, B. and Balasubramanian, S. (2016). Nutritive value of Indian Foods. National Institute of Nutrition, India pp 161.

Gwamba, J., Kruger, J. and Taylor, J.R.N. (2019). Influence of grain quality characteristics and basic processing technologies on the mineral and antinutrient contents of iron and zinc biofortified open-pollinated variety and hybrid-type pearl millet. International Journal of Food Science and Technology. 55(4): 1547-158. https://doi.org/10.1111/ijfs.14375.

Hulse, J.H., Laing, E.M. and Pearson, O.E. (1980). Sorghum and the Millets: Their Composition and Nutritive Value. London: Academic Press.

Jiri, O., Mafongoya, P.L. and Chivenge, P. (2017). Climate smart crops for food and nutritional security for semi-arid zones of Zimbabwe. African Journal of Food, Agriculture, Nutrition and Development. 17: 12280-12294. https://doi.org/10.18697/ajfand.79.16285

Krishnan, R. and Meera, M.S. (2018). Pearl millet minerals: effect of processing on bioaccessibility. Journal of Food Science and Technology. 55: 3362-3372. https://doi.org/10.1007/s13197-018-3305-9

Ndiiaye, C. (2018), Quality and Nutritional Impacts of Extrusion on Pearl Millet and Nutrient Dense Native Plant Blends. Thesis and Dissertations Available from ProQuest. https://docs.lib.purdue.edu/dissertations/AAI10748281.

Ramashia, S.E., Anyasi, T.A., Gwata, E.T., Meddows-Taylor, S. and Jidesani, A.I.O. (2019). Processing, nutritional composition and health benefits of finger millet sub-Saharan Africa. Food Science and Technology. 39: 253-266. https://doi.org/10.1590/fst.25017.

Rani, S., Singh, R., Sehrawat, R., Kaur, B.P. and Upadhyay, A. (2018). Pearl Millet Processing: A Review. In: Nutrition and Food Science, Emerald Group Publishing Ltd. 48(1): 30-44. https://doi.org/10.1108/NFS-04-2017-0070.

Rana, N. and Dahiya, S. (2019). Antioxidant activity, mineral content and dietary fibre of grains. Asian Journal of Dairy and Food Research. 38: 81-84.

Saleh, A.S.M., Zhang, Q., Chen, J. and Shen, Q. (2013). Millet grains: Nutritional quality, processing and potential health benefits. Comprehensive Reviews in Food Science and Food Safety. 12: 281-295. https://doi.org/10.1111/1541-4337.12012.

Serba, D.D., Perumal, R., Tesso, T.T. and Min, D. (2017). Status of global pearl millet breeding programs and the way forward. Crop Science. 12: 2891-2905. https://doi.org/10.2135/cropsci2016.11.0936.

Satankar, M., Patil, A.K., Kautkar, S. and Kumar, U. (2020). Pearl millet: A fundamental review on underutilized source of nutrition. Multilogic Science X. Issue XXXIV.

Serba, D.D. and Yadav, R.S. (2016). Genomic tools in pearl millet breeding for drought tolerance: status and prospects. Frontiers in Plant Science. 22. https://doi.org/10.3389/fpls.2016.01724.

Singh, A., Aggarwal, N., Aulakh, G.S. and Hundal, R.K. (2012). Ways and means to maximize the water use efficiency in field crops: A review. Greener Journal of Agricultural Sciences. 2: 108-129.

Singh, A., Gupta, S., Kaur, R. and Gupta, H.R. (2017). Process optimization for anti-nutrient minimization of millets. Asian Journal of Dairy and Food Research. 36: 322-326.

Suna, F. and Urooj, A. (2017). Impact of household processing methods on the nutritional characteristics of pearl millet (Pennisetum typhoides): A Review. MOJ Food Processing and Technology. 4: 28-32. https://doi.org/10.15406/mofpt.2017.04.00082.

Sridevi, B.V., Nirmala, B., Hanchinal, R.R. and Basarkar, P.W. (2011). Antioxidant contents of whole grain cereals, millets and their milled fractions. Journal of Dairy and Food Research. 30: 191-196.

Tadele, Z. (2018). African Orphan Crops under Abiotic Stresses: Challenges and Opportunities. Scientifica. 2018. https://doi.org/10.1155/2018/1451694.
Tito, R., Vasconcelos, H.L. and Feeley, K.J. (2018). Global climate change increases risk of crop yield losses and food insecurity in the tropical Andes. Global Change Biology. 24: 592-602. https://doi.org/10.1111/gcb.13959.

Upadhyaya, H.D. and Vetriventhan, M. (2018). Underutilized climate-smart nutrient rich small millets for food and nutritional security. Regional Expert Consultation on Underutilized Crops for Food and Nutritional Security in Asia and the Pacific - Thematic, Strategic Papers and Country Status Reports.

Varshney, R.K., Shi, C., Thudi, M., Mariac, C., Wallace, J., Qi, P., Zhang, H. et al. (2017). Pearl millet genome sequence provides a resource to improve agronomic traits in arid environments. Nature Biotechnology. 35: 969-976. https://doi.org/10.1038/nbt.3943.

Vinoth, A. and Ravindhran, R. (2017). Biofortification in millets: A sustainable approach for nutritional security. Frontiers in Plant Science. 8: 29. https://doi.org/10.3389/fpls.2017.00029.

Wang, J., Vanga, S., Saxena, R., Orsat, V. and Raghavan, V. (2018). Effect of climate change on the yield of cereal crops: A review. Climate. 6: 41. https://doi.org/10.3390/cli6020041.