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Inheritance of key traits in finger millet and its breeding implications in developing sustainable varieties in semi-arid regions

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Finger millet (*Eleusine coracana* L. Gaertn) is a food and feed crop for semi-arid regions. The crop is suitable for dry and hot environments, and it yields well even with minimal inputs. Its nutritional composition ranks higher than maize. Limited research studies have been done to improve the crop's productivity and even to breed sustainable finger millet varieties suitable in Sub-Saharan Africa. This review aims to comprehend the inheritance of key traits and their breeding implication in developing varieties for food, beverages, and feed for semi-arid regions. The review identified traits with high heritability, which were grouped into compulsory and value-added traits. Grain yield potential was identified as a compulsory trait for all sustainable finger millet varieties. Days to maturity, drought and heat tolerance, protein content and blast disease tolerance were compulsory traits for food varieties. Light-coloured grains, phosphorus use efficiency, essential minerals content, low phytates and *Striga* tolerance were value-added traits for food varieties. Grain size, brown coloured-grains, free amino nitrogen and diastatic power were compulsory traits for beverages/opaque beer varieties.

Essential minerals content, plant height and low phytates content were value-added traits for beer varieties. Dry matter stover yield, digestible dry matter digestible yield, digestibility, and plant height were compulsory traits for feed varieties. Several basal tillers, stover nitrogen content, stover crude protein content and soluble sugars content are value-added traits for feed varieties. Heritability plus genetic-advance as a percentage of the mean influence the choice of traits in a breeding programme. However, indirect selection methods like correlated trait inheritance and molecular markers can assist in breeding traits with high heritability.

Keywords: *Additive gene action, breeding programme, Eleusine coracana, heritability, genetic-advance, semi-arid regions, climatic change, phosphorous use efficiency*

INTRODUCTION

Finger millet (*Eleusine coracana* (L.) Gaertn) is one of the important millets worldwide. It is grown mainly for food, brewing gluten-free beverages/opaque beer, and feeding in marginal farming areas in which major cereals fail to give yields (Mamo et al., 2018). Poor people living in hot and dry parts of the world consider finger millet crops as staple grain crops (AICSMIP, 2009; Opole, 2019, Ramashia et al., 2019; Yayeh & Tarekegne, 2021). Finger millet belongs to the grass family *Poaceae* and its primary centre of origin is Ethiopia (Sapkal et al., 2018). It is mostly self-pollinating allotetraploid (2n=4x=36), with some amount of cross pollinating (1%) mediated by wind, genome constitution AABB (Sapkal et al., 2018). The domesticated finger millet crop is the result of selection from large-grain mutant of the wild *E. coracana* subsp. *africana* (Sapkal et al., 2018). The word millet is from French word 'mille' (thousand) which means one handful can contain 1000 of millet grains (Ramashia et al., 2019). The common name "finger millet" is derivative from the inflorescence form which have many spikelet's that bear a resemblance of a form of human fingers (Opole, 2019). The grain of finger millet is categorised by variation in colour (brown, white, and light brown varieties), high concentration of carbohydrates, dietary fibre, phytochemicals, and essential amino acids, essential minerals and gluten-free (a substance that causes coeliac disease) status in their grain (Tadele, 2016). The white coloured grains of finger millet is for baking purposes, brown/light brown grains are mainly used in porridge making, while brown coloured grain is used mainly for traditional beer brewing purposes (Sood et al., 2017). On nutritional composition, finger millet ranks higher than maize, but the grain is neglected and not well used due to limited crop improvement research. It has ten times higher calcium (350mg/100g) equated to common cereals (rice, wheat, maize, and sorghum) (Saleh et al., 2013). The grain has abidance of protein, iron, zinc, fibre, malting qualities; with a low glycemic index (GI) (Tadele & Assefa, 2012; Sapkal et al., 2018; Ramashia et al., 2019). Again, the crop can be grown for medicinal purposes (Tesfaye & Mengistu, 2017). It is a vital food crop for poor rural populations in semi-arid areas with calcium and anemia deficiency status widespread (Owere et al., 2015). However, with all these benefits, limited exploration studies are focused on such important crop species with the potential to enhance aspects of security in terms of food, nutritional and feed.

Finger millet gain can be utilised either through traditional or modern processes such as radiation, popping, fermentation, malting, direct cooking and soaking (Ramashia et al., 2019). The act of processing finger millet grains enhances sensory and dietetic properties reduces/inhibits the effects of tannins, phytic acids, anti-nutritional factors and phenols (Ramashia et al., 2019). The advantage of finger millet over other grains is the storability aspect of more than ten years without deterioration in quality or destruction by weevil (Lule et al., 2012). Furthermore, the long storage ability of finger millet makes it a vital food security strategy crop (Chazovachii et al., 2012). Nevertheless, its yield is insignificant mainly due to the absence of the latest bred varieties, management technologies, and other biotic and abiotic factors.

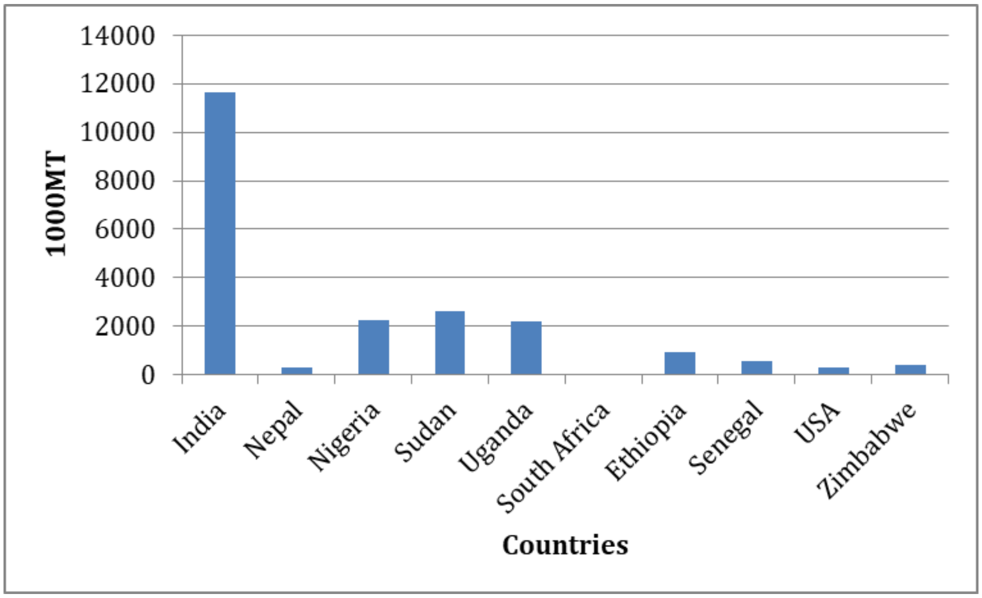

Figure 1a. Global finger millet production for year 2018 (Source: http://www.fao.org/faostat/en/#data/QC

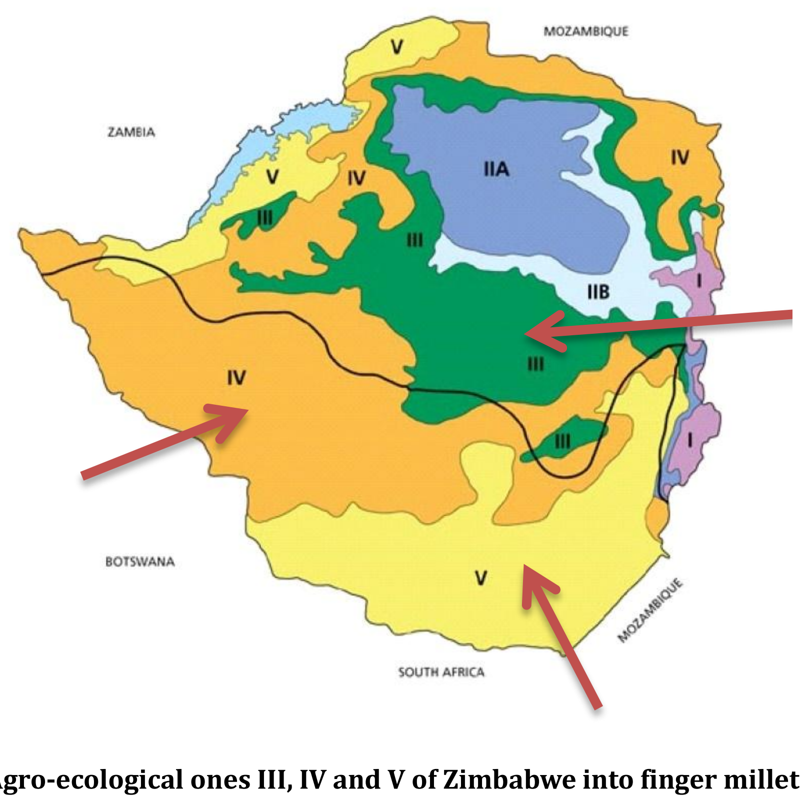

Figure 1b. Agro-ecological ones III, IV and V of Zimbabwe into finger millet production

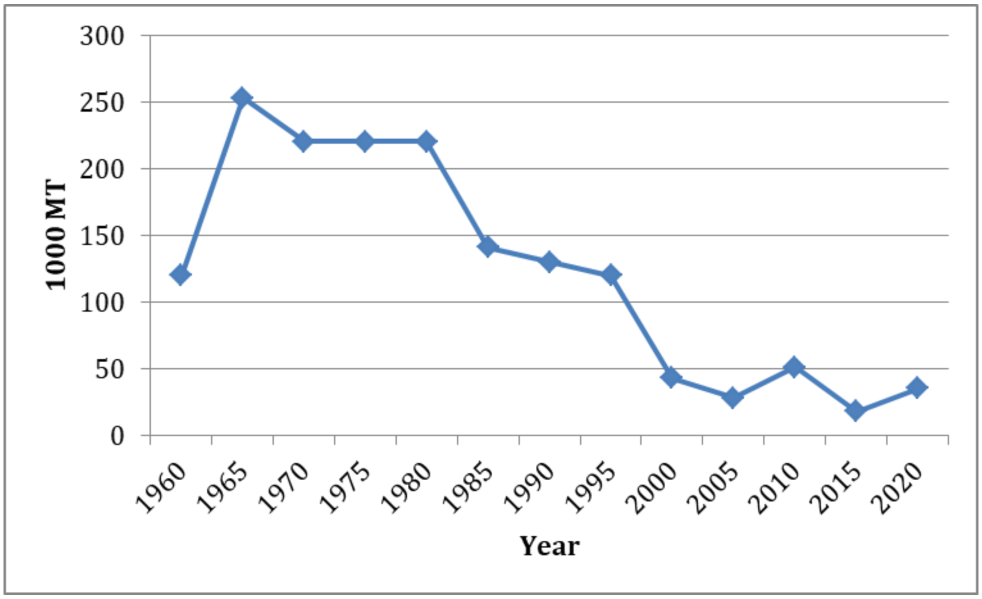

Figure 1c. Zimbabwe Finger fillet production by year (Source: IndexMundi, 2020)

Generally, fifty-five to sixty percent of the worldwide produced crop is from Africa, in countries like Zimbabwe, Kenya, Nigeria, Ethiopia, Uganda, Zambia Tanzania and Malawi (Dlamini & Siwela, 2015; Tarekegne et al., 2021). The annual global production level is around 4.5 to 5 million tonnes of grain. 2.5 million tonnes are produced by Indians alone whilst two million tonnes are produced by Africans (Ramashia et al., 2019). Figure 1a, shows the major global countries in finger millet for the year 2018 and India was the major producer in that year. In semi-arid regions in terms of production, finger millet is on number four after sorghum, pearl millet, and foxtail millet, correspondingly (Opole, 2019). In Zimbabwe (Figure 1b), finger millet production using landraces varieties is mainly in the marginal areas (agro-ecological zones III, IV and V) (Mukarumbwa & Mushunje, 2010). Even though the crop has all these importance for disadvantaged communities in semi-arid areas, little attention and concern have been given to mainstreaming the crop for breeding improvement.

The potential of finger millet under climate change

With all the challenges of food insecurity due to climate change effects, increase in finger millet production instead of maize might enhance food and feed security in Sub- Saharan Africa (SSA) and Zimbabwe in particular, though little research is done in yield improvement (Gukurume, 2010). Rainfall patterns have been severely affected by climate change across the globe and Zimbabwe in particular. Droughts are now a common experience in Zimbabwe. On top of the economic difficulties experienced in Southern African countries, this has led to a greater degree in the drop of grain crops on the small-scale farmers, of which the majority of them generally do farming in semi-arid areas (Muzerengi & Tirivangasi, 2019). Millets are important in tropical and semi-arid- regions worldwide because of their tolerance to pests and disease damage, good adaption, capability to withstand salinity status, drought-tolerant and small growing season (Chandra et al., 2016). Furthermore, the crop has efficient nitrogen and phosphorus use efficiency and can grow well with limited water availability (Gupta et al., 2017). Attributes such as an efficient antioxidant potential and increased signal perception contribute to drought tolerance ability.

Finger millet production (Figure 1c) has been declining sharply every year from 1980 to 2000 and as from the year 2000 to the year 2020, the rate of increase and decrease is almost constant. However, improving the yield potential per hectare of millet is important regarding nutrition and food security in the background of climate change effects and inconsistency. The decline in production experienced from the year 1980 to the year 2000 of millets might be due to the small encouragements focused on farmers and the lack of new novel varieties in Zimbabwe. The crop is compatible with semi-arid zones against maize because of its drought tolerant attributes once mentioned above (FAO, 2008). Its productivity is based on its lower risk of failure than major cereals and its strong adaptation advantage to climate change (Opole, 2019). Finger millet requires minimal inputs during production in the face of increasing populations worldwide, coupled with decreasing water availability in semi-arid regions; finger millet holds the key to food and feeds security (Mukarumbwa & Mushunje, 2010).

In Zimbabwe, finger millet is an under-utilized and under-researched crop and continued to be neglected in terms of support for production, promotion, research, and development. It's being rediscovered as a food and nutritional crop, and since 2015, its production has started to increase (Figure 3). One of the main reasons for the stagnation in production from 2005 to date might be the absence of improved finger millet cultivars. Most farmers in Zimbabwe grow maize even those in marginal areas (Figure 2) to ensure food security (Muzerengi & Tirivangasi, 2019). Maize makes up to approximately 80-90% of production (Muzerengi & Tirivangasi, 2019). The lack of finger millet crop improvement efforts in developing suitable varieties might be attributed to a poor understanding of the inheritance of key traits and implications in breeding suitable varieties for food, beverages/opaque beer, and feed. Also, the lack of modern technologies for grain processing and utilisation are some of the reasons for the stagnation in production as shown in recent years from 2010 to 2015 (Muzerengi & Tirivangasi, 2019; Phiri et al., 2019). Over the last few years from the year 2000, there has been increasing acknowledgment of its nutrient configuration and benefits as healthy food as shown in the constant part of Figure 1. More research efforts in developing high-yielding varieties, processing and utilisation technologies, and policy innervations are being implemented to promote the cultivation and consumption of this underutilised crop for sustainable agriculture and healthy lives (Chazovachii et al., 2012).

Most farmers landraces varieties with poor yield levels because of shortage of latest high-yielding commercial varieties on the market and no research funding and research focus have been channelled towards crop improvement (Phiri et al., 2019). In Zimbabwe, the crop is grown by small scale farmers who use their different means of picking the best varieties to grow. Landraces are commonly grown whose yields less leading to lower national average productivity of zero point two four tonnes per hectare compared to projected level of two to four tonnes per hectare nationally (Phiri et al., 2019). Only two varieties have been released by Crop Breeding Institute (CBI) and disseminated to farmers, but the market availability of those varieties is limited in some parts of the country. Limited information is known about those two varieties concerning nutritional composition, brewing characteristics, stover quantity and quality, blast disease tolerance, nitrogen and phosphorus use efficiency, drought and heat tolerance characteristics.

There is an imperative prerequisite to breed finger millet with higher yields through utilization of the genetic pool available to produce suitable varieties for food, beverages/opaque beer, and feed in semi-arid regions. Little is known about the inheritance of key traits in finger millet and traits implications in breeding varieties for food, beverages/opaque beer, and feed in semi-arid regions. This review aims to understand the inheritance of key traits on finger millet and its breeding implications in developing varieties suitable for food, beverages/opaque beer, and feed in semi-arid regions. This will provide ample opportunities for finger millet development through direct collection from the available germplasm or traits recombination.

Heritability and genetic advancement of key traits in finger millet

Trait heritability in broad sense is one of the interesting genetic parameters for the breeders, it measures value of breeder's contribution on character from selection in a population of off-springs (Falconer & Mackey, 1996). Traits with a bigger heritability percentage imply ease of inheritability of trait and traits with small heritability percentage means the environment is congruently projecting in the trait expression (Hayes et al., 1955; Ganapathy et al., 2011; Negi et al., 2017). Heritability is directly related to a selection made and directly linked to genetic advance (Wolie et al., 2013). Heritability percentages of quantitative traits are normally because of sensitivity to environmental factors and genetic advance effect enhance heritability estimates should be used to increase selection efficiency (Wolie et al., 2013). Additive gene effects are due to high heritability chances coupled with high genetic advance, this will lead to ease and effective selection. Heritability caused by epistasis and dominance; normally has low genetic gain (Larik et al., 2000). Parameters such as genetic advance, heritability and genetic variability are paramount for breeders and provide the opportunity for the selection of key traits in combination with desirable traits (Lule et al., 2012; Negi et al., 2017).

In this review, we discuss the details of numerous studies to comprehend the inheritance of key traits on finger millet and their influence on the breeding for food, beverages/opaque beer, and feed. In Tables 1, 2, and 3, we reviewed the literature on the inheritance of economic traits for food, beverages/opaque beer and feed from the database and major journal sites ranging from 2010 to till date with some exceptional cases. We discussed the heritability of these traits in general and implications in breeding finger millet varieties suitable for food, beverages/opaque beer, and feed. We here pinpointed and discussed constraints to breed finger millet traits. Lastly, we listed compulsory traits and value-added traits for food, beverages/opaque beer, and feed to guide future breeding programmes in the semi-arid region.

Finger millet key traits and its heritability

Generally, the estimate of heritability assists breeders to concentrate limited resources for the collection of desired traits (Ogunniyan & Olakojo, 2014). Heritability estimates are classified as zero to thirty percent for low, thirty-one to sixty percent for medium and greater than sixty percent for high (Robinson et al., 1949; Johnson et al., 1955). However, Adhikari et al. (2018), grouped heritability as 0-20% low, 20-40% as moderate and >40% as high. Genetic advance measured in percent is in three groups, zero to ten percent as low, eleven to twenty percent as moderate and greater than twenty one percent as high (Johnson et al., 1955). In the present literature review's key trait heritability assessment, classification of heritability estimation and genetic advance as percent mean adopted classes used by Johnson et al. (1955). Heritability estimates of traits in most of the literature review in this article were in a broad sense. Genetic gain measured via broad sense heritability ways does not indicate the effect of selection, hence, to ensure effect of active assortment for upgrading relatively heritability estimates coupled by genetic advance as percent mean (GAM) should be used. Furthermore, the manner of inheritance and gene action was reviewed to give a better estimate of narrow sense heritability (Table 1-3).

Table 1. Heritability estimates of key finger millet traits for food

All breeding target levels of finger millet varieties suitable for food were compared to traits level in Finger Millet variety 1 (FMV1) as common check variety in Zimbabwe.

Trait	Target trait level	Trait level in FMV1	Heritability/gene action and genetical value	References
Grain yield potential (t/ha)	>3.5 in potential varieties for Zimbabwe	2.95	Moderate heritability and genetic advance as percent of mean (GAM). Means non-additive and additive gene action are at play.	Sao et al., 2016 Singamsetti et al., 2018 Anuradha and Patro, 2019.
Grain yield per plant (g)	6 - 10	-	High heritability (76.47%) and high GAM (36.70%). Means additive gene action.	Upadhyaya et al., 2011 Sapkal et al., 2018
Number of Productive tillers on a plant	2 - 5		Heritability >60% and GAM >21% Meaning to say additive and non-additive genes are in control.	Patil and Mane, 2013 Owere et al., 2016 Anuradha & Patro, 2019.
Fingers per head per plant	7 - 10	9	Heritability >85.58% and GAM >23.60%. Additive gene action.	Patil & Mane, 2013. Owere et al., 2016 Anuradha & Patro, 2019. Waghmode et al., 2020
Main ear head length (cm)	6 - 10	7.77	Heritability >61% and GAM >21% Additive gene effect.	Ganapathy et al., 2011. Patil & Mane, 2013. Jyothsna et al., 2016. Devaliya et al., 2018.
Finger length (cm)	5 - 10	-	High heritability (74.46%) and high GAM (32.22%). Additive gene effect.	Debbarma, 2013. Manyasa et al., 2016 Keerthana et al., 2019
Finger width (cm)	2 - 5	-	Heritability >61% and GAM >11% Both gene actions at play	Anuradha & Patro, 2019
1000 grain weight (g)	2.3 - 5	-	High heritability (73.76%) and high GAM (31.59%). Both gene additions at play.	Wolie et al., 2013 Manyasa et al.,2016 Keerthana et al., 2019
Grain density (Number of grains cm^{-1})	60 - 80	-	Heritability >31% and GAM >11%. Both gene actions in control.	Waghmode et al., 2020
Days to maturity (days)	<100	140	High heritability (94.33%) and high GAM. Both gene actions in control.	Sao et al., 2016 Anuradha & Patro, 2019.
Days to 50% flowering (days)	<50	-	High heritability (98.80%) with moderate GAM. Additive gene action.	Patil & Mane, 2013. Singamsetti et al., 2018. Anuradha & Patro, 2019.
Thresh ability (%)	>75%	-	Low heritability and low GAM. Means non-additive gene effect.	Owere et al., 2015
Drought and heat tolerant (very high)	Moderate to high	-	Low heritability and polygenic inheritance. In Wheat and Barley, its non-additive gene action.	Sallam et al., 2019

Root biomass	Moderate to high	-	Limited research is done in finger millet but in Wheat, it has high heritability (60%). In wheat, it has additive gene action.	Mathew et al., 2018
Root to shoot biomass allocation	Moderate to high	-	Limited research studies were done on finger millet but in wheat, it has low heritability (46.6%). Non-additive gene action in wheat.	Mathew et al., 2018
Root length (cm)	>53	-	Limited research studies are done on finger millet but in rice, it has heritability >61% and GAM >21%. Additive gene in control.	Sathya & Jebaraj, 2013
Root architectural traits	Moderate to high	-	Low heritability (multigenic controlled). In wheat, the seminal root angle has high heritability, but the general root system has low heritability.	Hall & Richards, 2013 Mahmood et al., 2015 Mathew, et al., 2018
Leaf rolling (1-10 scale)	>3	-	High heritability.	Simbagije, 2016 Mitra, 2001
Leaf osmotic potential/adjustment.	Moderate to high	-	Monogenic inheritance In rice, it has high heritability	Mitra, 2001 Sellammal et al., 2014
Metabolites concentrations e.g., proline content) [µmol/g fresh weight]	Moderate to high	-	Limited research studies were done in finger millet but in maize and rice, it's highly heritable and has high genetic advance.	Mahmood et al., 2015 Sathya & Jebaraj, 2013
Leaf area index	Low to moderate	-	Heritability >86% and high GAM >47.15%. Additive gene in control.	Sindhuja et al., 2019
Leaf senescence	Low to moderate	-	High heritability and additive gene action.	Issa et al., 2018
Specific leaf area	Moderate to high	-	Limited research studies were done on finger millet, but in peanut, it has high heritability. Additive gene action in peanut	Songsri et al., 2008
Chlorophyll content (SPAD chlorophyll meter reading)	Moderate to high	-	Limited research studies are done on finger millet but in rice, it has high heritability and high genetic advance. In groundnuts, it has high heritability (71.7%). Additive gene action.	Sathya & Jebaraj, 2013 Oppong-Sekyere et al., 2019
Chlorophyll stability index	Moderate to high	-	Limited research studies were on finger millet but in rice, it	Sathya & Jebaraj, 2013

			has high heritability and high genetic advance. Additive gene action in rice.	
Athermotolerance index	Moderate to high	-	Limited research studies were done in finger millet, but pearl millet has high heritability. Additive gene action in pearl millet.	
Canopy air temperature depression (^{o}C)	Moderate to high	-	Limited research studies were done in finger millet but in rice, it has high heritability. Additive gene action in rice	Sellammal et al., 2014 Narayanan, 2018
Membrane damage	Low to moderate	-	Limited research studies were done in finger millet but in wheat, it has high heritability. Additive gene action in wheat.	Narayanan, 2018
Stomatal conductance (m$^{-2s-1mmol}$)	Low to moderate	-	Limited research studies were done in finger millet but in wheat, it has heritability >61% and GAM >21%. Additive gene action in wheat.	Heidari et al., 2020
Harvest index under drought condition (biomass allocation)	>0.4	-	High heritability (94%) and high genetic advance (80.67%). In sorghum, it has moderate heritability (0.5).	Akech, 2015 Jawale et al., 2017 Sindhuja et al., 2019 Brenton et al., 2016 Waghmode et al., 2020
Water use efficiency (WUE)	Moderate to high	-	Limited research studies were done in finger millet but in foxtail millet (*Setaria spp*), it's controlled by additive gene action and heritable. In maize, it has moderate heritability.	Feldman et al., 2018 Leakey et al., 2019
Protein content (%)	>9	-	High heritability (96.1%) and high genetic advance. Additive gene in control.	Vadivoo et al., 1998 Upadhyaya et al., 2011 Jawale et al., 2019
Calcium content (mg/100g)	>350	-	High heritability (96.1%) and high GAM (25.53%). Additive gene action.	Vadivoo et al., 1998 Govindaraj et al., 2011 Upadhyaya et al., 2011 Jawale et al., 2019 Waghmode et al., 2020
Zinc content (mg/100g)	>8	-	No many research studies were done in finger millet, but in pearl millet and sorghum millet, additive gene is in control. Heritability >99.90% and GAM >37.78%.	Govindaraj et al., 2011 Govindaraj et al., 2013 HarvestPlus, 2014 Govindaraj et al., 2016
Iron content (mg/100g)	>4	-	High heritability (99.0%) and higher GAM (37.78%). Additive gene in control.	Govindaraj et al., 2011 HarvestPlus, 2014 Sapkal et al.,2018 Jawale et al., 2019

Phosphorus content (mg/100g	>210	-	High heritability and high GAM. Additive gene in control.	Govindaraj et al., 2011 Ayesha et al., 2019
Fibre content (%)	8 - 12	-	Heritability >61% and GAM >21%. Additive gene in control	Dhamdhere, 2008 Patel et al., 2018
Lysine content (%)	>2	-	Limited research studies were done in finger millet but in sorghum, it is monogenic recessive(*hl*) gene action with low heritability and low genetic advance. In barley, its single recessive gene (*lys*) action	Saini et al., 2020
Plant height (cm)	>85	84.7	High Heritability of 92.26% and moderate GAM of 17.87%	Owere et al., 2016 Anuradha & Patro, 2019
Nitrogen use efficiency (NUE) and nitrogen utilization efficiency) (low N tolerance	High	-	Heritability for NUE alone is very low (low genetic gain) and is polygenic genetically controlled. Heritability of component traits (uptake and utilization) is higher.	Ranjan & Yadav, 2019 Witcombe et al., 2008 Ranjan & Yadav, 2019
Phosphorus use efficiency	High	-	Moderate heritable trait, in maize it is conditioned by both gene action in control	Da Silva et al., 1992
Grain colour	white	-	Limited research studies were done in finger millet but in sorghum, grain colour in influenced by both dominant and recessive alleles	Clará Valencia & Rooney, 2009 Patil, 2017
Tolerance to *Striga*	Moderate to high	-	In sorghum, recessive gene action (resistance) with low heritability and low genetic advance. No literature exists on genetic control	Kountche et al., 2016 Gobena et al., 2017
Tolerance to Fall armyworm	Moderate to high	-	Limited research studies were done in finger millet but in maize, it is controlled by additive gene action (in conditioning leaf-feeding resistance). High heritability (77%) In maize, it is controlled by additive and non-additive effects. Heritability of 53% (superior limit)	Wiseman & Davis, 1979 Widstrom et al., 1972 Widstrom et al., 1992 Mihm, 1997 Rea et al., 2002
Tolerance to blast disease	Moderate to high	-	Moderate heritable trait. Both gene actions in control	Owere at el., 2016
Grain size (mm)	>2	-	High heritability	Murty, 1992

			Additive gene action	
Phytates contents (%)	<0.48	-	In pearl millet have both gene actions and heritability >99.90% and GAM >26.57%).	Govindaraj et al., 2011
Phenolic content (%)	<3	-	Phenolics content in Black gram has low heritability (0.44) with moderate GAM (12.96%)	Singh et al., 2017
Tannins content (%)	<0.04	-	Limited research studies were done in finger millet but in sorghum, tannins are controlled by single gene (*Tannin1*)	Xie & Wu, 2019

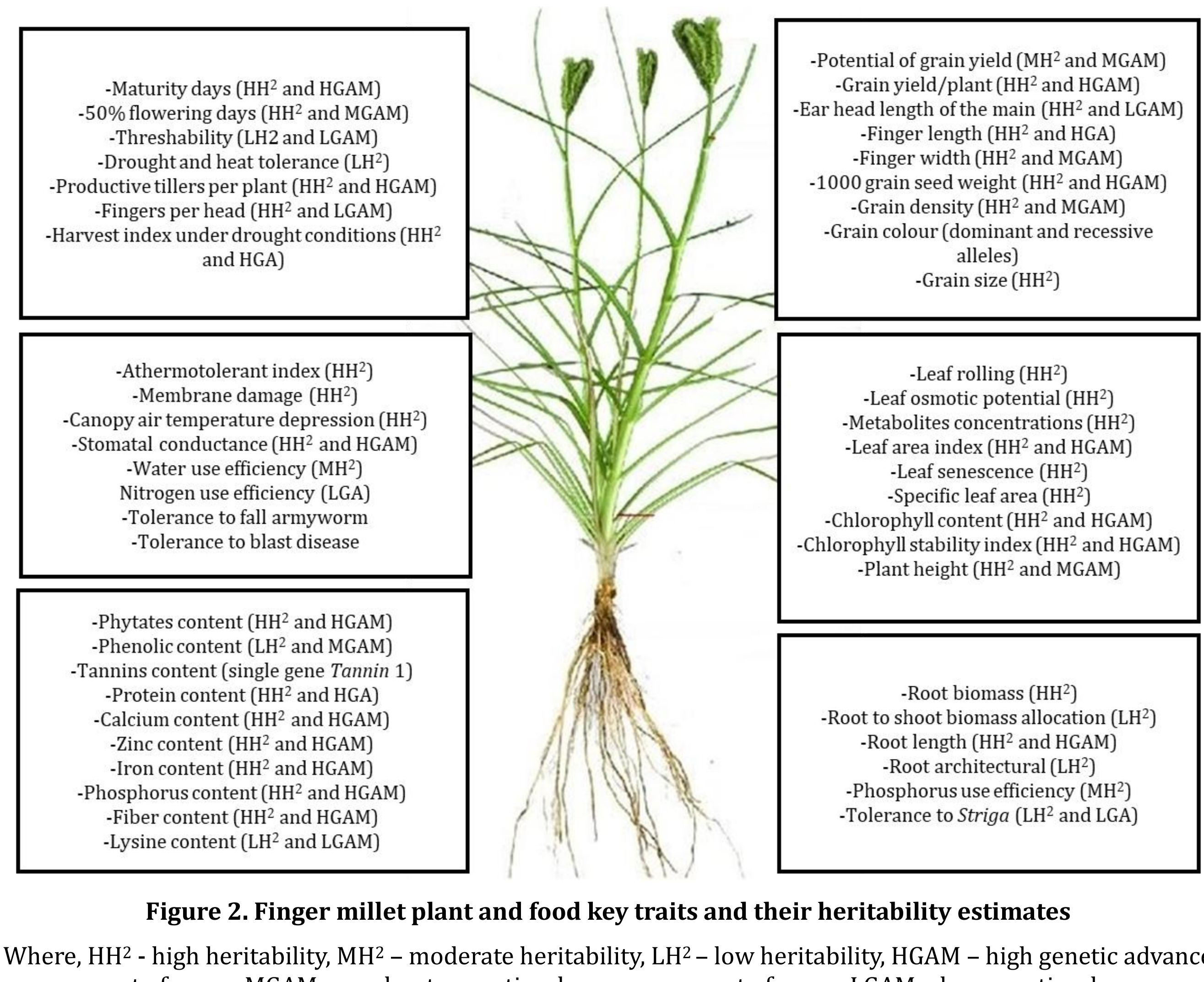

Figure 2. Finger millet plant and food key traits and their heritability estimates

Where, HH^2 - high heritability, MH^2 – moderate heritability, LH^2 – low heritability, HGAM – high genetic advance as percent of mean, MGAM – moderate genetic advance as percent of mean, LGAM – low genetic advance as percent of mean.

Crop improvement of Key traits in finger millet to enhance the yield and nutritional value.

The literature review here in Table 1 revealed heritability >61% coupled with genetic advance >21% as percent of mean on indicated traits such as protein content, root length, leaf area index, chlorophyll content, chlorophyll stability index, stomatal conductance, harvest index and drought and/or heat tolerance index, calcium content, iron content, fibre content, high phosphorus content and zinc content in pearl millet, tillers mainly productive ones per plant, main ear head, length of finger, yield of grain per plant, 1000 grain weight and days to maturity (Anuradha & Patro, 2019; Keerthana et al., 2019; Oppong-Sekyere et al., 2019; Heidari et al., 2020; Sathya & Jebaraj, 2013; Sindhuja et al., 2019; Mahmood et al., 2015; Upadhyaya et al., 2011; Jawale et al., 2019; Waghmode et al., 2020; Govindaraj et al., 2016; Sapkal et al., 2018; Ayesha et al., 2019, Sao et al., 2016; Patel et al., 2018). This proposes that the traits mentioned above are less controlled by the environment in their appearance and governed by additive genes. Plant breeders therefore can make selections efficiently based on phenotypic expression of these traits on distinct plant by adopting simple and early assortment methods when breeding finger millet varieties suitable for food. Some traits have heritability >61% combined with moderate to low genetic advance as percent of mean such traits are number of fingers per head, finger width, days to 50% flowering and plant height (Waghmode et al., 2020; Anuradha & Patro, 2019; Singamsetti et al., 2018; Owere et al., 2016). This indicates no-additive gene effect and heritability may be caused by dominance and epistasis because of the genetic gain <10%. Hence, selection in early generations for these traits may be effective during the breeding finger millet varieties for food. Some traits have heritability >61% alone without indicating genetic advance percent of mean estimates. This scenario was observed on; root biomass, leaf osmotic adjustment in rice, leaf rolling, leaf senescence, specific leaf area in peanut plant, metabolites concentrations in maize, thermotolerance index in pearl millet, canopy air temperature depression in rice, and membrane damage in wheat (Sellammal et al., 2014; Simbagije, 2016; Issa et al., 2018; Narayanan, 2018; Feldman et al., 2018; Oppong-Sekyere et al., 2019; Songsri et al., 2008; Mitra, 2001). Nitrogen use efficiency in the uptake and utilization component traits revealed high heritability (Witcombe et al., 2008; Ranjan & Yadav (2019). Phosphorus use efficiency is heritable and is conditioned by both gene action effects (Da Silva et al., 1992; Schegoscheski et al., 2019). Grain color is influenced by both dominant and recessive alleles (Clará Valencia & Rooney, 2009). Hence selection for grain colour might be postponed to later generations to harness the recessive alleles in the segregating genotypes during breeding exercise for finger millet varieties suitable for food in semi-arid regions. Estimating the heritability range alone can't give a healthier idea in choosing these traits in finger millet breeding programmes. However, it is not necessarily that a trait presentation heritability >61% will also exhibit genetic advance >21% (Johnson et al., 1955). Genetic gain/advance is a greater pointer of advancement that can be anticipated because of physical exercise assortment from a population. Estimation of heritability range plus genetic advance give a more dependable guide of assortment (Johnson et al., 1955). In this scenario, heritability might be predominantly influenced by either of the genes (additive or non-additive gene). If there is the incidence of additive gene action on these traits implies that progress may be made in complete assortment in breeding finger millet varieties for food whereas if its non-additive gene action, it may slow assortment progress for these traits and assortment may be done in later generations or based on indirect selection methods. Heritability ranging <60% combined with genetic advance ranging <20% revealed on grain density trait (Waghmode et al., 2020). Low heritability was revealed in root architecture, drought and heat tolerance (Witcombe et al., 2008; Mahmood et al., 2015; Mathew et al., 2018; Sallam et al., 2019; Ranjan & Yadav, 2019). Heritability <30% coupled with genetic advance <10% revealed in threshability, nitrogen use efficiency and lysine content traits (Reddy et al., 2013; Owere et al., 2015; Saini et al., 2020). This suggests the presence of involvement of environment influence, both gene actions on such traits. Hence, these traits may be difficult to exploit through simple selection procedures. In a resource-limited breeding programme these traits should be selected based on indirect selection methods.

Heritability of Key biotic stress traits in finger millet

Striga, fall-armyworm, and blast disease are common biotic factors affecting finger millet production in hot and dry regions in Africa and Zimbabwe in particular. Finger millet variety appropriate for the food in these regions should have tolerance traits to these three biotic factors. Blast disease caused by *Pyricularia grisea* (Cooke) Sacc, causes yield losses higher than 50% on finger millet and at times higher than 90% if season is favourable (Owere et al., 2016). The literature review here in Table 1 revealed *Striga* tolerance trait in a related crop like sorghum, its inheritance is controlled by recessive genes action coupled with heritability <30% and genetic advance <10% (Kountche et al., 2016; Gobena et al., 2017). Heritability <30% with genetic advance <10% indicates that there is involvement of no-additive gene actions for *Striga* tolerance traits, which may be difficult to exploit through simple selection procedures in the breeding finger millet varieties for food in semi-arid regions. Regarding fall armyworm tolerance trait, in other crops like maize, additive gene action is involved in conditioning leaf-feeding resistance, suggesting the presence of heritability >61% with genetic advance >20%. This indicates that modest selection may be rewarding in breeding finger millet varieties tolerance to fall armyworm and suitable for food in semi-arid regions. Literature review here in Table 1, according to Widstrom et al. (1992), Mihm (1997), and Rea et al. (2002), high heritability in maize for fall armyworm resistance indicates additive effects and selection for fall-armyworm tolerant traits in finger millet varieties suitable for food is effective. Blast disease tolerance trait is heritable and has both gene action in control (Owere et al., 2016). However, heritability estimates alone without genetic advance estimates cannot give a healthier idea in choosing an appropriate breeding method for blast disease tolerance trait in finger millet. Both gene actions in control indicate that modest selection might be difficult in improving finger millet varieties appropriate for the food in hot and dry regions.

Inheritance of anti-nutritional traits on finger millet varieties suitable for food

Tannins, phytates, and phenolics are anti-nutritional factors inherent in finger millet to keep predatory insects at bay (Kumar et al., 2016). These factors to humans may straight or secondarily disturb the digestion of nutrients in the gut but preparation approaches such as fermentation, cooking, soaking, puffing, debranning and autoclaving of grain result in lowering the intensities of these factors (Samtiya et al., 2020). The literature review here in Table 1 revealed that in some related crops such as pearl millet, phytates content is highly heritable coupled with genetic advance >20%. Phenolics content has a heritability <30% associated with genetic advance <20% (Singh et al., 2017). In some crops like sorghum, tannins are controlled by a single gene (*Tannin1*) (Xie & Wu, 2019). This indicates the phytates are predominance controlled by additive gene action thereby direct selection for low levels of phytates contents is highly effective. Phenolics content revealed the presence of a thin series of inconsistency and higher genotype by environment interface (no-additive gene action). Regarding tannins trait, selection for low levels in finger millet varieties is fairly easy.

Table 2. Heritability estimates of finger millet traits for beverages and opaque beer

All breeding target levels of finger millet varieties suitable for beverages and opaque beer were compared to trait level in Finger Millet Variety 1 (FMV1) as common check variety in Zimbabwe.

Trait	Target trait level	Trait level in FMV1	Heritability/gene action and genetical value	References
Free amino nitrogen (FAN) content (mg/L)	>130	-	Limited research studies were done on finger millet but in wheat and Barley, it is controlled by non- additive gene action (oligogenic nature of inheritance)	Saini et al., 2020
Soluble Nitrogen (mg/100g)	>457	-	No literature exists on heritability	
Diastatic power (SDU/g)	>25	-	Limited research studies done on finger millet but in wheat, it has low heritability (0.26)	Baker et al., 1971
Germination percentage of grains (%)	>95	-	Limited research studies on finger millet but in pearl millet, it is a highly heritable trait. Cumulative gene action in pearl millet.	Totok et al., 1998
Moisture content of grains after steeping (%)	>43	-	No literature exists on heritability	
Grain colour (1 -10 scale)	>2	-	Limited research studies on finger millet, brown colour of grain is dominant over white colour. But in sorghum, grain colour in influenced by both dominant and recessive alleles	Clará Valencia & Rooney, 2009 Patil, 2017
Grain size (mm)	>2	-	High heritability. Additive gene action.	Murty, 1992
Protein content (%)	>9	-	High heritability (96.1%) and high GAM. Additive/accumulative gene action	Vadivoo et al., 1998 Upadhyaya et al., 2011 Jawale et al., 2019
Calcium content (mg/100g)	>350	-	High heritability (96.1%) and high GAM (25.53%). Additive gene action.	Vadivoo et al., 1998 Govindaraj et al., 2011 Upadhyaya et al., 2011 Jawale et al., 2019 Waghmode et al., 2020
Zinc content (mg/100g)	>8	-	Limited research studies done on finger millet but in pearl millet and sorghum, it is controlled by accumulative additive gene action. Heritability >99.90% and GAM >37.78%.	Govindaraj et al., 2011 Govindaraj et al., 2013 HarvestPlus, 2014 Govindaraj et al., 2016

Iron content (mg/100g)	>4	-	Heritability >99.0% and GAM >37.78%. One gene action in control (additive).	Govindaraj et al., 2011 HarvestPlus, 2014 Sapkal et al.,2018 Jawale et al., 2019
Phosphorus content (mg/100g)	>210	-	High heritability and high GAM. One gene action in control (additive).	Govindaraj et al., 2011 Ayesha et al., 2019
Plant height (cm)	>85	84.7	High heritability of 92.26% and moderate GAM 17.87%.	Owere et al., 2016 Anuradha & Patro, 2019

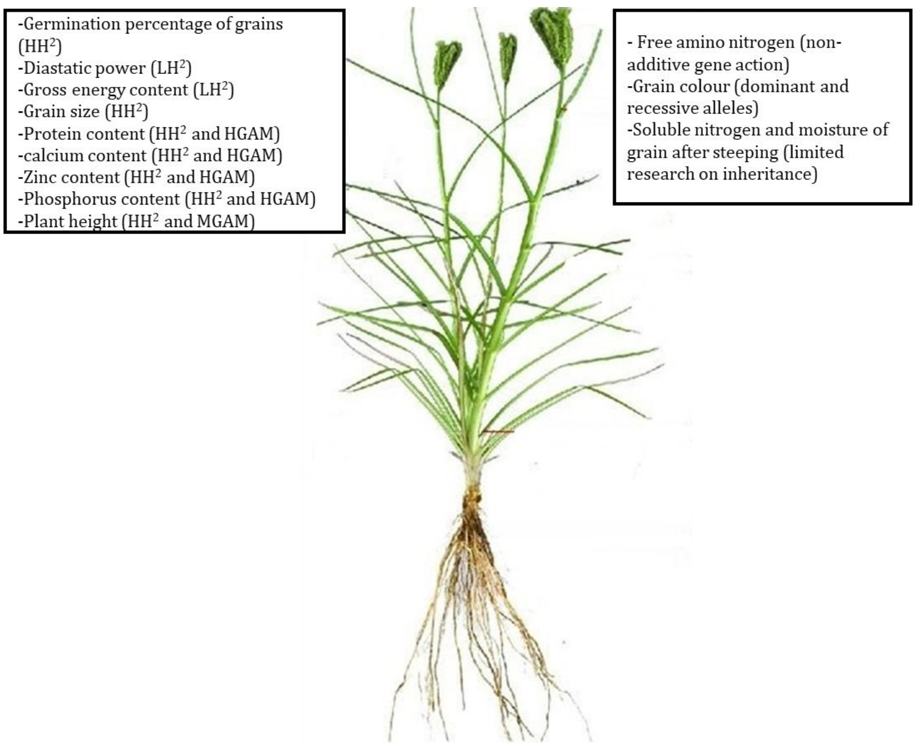

Figure 3. Finger millet plant; beverages and opaque beer key traits and their heritability estimates

Where, HH^2 - high heritability, MH^2 – moderate heritability, LH^2 – low heritability, HGAM – high genetic advance as percent of mean, MGAM – moderate genetic advance as percent of mean, LGAM – low genetic advance as percent of mean.

Breeding key traits in finger millet traits for beverages and opaque beer

Since time immemorial, in Africa, other cereals and finger millets have been the main ingredient in brewing traditional beer and Zimbabwe in particular (Usai et al., 2013). The brewing process involves fermentation of malted grains. Malting is the precise germination of grains in favourable to controller environments of steeping, germination and kilning (Schmitt et al., 2013). Sorghum is malted to produce alcoholic beverages/opaque beer and weaning foods.

Table 3. Heritability estimates of key finger millet traits for livestock feed

All breeding target levels of finger millet varieties suitable for beverages and opaque beer were compared to trait level in Finger Millet Variety 1 (FMV1) as common check variety in Zimbabwe.

Trait	Target trait level	Trait level in FMV1	Heritability/gene action and geneticl value	References
Stover dry matter yield (t/ha)	>2.9	-	High heritability (82.70%) and high GAM. Additive gene action.	Jyothsna et al., 2016 Devaliya et al., 2018 Anuradha & Patro, 2019
Stover digestible dry matter yield (g/m^2)	>100	-	Limited research studies done on finger millet but in pearl millet, it has high heritability (0.85)	Blümmel et al., 2007
Stover digestibility (%)	>40	-	Limited research studies done in finger millet but in pearl millet it has high heritability (0.94%).	Blümmel et al., 2007
Stover nitrogen content (%)	>1	-	Limited research studies done in finger millet but in pearl millet it has moderate heritability (0.56).	Blümmel et al., 2007
Soluble sugars (%)	>3	-	Limited research studies done in finger millet but in pearl millet it has high heritability (0.83),	Blümmel et al., 2007
Metabolisable energy yield (MJ/m^2)	>5	-	Limited research studies done on this crop, but in other crops (pearl millet) it has high heritability (0.85)	Blümmel et al., 2007
Calcium content (mg/100g)	>350	-	High heritability (96.1%) and higher GAM (25.53%). Only one gene action is in control.	Vadivoo et al., 1998 Govindaraj et al., 2011 Upadhyaya et al., 2011 Jawale et al., 2019 Waghmode et al., 2020
Phosphorus content (mg/100g	>210	-	High heritability and high GAM. Only one gene action is in control.	Govindaraj et al., 2011 Ayesha et al., 2019
Stover crude protein (g/kg)	140	-	Limited research studies done on finger millet, but in pearl millet, it has both gene actions in control.	Kumar et al., 2012
Basal tillers per plant (number)	2 - 10	-	Heritability >61% and GAM >20%. Both gene actions in control.	Patil & Mane, 2013 Owere et al., 2016 Anuradha & Patro, 2019.
Plant height (cm)	>80	84.7	High heritability of 92.26% and moderate GAM of 17.87%	Owere et al., 2016 Anuradha & Patro, 2019

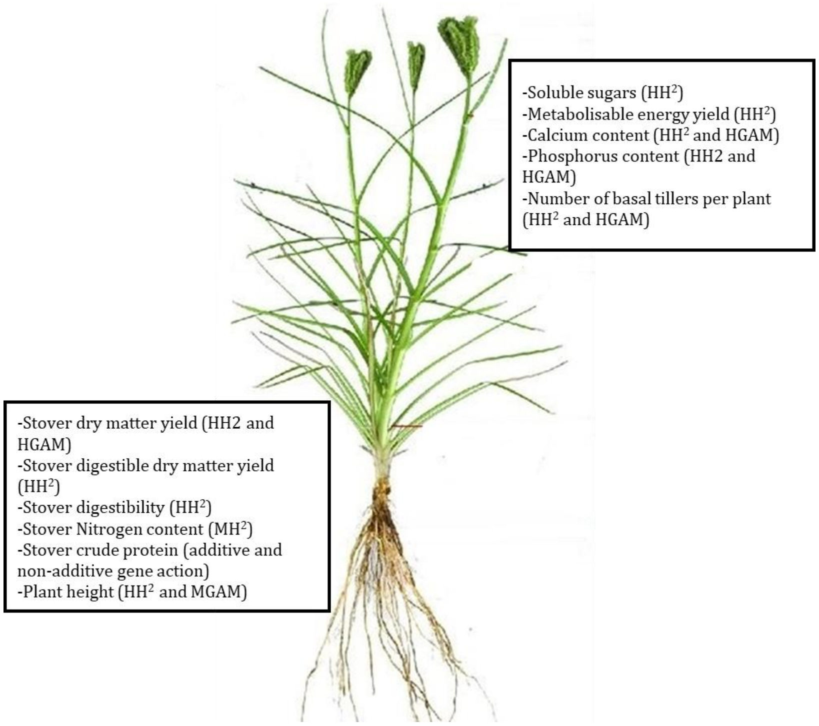

Figure 4. Finger millet plant and heritability estimates of key traits for livestock feed

Where, HH^2 - high heritability, MH^2 – moderate heritability, LH^2 – low heritability, HGAM – high genetic advance as percent of mean, MGAM – moderate genetic advance as percent of mean, LGAM – low genetic advance as percent of mean.

Due to the availability of high yielding sorghum commercial varieties on the market and limited investigations of using finger millet in brewing opaque, sorghum is used mainly in brewing commercial opaque beer in Zimbabwe. The brewing using finger millet malt of local traditional opaque beer is common in many countries (Usai et al., 2013). Limited research has been carried out on the germination and malting properties of finger millet in brewing beer and as a possible replacement of sorghum and barley malt. The superiority of this beer is hinged on the quality of the malt (Dewar et al., 1995). Furthermore, malt quality is hinged on many parameters like free amino nitrogen content, diastatic power, soluble nitrogen, hot water extract, moisture content of grains, and germination energy of finger millet (Dewar et al., 1995). Finger millet grain malting has been studied to a limited extent and information regarding the heritability of malting quality characteristics of finger millet malt is scarce. The literature review here in Table 2 revealed that free amino nitrogen has non-additive gene action (oligogenic nature of inheritance) (Saini et al., 2020). Diastatic power and gross energy content traits, are some of the important malting quality parameters and the inheritance of these traits are some related crops such as wheat, these traits have low heritability (Baker et al., 1971; Roche & Flower, 1976). Limited research has been done on finger millet concerning the inheritance of most important beverages and opaque beer in finger millets traits in other related crops like pearl millet, the trait is heritable (Totok et al., 1998). Grain size increases the surface area for water absorption to initiate germination processes for the malting processes, which have high heritability (Murty, 1992). Grain colour is influenced by both dominant and recessive alleles (Clará Valencia & Rooney, 2009). However, heritability only is not the only indicate of genetic advancement that would result in selection for these traits. This might suggest that these traits might have both gene actions in control and selection is difficult to exploit, take advantage of such traits via modest assortment procedures. Breeding for grain colour controlled by both additive and non-additive gene action may be difficult to exploit through modest selection procedures in the early breeding method of finger millet. The other malting quality parameters such as soluble nitrogen, and moisture content of grains after steeping, the literature review here in Table 2 revealed that no literature exists on the genetic control of these traits. The MC of grains after steeping is vital in malting procedures, the grain should engross sufficient HO_2 to trigger enzymatic processes and initiate sprouting which eventually influences the superiority of beer formed by the malt. Nutritional composition and mineral composition traits are some of the important traits to be considered in the breeding finger millet varieties suitable for beverages (maheu) and opaque beer. The literature reviewed in Table 1 revealed has similar literature review regarding genetic advance and heritability of such traits. Hence, for discussion on genetic advance and heritability, visit the above section 1 on breeding finger millet varieties suitable food where all was discussed.

Breeding livestock feed traits in Finger millet

Shortage of stover is the restraining factor for growing livestock production in semi-arid regions, particularly in Zimbabwe (Wafula et al., 2017). Climate change effects have resulted in decreasing in water availability in hot and dry regions; crops that efficiently utilize water might be the alternative stover crops. The emerging global warning scenario has made finger millet breeders aim to for breeding finger millet varieties with numerous purposes (Wafula et al., 2017). While the finger millet grains might be used for human consumption, stover of the crop might be a brilliant dry matter for livestock in semi-arid regions (Verma and Patel, 2013). Regarding nutrient configuration, millets have higher nutrients than sorghum and maize for phosphorus, potassium and calcium levels on stover material (Gowda et al., 2015). The basal tillers on the plant and the height of the plant influence the yield level of stover dry matter yield. The literature reviewed here in Table 3 revealed heritability >61% linked with genetic advance of higher to moderate range for the following traits; stover dry matter yield, number of basal tillers per plant, plant height, phosphorus content, calcium content (Patil & Mane, 2013; Jyothsna et al., 2016; Devaliya et al., 2018; Anuradha & Patro, 2019; Ayesha et al., 2019; Waghmode et al., 2020). Soluble sugars and metabolisable energy yield traits in finger millet but in pearl millet, these traits have high heritability (Blümmel et al., 2007). Plant height reviewed a genetic advance <20% which implies dominance and epistasis is in control as the genetic gain is low. Hence, selection may be postponed to a later generation to harness the dominance and epistasis effects on the plant height trait. Stover nitrogen content is an important determinate of stover quality, and it should be considered when breeding finger millet varieties for livestock feed. Stover material with greater than 1% Nitrogen content is more palatable and more preferred by livestock compared to stover material with high roughage only (Blümmel et al., 2007). The literature reviewed here in Table 3 revealed that limited research had been done to appreciate the inheritance of this trait on finger millet but in pearl millet, stover nitrogen content has a heritability of >56% (moderate) (Blümmel et al., 2007). Stover crude protein content is controlled by both gene actions (Kumar et al., 2012). These two traits are predominantly controlled by both gene actions and picking in early generations of these traits might be difficult in trying to improve stover nitrogen content. Calcium and phosphorus determine the nutritional value of stover and are important nutrient compositions to consider when breeding finger millet varieties suitable for livestock feed. The literature review here in Table 3 revealed heritability >61% coupled with genetic advance >20% for calcium and phosphorus nutrients traits (Vadivoo et al., 1998; Govindaraj et al., 2011; Upadhyaya et al., 2011; Jawale et al., 2019; Waghmode et al., 2020). This indicates a prevalence of accumulative gene action in affecting the transfer of calcium and phosphorus and direction phenotypic picking might be eased in the development of such finger millet traits.

Discerning the traits association or combining abilities of key agronomic, yield and nutritional traits among finger millet varieties/germplasms

The relationship of traits with simply inherited traits accelerates the selection process in finger millet breeding (Basavaraj et al., 2017). Understanding the association or favourable combining ability between traits in breeding finger millet varieties suitable for food, beverages/opaque beer and feed helps in the simultaneous improvement of direct or indirect traits (Anuradha et al., 2017a). It is important to note that any genetic gains in finger millet varieties suitable for food, beverages/opaque beer and feed are not made at the expense of grain yield potential. Breeding for gain yield improvement is the main objective for farmers who are food insecure in semi-arid regions. Consequently, knowledge of linkage of such finger millet traits with grain yield would progress picking efficiency (Kumari et al., 2018). Grain yield is positively correlated with 50% flowering days, productive tillers, panicle width, length of finger, number of grains per spikelet, 1000 grain weight, finger number, plant height, single plant yield, the weight of 20 mature ears and threshing ratio (Owere et al., 2015; Kumari et al., 2018). The productive tillers per plant and length of the finger are central to yield influencing traits and need to be considered while framing selection criteria in the finger millet breeding programmes. Since these traits have a substantial affirmative relationship with grain yield and affirmative inter-relationship among themselves (Ganapathy et al., 2011). Furthermore, the grain mass per head, plant height, flag leaf length and productive tillers exert optimistic straight outcomes on the grain yield (Owere et al., 2015). Genetic improvement of these traits has a good influence on improving crop yield (Lule et al., 2012). However, Lule et al. (2012) stated an opposing correlation of grain yield with 1000 grain weight, days to heading, days to maturity and flag leaf width. This negative association of yield and these traits suggest that more effort should be concentrated on these traits using restricted selection indices. Late-maturing finger millet genotypes are associated with morphological traits such as open ear type, narrow finger width, few spikelets per finger and lower grain per spikelet (Lule et al., 2012). Increased grain yield is generally connected to productive tillers per plant, panicle length, plant height, panicle diameter and panicle yield per plant in pearl millet. Grain iron trait is also associated with the following grain mineral, zinc, phosphorus and manganese. Anuradha et al. (2017b). Again, high iron density in the grain is associated with high zinc density in finger millet grains (Upadhyaya et al., 2011). Finger millet accessions rich in zinc content are related to high yield potential compared to accessions with high levels of protein and iron content. Calcium content is also associated with iron, magnesium and manganese (Badigannavar & Ganapathi, 2018). This suggests that during the selection of finger millet varieties suitable for food, beverages/opaque beer and feed these traits association may be indirectly selected. Landraces rich in copper content are associated with agronomic traits such high number of tillers and a greater number of fingers per head (Kazi & Auti, 2017). Again, landraces rich in micronutrients such as iron, zinc, and manganese exhibit more number fingers and more grains, (Kazi & Auti, 2017). This correlation study confirms that it is possible to breed finger millet varieties with high mineral density and various desirable agronomic characters. Dry fodder and grain yield are associated with traits such as fingers per ear, tillers per plant and plant height (Krishnappa et al., 2009). This suggests that dry fodder yield and yield of grain traits have combing ability with the number of fingers per ear, tillers per plant and plant height. Finger millet tillers and stem girth is also associated with plant height; hence the selection of these traits increases the stover yield of finger millet (Khairwal & Singh, 1999).

Challenges to breed finger millet traits

Finger millet crop is an allotetraploid (2n=4x=36) with an AABB genome, with a self-pollinating ability and artificial hybridisation by the crossing of such plant for appropriate parental lines is difficult. It is believed that the A genome precursor is the wild diploid species *E. indica* (2n=2x=18) and while the B genome precursor is unknown, hence this scenario of complex genome leads to difficulties in trait appearance (Liu et al., 2011). The crop is classified as an underutilized/orphan crop because of its unfriendly association with any cereal of importance because of the size of its genome (tetraploidy) (Goron & Raizada, 2015). The little effort has been made to generate genomic resources for this species including genome sequencing. Further, allopolyploids derived through hybridization and chromosome doubling between the two different species have differing maternal genomes (AABB) (Yoo et al., 2014). Therefore, finger millets contain two pairs of counterpart chromosomes derived from two species. Genome assemblage and footnote of polyploidy species is a major task in genomic due to duplicated genes derivative from genome duplication) and by characterization are similar and the separation assembly process is problematic. Furthermore, the superiority of the polyploidy assembly for the scaffold length is usually low in these plants. The incidence of repeated genes and polyploidy split the assemblage foremost into smaller scaffolds and contigs (Pryszcz & Gabaldon, 2016). Some of finger millet breeding target traits such as yield and associated parameters are difficult to breed as they have complex inheritance and are affected by the environment. The yield trait of finger millet is complex and is influenced by many of component characters and environments directly or indirectly. The finger millet genotype's traits performance depends on its genetic potential and the environment where it is grown. Finger millet (G x E) connections are among the main factors limiting finger millet's response to selection and the efficiency of breeding programmes. Determining genetic stable, physiological traits and adaptable of a cultivar across multiple environments is a prerequisite in breeding elite lines and a challenge for breeders. Hence, the classification of well stable and adaptable variety with low G x E interface is the key aim of a breeder for traits such as high yielding grain nutrients and mineral dense content as it is influenced by environmental factors such as soil organic matter and precipitation (Vetriventhan et al., 2020). Sub-dividing different locations into smaller uniform regions and picking genotypes with superior constancy transversely a widespread range of locations are two approaches for rising genotypes with little G x E connections (Sood et al., 2018). Traditional breeding ways such as mass selection, pedigree selection and pure line selection in self-pollinating crops such as finger millet have delivered a series of varieties well-matched to varied different growing conditions globally. However, the dependence of these methods on recurrent series of inbreeding needs ten to fifteen to breed and release finger millet variety. The conventional long-lasting finger millet refinement cycles might be a barrier to hastening finger millet exploration with technologies and modern tools. Again, finger millet hybridization is a difficult task due to its floral morphology and anthesis behaviour. Hence, the understanding of the floral flower form and means of pollination structure helps in developing means for emasculating means and the development of crossing protocols (Vetriventhan et al., 2020). Finger millet breeding is supported by MMA tools to trail suitable traits precisely compared to conventional breeding if the appropriate and ease way to go. The precise selection at the genome level improves and quickens genetic gain through improving assortment intensity, accuracy and reduces breeding cycle to release a variety length. Genomic selection forecasts a genetic gain of unseen phenotypes amongst finger millet populations hinged on the breeding objectives presumed from genome-wide information scored phenotypically (Watson et al., 2018; Bohra et al., 2020). Finger millet is adapted to varied climatic conditions and its production is not affected by biotic and abiotic stresses. Plant growth and yield traits are affected by abiotic stresses like drought, saline and deficiencies of nutrients.

The development of a new finger millet variety with the aid of genomic studies of WGS may speed up the release of genotypes tolerant to biotic and abiotic factors (Ceasar et al., 2023). Geneticists and plant breeders have widely tried to find out the diversity of calcium content traits at the genome level on germplasm resources of finger millet. The challenge is now on how finger millets specific traits resources can be broken to develop custom-made specific cultivars such as Calcium-bio-fortified finger millet varieties that a suitable for diverse maturity clusters and cropping patterns (Vetriventhan et al., 2020). Globe genebanks conserve more than 37,000 accessions and 15 accessions are identified as promising for further refining grain calcium levels in cultivated crops (Upadhyaya et al., 2011). Larger assemblages of germplasm resources of finger millet are helpful in improving the concentration of specific traits, but the majority are yet to be for breeding for trait-specific cultivars such as high calcium finger millet varieties. Challenges arise because of issues such as inadequate strategies and week harnessing of valuable genetic diversity found in groups, introduction barriers and exotic germplasm crossing, insufficient prior to breeding programmes to simplify introgression of required nutrition superiority to the breeding line and recirculation of similar working assemblages of breeders (Upadhyaya et al., 2014). Furthermore, trait-specific germplasm resources exist from germplasm collections but their barriers to obtaining or accessing it for usage because of global restrictions to interchange accessions due to legal issues of transfer agreements on seeds (Puranik et al., 2017). Molecular markers (MM) for categorising vital characters such as protein content, grain calcium, resistance to biotic and abiotic factors are inadequate for finger millet compared with maize. Genomic tools such as Simple Sequence Repeats (SSRs) markers have been used to evaluate the range of genetic diversity of these specific traits in finger millet genotypes. Nevertheless, the development nature, preventive recombination proportions and historic genetic challenges faced during isolation traits for the domestication of finger millet purpose impact the magnitude of accessible genetic diversity. There has been little development on the utilization of crop genetic map during the mapping of traits though the assemblage of the only molecular marker-based connection map was made many years ago. It has not been fully exploited for cataloguing and identifying QTL (quantitative trait locus) controlling specific traits like grain calcium content due to an inadequate number of edifying markers (Puranik et al., 2017; Sharma et al., 2017). The shortage of adequate markers and genomic sequence material in this crop has led to restricted development efforts for specific traits like nutritional upgrading. Nevertheless, the developments in large-scale genome technologies led to the construction of genome-wide markers utilized for large-scale picking of loci like SNP (single nucleotide polymorphism) markers through usage of genotyping-by sequencing (Kumar et al., 2016). Despite of little close of polymorphisms in utilised genotypes, SNPs provide clarification for variation in specific traits like calcium content amongst genotypes. However, before utilization of SNPs, there is a need to distinguish real SNPs amongst diverse genotypes from the homeologoues SNPs inside discrete genotypes because of allotetraploidy of the crop (Puranik et al., 2017).

The plant type concept key with compulsory and value-added traits, and their ranking for developing finger millet varieties suitable for food, beverages/opaque beer, and feed

Finger millet varieties suitable for food, beverages/opaque beer and feed require different traits to fulfill the desired end-use product. Compulsory traits are expected to be found in a distinct variety for each of the three targets' end-use products. Again, value-added traits increase the distinctness and value of these varieties for the three target end-use products. Using the genetic advance and heritability levels of key traits information revealed in literature reviewed in Table 1, 2, and 3. We managed to compile Table 4 with highlighting the compulsory traits, value-added traits, and ranking of these traits based on the importance of the trait to the distinctness of finger millet varieties.

Table 4. Compulsory traits, value-added traits, and their ranking for developing finger millet varieties suitable for food, beverages/opaque beer, and feed

Traits for food varieties	Traits for Beverages/opaque beer varieties	Traits for feed varieties	Trait ranking
Compulsory traits	**Compulsory traits**	**Compulsory traits**	
Optimum grain yield potential	Optimum grain yield potential	Optimum grain yield potential	1
Days to maturity	Germination energy	Stover dry matter yield (DM)	2
Drought and heat tolerance	Desirable grain size	Stover digestible dry matter yield (DDM)	3
Plant height	Dark brown coloured grains	Stover metabolisable energy yield (ME)	4
Protein content	Free amino nitrogen	Stover digestibility	5
Nitrogen use efficiency (NUE)	Diastatic power	Plant height	6
Value-added traits	**Value-added traits**	**Value-added traits**	
Light-coloured grains	The Moisture content of grain	Number of basal tillers	1
Phosphorus use efficiency (PUE)	Soluble nitrogen	Stover nitrogen content	2
Iron content	Iron content	Stover crude protein content	3
Calcium content	Calcium content	Soluble sugars content	4
Phosphorus content	Plant height		5
Low phytates content	Low phytates		6
Tolerance to *Striga*			7

The plant type concept of finger millet varieties suitable for food

Key traits for food varieties finger millet were identified and grouped into two groups which are compulsory traits and value-added traits. The compulsory key traits for food finger millet varieties are those traits related to grain yield potential improvements and selected linked traits such as plant yield, main ear head, productive tillers per plant, length of finger, 1000 grain weight, and 50% flowering days. Yield potential/hectare and selected related traits for yield improvement is the priority in breeding finger millet varieties suitable for food in semi-arid regions. Finger millet height of plant and maturity days traits are some of the compulsory traits identified for food finger millet varieties. Most end-use products of finger millet have a problem with grit and this problem discourages people from utilization finger millet for food products and grit might be associated with postharvest processes such as harvesting and threshing. Desirable plant height might reduce admixtures during mechanical harvesting of the finger millet due to good clearance height for the cutter bar of the combine harvester. Again, farmers in semi-arid regions are highly prone to drought and heat incidences, hence, breeding programme for food finger millet varieties should focus on the short season or early maturity varieties that efficiently utilize the little available water to maximize seed production (drought escaping varieties). Furthermore, drought and heat tolerance traits are compulsory for food finger millet varieties. Climate change affects global crop production and drought and heat are the major abiotic factors affecting finger millet production. Hence, breeding programmes for food finger millet varieties should target varieties tolerant to these abiotic constraints because rainfall in semi-arid regions is generally erratic and insufficient, causing unpredictable drought and heat stress is also common. However, drought and heat tolerant traits have complex inheritance, hence selected drought and heat tolerant traits such as root biomass, root length, leaf rolling, leaf osmotic adjustment, metabolites concentrations, leaf area index, chlorophyll content, chlorophyll stability index, canopy air temperature depression, stomatal conductance, harvest index, and phosphorus use efficiency should be considered when breeding finger millet varieties suitable for food in semi-arid regions. Furthermore, a compulsory trait for food finger millet varieties is protein content. This trait is for attaining food and nutritional security for people in semi-arid regions. Protein malnutrition (hidden hunger) generally affects almost half Africa's continental population, especially preschool children and women. Protein deficiency causes retarded physical and mental growth (Upadhyaya et al., 2011). Millets grain proteins are superior to maize and contain high amounts of crucial amino acids such as sulfur-containing amino acids (cysteine and methionine) (Ramashia et al., 2019). Hence, food finger millet varieties with a higher level of protein content will address protein deficiency a common challenge in the semi-arid regions. The second group of key traits identified for food finger millet varieties is the value-added group. Value-added traits increase the distinctness and value of finger varieties suitable for food in semi-arid regions. The first value-added trait for food finger millet varieties is light-coloured grains. Light-coloured finger millet contains a minimal level of tannin and phenol as compared to brown varieties (Kumar et al., 2016; Parida et al., 1989). Tannin compounds mainly affect colour, flavour and availability of vital nutrients from the grain and product produced (Shibairo et al., 2014). Hence, breeding food finger millet varieties with value-added trait of light-coloured grains will address the above-mentioned challenge (tannins and phenolics) found brown coloured grains. Further, value-added trait for food finger millet varieties is phosphorus use efficiency (PUE). Phosphorus is an essential nutrient in plant growth and is one of the most growth preventive nutrients in semi-arid regions as up to 80% of P is predominantly fixed as organic P in most soils (Adhya et al., 2015). Sources of Phosphorus fertilizers are natural rock phosphate decreasing significantly because of nonstop removal and may get drained in the near future. This has caused a variable increase in farmer's cost of inputs such as fertilizer leading to the failure of basal fertilizer in most fields in semi-arid regions (Ramakrishnan et al., 2017). Breeding food finger millet varieties with a value-added trait of phosphorus use efficiency will maximize P efficiency utilisation and grow under P minimal conditions. This will reduce fertilizer application rates, cutting on the production costs of resource-poor farmers in semi-arid regions and as well as to reduce grain phytate content. Calcium content, phosphorus content and iron content are some of the essential value-added traits for food finger millet varieties. Calcium is essential for pregnant women, elderly, obese people, diabetes and malnutrition and growing children (Ramashia et al., 2019). Eating finger millet products daily might mitigate teeth disorders and bone as these challenges are indicators of calcium deficiency. Energy metabolism and body tissue development are influenced by phosphorus (Ramashia et al., 2019). Challenges of anemia, migraines, heart attack risk, asthma and high blood pressure can be addressed by including enough iron in our daily diets via the consumption of finger millet variety with high iron content (Shibairo et al., 2014). Most people living in semi-arid regions have restricted entrance to animal food products (Ramashia et al., 2019). Hence, food finger millet varieties with these essential minerals will be more nutritious to address the deficiency challenges for people living in semi-arid regions. A low level of phytates content is another value-added trait for food finger millet varieties. Phytate, an anti-nutrient, is the form of phosphorus storage in finger millets. Furthermore, phytate chelates the essential minerals such as Mg, Zn, Fe and Ca, reducing their bioavailability for adsorption (Kumar et al., 2016). In worst cases, it causes mineral deficiencies in millets-based diets as it directly or indirectly affects the bioavailability and absorption (Kumar et al., 2016). Processing millets into a food can reduce this anti-nutrient but breeding a food finger millet variety with a low level of phytates content is advantageous as processing will completely reduce the minimal levels available, rendering the food product from millets free of anti-nutritional factors. *Striga asiatica* (L.) Kuntze, (witchweed) tolerance is also value-added trait for food finger millet varieties. *Striga* is a tenacious biotic threat to cereal production in hot and dry areas of Sub-Saharan Africa (Kountche et al., 2016). A crop yield loss because of *Striga* attacks may to complete crop failure and has an annual yield loss exceeding US$10 billion (Pennisi, 2015; Kountche et al., 2016). *Striga* challenge is the problem of marginal areas with poor soil fertility management practices (Parker, 2009). Hence, an effective, long-lasting solution for *Striga* might be breeding food finger millet varieties with genetic control tolerance as a value-added trait to address the challenge faced by resource-poor farmers in semi-arid regions.

The plant type concept in finger millet for beverages and opaque beer

Key traits for beverages/opaque beer varieties finger millet were identified and grouped into two groups which are compulsory traits and value-added traits. The compulsory traits for beverages/opaque beer finger millet varieties are traits associated with grain yield potential improvement, such as above. Grain yield potential/hectare and these selected associated traits for yield improvement are the priority in breeding finger millet varieties for hot and dry regions. Most farmers in semi-arid regions are mainly poor farmers, hence need to optimize yield to maximize profits. The commercialisation of this crop enables profit making and improvement of living standards of the small-scale farmers in hot and dry regions. The next compulsory trait for beverages/opaque beer finger millet varieties is desirable grain size. Grain size plays a crucial role in moisture absorption during malting processes; it increases the surface area of the grain to initiate the germination process for quick and uniform germination. Hence, the breeding programmes for beverages/opaque beer finger millet varieties should prioritize grain size improvement for the attainment of quick and uniform germination for the quality malting process. A dark brown coloured grain is another identified compulsory trait for beverages/opaque beer finger millet varieties. Suspended content, yeasts, and residues of undigested starch influence the opaqueness of beer (Usai et al., 2013). Hence brown coloured grain directly influences the opaqueness of the beer. Another factor that influences the opaqueness of beer is the red colour of anthocyanin red pigments of grain exposed by mashing and souring of grain during brewing process (Chitsika & Mudimbu, 1992). This explanation clearly shows how important is the grain colour in influencing opaqueness, hence, the grain colour of finger millet varieties suitable for opaque beer should be dark brown for the normal colour of beer. The Breeding and selection programmes should focus on brown coloured grains of finger millet. Free amino nitrogen is also identified as a compulsory trait for finger millet varieties suitable for beverages/opaque beer. Opaque beer production is due to both lactic acid and alcoholic fermentation stages (Usai et al., 2013). Enough free amino nitrogen is important for yeast growth during fermentation for quality opaque beer. The breeding programmes for opaque beer finger millet varieties should focus on producing varieties with desirable level of free amino nitrogen. Diastatic Power (DP) is identified again as a compulsory trait for finger millet varieties suitable for beverages/opaque beer. Diastatic power is simple activity resulting from the synchronized action of *alpha* and *beta* amylases when the extract fermentation process occurs, converting starch to alcohol (Shayo et al., 2001). Twenty-eight SDU/g is the optimum diastatic power used widely in brewing beer (Dewar et al., 1995). Diastatic power is affected by germination time, temperature and moisture (Shayo et al., 2001). Millet varieties have variation of diastatic power due to the genetic character or growth conditions. The breeding programmes for opaque beer finger millet varieties should select for higher diastatic power closer to 28 SDU/g the minimum requirement suitable for malting purposes. The second group of key traits identified for beverages/opaque beer finger millet varieties is the value-added group of traits. As mentioned earlier, value-added traits increase the distinctness and value of finger varieties suitable for beverages/opaque beer in semi-arid regions. The moisture content of grains after steeping is the first identified key value-added trait for finger millet varieties suitable for beverages/opaque beer. A desirable increase in the moisture content of grain after steeping is a paramount important trait when in the process of malting grain, as it must imbibe adequate water for the germination process to start which will influence the superiority of beer (Usai et al., 2013). Breeding and selection programmes should select this trait as it affects the malting quality. Plant height is a key value-added trait for beverages/opaque beer finger millet varieties. Desirable plant height provides a desirable clearance height for the combine cutter bar to avoid contamination of harvested grain with grit as we aim to mechanically combine harvest finger millet after commercializing the crop. Most end-use products of finger millet have a problem of grit contamination, which discourages people from using finger millet for food products. This grit contamination might be associated with postharvest processes such as harvesting and threshing. Hence, desirable plant height might reduce admixtures during mechanical harvesting of the finger millet because it will have a good clearance height for the cutter bar of the combine harvester. It clearly shows that plant height is a compulsory key trait for food finger millet varieties to be considered when framing the breeding programme.

The plant type concept in finger millet for livestock feed

Key traits for feed varieties finger millet were identified and grouped into two groups which are compulsory traits and value-added traits. The first compulsory traits for feed finger millet variety are yield potential improvements and selecting all characters linked. Yield potential/ hectare and the selected associated traits for yield improvement is the priority in breeding finger millet varieties suitable for feed in semi-arid regions. After harvesting grain, the leftover will be fed to livestock. Stover of finger millet is a good alternate fodder for livestock in semi-arid regions (Wafula et al., 2017). The commercial sales of finger millet grain will financially boost farmers and the stover leftover after harvest will supply enough stover for livestock during the dry season in semi-arid regions. Stover dry matter yield is another identified compulsory trait for feed finger millet varieties in semi-arid region. Feed shortage is greatly affecting anticipated livestock production in semi-arid regions (Baath et al., 2018). The low livestock productivity in hot and dry areas is caused by the poor quality of feed stover in the dry seasons (Renard, 1997). This problem can be addressed by breeding a multipurpose variety of finger millet to satisfy the traits of needs of both humans and livestock. Stover digestible dry matter yield and stover digestibility are also identified as a compulsory trait for finger millet varieties suitable for feed in semi-arid regions. These two traits influence the daily stover feed intake of livestock. The low digestible dry matter affects livestock productivity as the high-quality biomass provided by these perennial grasses declines during the dry season (Baath et al., 2018). Stover from finger millet is nutritious (contains 61% of total digestible nutrients) (Wafula et al., 2017). Therefore, the selection of digestible dry matter feed finger millet varieties will meet the stover requirement for livestock, as the quality of stover is a very important issue concerning livestock health status and animal productivity. The plant height of finger millet varieties suitable for feed is an important trait to consider when breeding a feed variety of finger millet. The tall canopy influences stover production yield compared to shorter stover production (Baath et al., 2018). Furthermore, stover yield is associated with plant height (Yadav et al., 2012). Hence, this is a compulsory trait for finger millet varieties to feed in hot and dry areas. Basal tillers per plant are also a value-added trait for finger millet varieties suitable for livestock feed in semi-arid regions. Stover yield is positively linked with productive tillers per plant (Kumar et al., 2012). Hence, to boost the yield level of finger millet varieties suitable for feed, this trait should be improved and selected for in the breeding programmes. Stover nitrogen content is identified as value-added trait for finger millet varieties suitable for feed. Low nitrogen content is the most preventive factor when exploiting stover for livestock stover of fodder. Stover with less than one to one point two of nitrogen percentage, generally influences the voluntary and daily animal feed intake (Van Soest, 1994). Hence, breeding a finger millet variety is important to address these challenges. On the other hand, fertilizer application affects stover nitrogen content. Stover crude protein is also value-added trait for finger millet varieties for hot and dry areas. Quality stover for livestock should be palatable and promote increased daily feed intake with minimum anti-nutritional factors on grain (Smith et al., 1997). Selection for increased crude protein leads to increased digestibility. Hence breeding and selection for the increased crude protein in finger millet varieties suitable for feed will boost the quality of stover and simultaneously improve the digestibility of finger millet stover. Soluble sugars are another important key value-added trait to consider when breeding finger millet varieties suitable for feed-in semi-arid regions. Stover sweetness taste is an important trait of stover quality for livestock feed as it increases voluntary feed intake. Sugar content in the finger millet plant should be evenly distributed between the stem and the leaves to avoid selective grazing. Therefore, the sugar content of stover should be evenly distributed on all portions to avoid selectivity grazing by livestock.

CONCLUSION

Heritability >61% and genetic advance >20% influences traits during the breeding of finger millet crop in any programme. In this review, key finger millet traits for food, beverages/opaque beer and feed varieties for semi-arid regions were identified and grouped into two groups; that is compulsory traits and value-added traits. These two groups of traits increase the distinctness and value of the finger millet varieties. Regarding food finger millet varieties, identified key compulsory traits were optimum yield potential, days to maturity, drought and heat tolerance, plant height, protein content and blast disease tolerance. Identified key value-added traits for food varieties were light-coloured grains, phosphorus use efficiency, essential minerals content (calcium, phosphorus and iron), low level of phytates and *Striga* tolerance. Again, identified compulsory traits for beverages/opaque beer finger millet varieties were optimum yield potential, desirable grain size, dark brown coloured grains, free amino nitrogen and diastatic power. Identified value-added traits for beverages/opaque beer finger millet varieties were moisture content of the grain, essential minerals content (calcium and iron), plant height and low level of phytates. Lastly, identified compulsory traits for livestock feed finger millet varieties were optimum grain yield potential, stover dry matter yield, stover digestible dry matter yield, stover digestibility and plant height. Identified value-added traits for livestock feed were the number of basal tillers, stover nitrogen content, stover crude protein content and soluble sugars content. Breeding and selection of specific traits for specific finger millet varieties such as food, beverages/opaque beer and feed is possible as most compulsory and value-added traits for these varieties have heritability >61% coupled with genetic advance >20%, implying that improvement is easily made assortment picking. However, linked trait inheritance, MMA breeding and indirect selection methods can assist for traits with low heritability.

AUTHOR CONTRIBUTIONS

All authors BM, EG, ASP and MC contributed equally to the development and writing of the review. BM prepared the original draft review and EG and MC contributed specifically to the structure of the review sections. ASP edited the review manuscript. All authors read, approved and agreed to be accountable for the content of the work.

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COMPETING INTERESTS

The authors have declared that no conflict of interest exists.

ETHICS APPROVAL

Not applicable

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