

Review

The future of sorghum cultivation in drought conditions in Zimbabwe

Nathan Banalya* and Sebastian Chakeredza

Department of Agriculture Sciences, Faculty of Agriculture and Natural Sciences, College of Health, Agriculture and Natural Sciences, Africa University, P. O. Box 1320, Mutare, Zimbabwe.

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Sorghum (*Sorghum bicolor* L.) is a vital cereal crop for food security in semi-arid regions of Zimbabwe, where recurrent droughts and erratic rainfall patterns threaten agricultural productivity. This review synthesizes current knowledge on genetic variability and heritability of key drought tolerance traits, such as stay-green, leaf rolling, root architecture, and grain yield within sorghum germplasm. Emphasis is placed on conventional breeding methods, which remain central to varietal development in resource-limited settings. The study explores the role of landraces and improved varieties in contributing to genetic diversity, and evaluates heritability estimates from multi-environment trials to guide selection strategies. Participatory breeding, managed stress environments, and multi-location testing are discussed as critical components for enhancing selection efficiency and varietal adaptability. By consolidating regional and global findings, this review provides a framework for breeders aiming to develop resilient sorghum varieties tailored to Zimbabwe's agro-ecological conditions. The insights presented here support ongoing efforts to strengthen climate-smart agriculture and promote sustainable crop improvement in dryland systems.

Key words: Conventional breeding, drought tolerance, field-based screening, genetic variability, heritability, sorghum

INTRODUCTION

Sorghum (*Sorghum bicolor* L.) is a strategic cereal crop in Zimbabwe, particularly in semi-arid regions where erratic rainfall and recurrent droughts severely constrain the productivity of maize and other staples (Chidoko et al., 2026). As a drought-resilient species, sorghum contributes significantly to food security, livestock feed, and climate-smart agriculture, making it indispensable for smallholder farming systems (Alidu et al., 2019). Despite its adaptive potential, national yields remain low due to limited genetic

improvement, inadequate seed dissemination, and poor adoption of drought-tolerant varieties (Mashingaidze et al., 2013).

Moreover, conventional breeding continues to serve as the cornerstone of sorghum improvement in resource-constrained settings. It provides practical avenues for selecting and recombining desirable traits such as stay-green, early maturity, and robust root architecture without reliance on advanced molecular tools. Central to this

*Corresponding author. E-mail: banalyan@africau.edu.

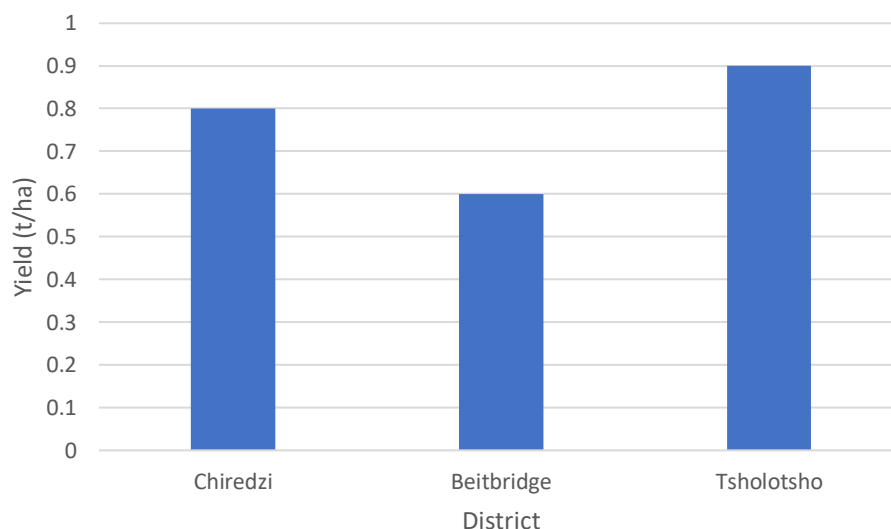


Figure 1. Sorghum yield by district in Zimbabwe.

process is the evaluation of genetic variability and heritability of drought-tolerance traits within both local landraces and improved germplasm. Such evaluations are critical for identifying suitable parent lines and developing resilient cultivars tailored to Zimbabwe's diverse agro-ecological zones (International Crops Research Institute for the Semi-Arid Tropics [ICRISAT], 2020). In addition, Zimbabwe smallholder farmers in districts such as Buhera and Mutoko face persistent challenges, including crop failure, poor seed access, and limited mechanization. Addressing these constraints requires breeding strategies that harness existing genetic diversity while ensuring adaptability to semi-arid conditions. This review synthesizes current findings on genetic variability and heritability of drought-tolerance traits in sorghum, with emphasis on conventional breeding approaches. The aim is to highlight opportunities for strengthening sorghum improvement programs in Zimbabwe, thereby advancing national goals of food sovereignty, climate resilience, and reduced vulnerability to environmental shocks.

OVERVIEW OF SORGHUM PRODUCTION IN ZIMBABWE

Sorghum production in Zimbabwe is a cornerstone of agricultural resilience, particularly in semi-arid regions where rainfall is erratic and droughts are frequent. As a drought-tolerant cereal, sorghum thrives in marginal soil and low-rainfall conditions, making it indispensable for smallholder farmers in provinces such as Matabeleland, Masvingo, and parts of Manicaland. Musara et al. (2019) emphasize that sorghum is not only a staple food but also a key input for livestock feed and brewing industries,

contributing to both food security and rural livelihoods. The crop's adaptability to harsh environments has positioned it as a climate-smart solution in the face of increasing climatic variability. Maphosa (2022) note that sorghum's potential in drought-prone areas is vast, with opportunities for value-added products such as ethanol and low-calorie foods. However, despite its ecological advantages, sorghum farming in Zimbabwe faces persistent challenges. Chief among these is low productivity, often attributed to poor agronomic practices, limited access to improved seed varieties, and inadequate extension services. Makuchete et al. (2024) found that soil fertility and rainwater management significantly influence sorghum yields, with farmers in low-fertility zones experiencing the greatest constraints. Drought remains a dominant threat, reducing planting windows and affecting crop maturity. In Matabeleland North, for instance, adoption of sorghum remains as low as 37%, partly due to reliance on retained seeds and lack of mechanization (Maphosa et al., 2025). Additionally, poor market access and post-harvest losses further discourage investment in sorghum farming. A study by Mpala and Simatele (2023) revealed that farmers often lack knowledge and resources, leading to low yields and missed opportunities for commercialization. To illustrate the disparities in productivity, Figure 1 compares sorghum yields across three districts in Zimbabwe:

As shown in Figure 1, Tsholotsho records the highest yield at 0.9 tons/ha, followed by Chiredzi at 0.8 tons/ha, while Beitbridge lags at 0.6 tons/ha. These variations are shaped not only by agroecological differences but also by specific factors such as rainfall distribution, soil fertility, planting basin design, and farmer management practices which collectively influence sorghum productivity across

districts in Zimbabwe. Sorghum remains a strategic crop for Zimbabwe's semi-arid regions, offering resilience against climate shocks and potential for economic empowerment. Addressing agronomic constraints, improving seed systems, and strengthening market linkages are essential to unlocking its full potential. Future interventions must be context-specific, integrating soil management, farmer education, and value chain development to ensure sustainable sorghum production.

USES OF SORGHUM

Sorghum is a vital staple crop in Zimbabwe, particularly in semi-arid regions where maize production is less reliable. It is consumed in various forms, including *sadza*, porridge, and traditional fermented beverages. According to Maphosa and Jideani (2017), sorghum is valued for its gluten-free properties, high dietary fiber, and micronutrient content, making it suitable for people with celiac disease and for improving household nutrition. Mukarumbwa and Mushunje (2010) highlight that sorghum contributes significantly to caloric intake in drought-prone areas, where it is often preferred over maize due to its resilience. Its role in food security is especially pronounced among smallholder farmers in Matabeleland and Midlands provinces. Sorghum is also widely used as livestock feed in Zimbabwe, both as grain and Stover. The crop supports integrated crop-livestock systems, particularly in mixed farming setups. Etuk et al. (2012) note that sorghum grain is a valuable energy source in poultry and pig diets, although tannin levels in some varieties may require processing to improve digestibility. Mapiye et al. (2009) emphasize the importance of sorghum Stover for dry-season feeding of cattle and goats, especially in communal areas. Dual-purpose sorghum varieties are increasingly promoted to meet both human and animal feed needs, enhancing farm-level efficiency and resilience. Industrially, sorghum is used in brewing, milling, and biofuel production. In Zimbabwe, it is a key ingredient in opaque beer, which is widely consumed and commercially produced. According to Juana and Mabugu (2005), agriculture contributes over 60% of raw materials to Zimbabwe's agro-processing sector, with sorghum playing a growing role. Nyoni et al. (2022) notes that sorghum's starch-rich grain is suitable for ethanol production and gluten-free flour, offering opportunities for rural enterprise development and value addition. The Zimbabwe Agricultural Growth Programme (ZAGP) has also identified sorghum as a strategic crop for expanding agro-industrial linkages and promoting inclusive value chains.

Agronomically, sorghum contributes to soil health, crop rotation, and climate resilience. Its deep root system improves soil structure and reduces erosion, while its drought tolerance makes it ideal for conservation agriculture. Maphosa et al. (2020) describe sorghum as a

climate-smart crop that fits well into low-input systems in Zimbabwe's drylands. It is often intercropped with legumes to enhance nitrogen fixation and diversify farm output. Sorghum also plays a role in weed suppression due to its allelopathic properties, which help reduce herbicide dependence and support sustainable land management (Kawisi et al., 1995). Beyond its economic and agronomic value, sorghum holds deep cultural significance in Zimbabwean communities. It is used in traditional ceremonies, ancestral offerings, and communal brewing practices. According to Chabata (2019), sorghum beer is central to social gatherings, funerals, and rites of passage, symbolizing unity and continuity. Its cultivation and use are embedded in indigenous knowledge systems, reinforcing its role in cultural identity and heritage preservation. These cultural dimensions elevate sorghum as a crop of social and spiritual importance, deeply woven into the fabric of rural life.

DROUGHT STRESS AND ITS IMPACT ON SORGHUM

Drought stress poses a significant threat to sorghum production, particularly in semi-arid regions like Zimbabwe where rainfall is increasingly erratic. Physiologically, drought affects sorghum at multiple growth stages, reducing leaf expansion, impairing photosynthesis, and limiting nutrient uptake. According to Abreha et al. (2022), drought stress leads to stomatal closure, decreased chlorophyll content, and reduced transpiration, all of which culminate in lower biomass and grain yield. These physiological disruptions are most pronounced during the flowering and grain-filling stages, where water scarcity can drastically reduce seed set and grain weight.

In response to drought, sorghum exhibits several adaptive traits that enhance its tolerance. One of the most studied is the "stay-green" trait, which allows the plant to maintain green leaf area during post-anthesis drought, thereby sustaining photosynthesis and grain filling, as shown in Table 1. In addition, genotypes with strong stay-green characteristics showed higher relative water content and better yield stability under water-limited conditions. Another key trait is leaf rolling, a mechanism that reduces leaf surface area exposed to sunlight and minimizes water loss through transpiration. These morphological adaptations are often accompanied by deeper root systems and osmotic adjustment, enabling the plant to access moisture from deeper soil layers. Moreover, drought-tolerant sorghum genotypes often exhibit enhanced antioxidant activity and accumulation of osmoprotectants like proline, which help mitigate oxidative damage and maintain cellular integrity during stress (Alzahrani et al., 2025). Breeding programs targeting these traits have shown promise in developing resilient cultivars suited for dryland farming. Similarly, the evaluation of genetic variability and heritability of these adaptive traits is

Table 1. Summary of drought-tolerant traits in sorghum and their roles in breeding

Trait	Physiological role	Breeding relevance
Stay Green	Delays leaf senescence, maintains photosynthetic activity under post-flowering drought	Associated with improved grain filling, higher Stover quality, and yield stability under terminal drought. Widely used in conventional breeding
Leaf Rolling	Reduces leaf surface area exposed to sunlight, minimizes transpiration, and conserves water	Serves as a rapid visual marker of drought response. Useful in farmer participatory selection and early generation screening for water use efficiency.
Root depth	Enhances water extraction from deeper soil layers, supports sustained growth under stress	Critical for adaptation in semi-arid zones. Breeding for deeper, more robust root systems improves drought resilience but requires careful phenotyping
Osmotic adjustment	Accumulation of solutes (proline, sugars) maintains cell turgor and metabolic activity	Improves survival under severe water deficit. Heritable but complex trait; breeding programs integrate it with stay green and root traits for holistic drought tolerance.

central to identifying promising parent lines and advancing cultivar development. Stay-green expression, for instance, has been linked to improved grain yield and Stover quality under terminal drought, while leaf rolling is associated with efficient water conservation and canopy temperature regulation. By quantifying the heritable components of these traits across diverse germplasms, breeders can make informed selections that combine drought tolerance with agronomic desirability. Such efforts are particularly relevant in Zimbabwe's semi-arid zones, where smallholder farmers rely on sorghum as a staple for both food and livestock feed. Importantly, continued research and breeding efforts are therefore essential to harness these traits for climate-resilient agriculture. Integrating conventional breeding approaches with participatory farmer selection ensures that improved cultivars are not only drought-tolerant but also culturally acceptable and economically viable. Strengthening seed systems, expanding multi-location trials, and aligning breeding priorities with national food security goals will accelerate the adoption of resilient sorghum varieties. Ultimately, leveraging genetic variability and the heritability of drought tolerance traits offers a sustainable pathway to enhance productivity, reduce vulnerability to climate shocks, and secure livelihoods in Zimbabwe's semi-arid regions.

GENETIC VARIABILITY IN SORGHUM GERMPLASM

Genetic variability in sorghum germplasm is a cornerstone of crop improvement, offering the raw material for breeding resilient, high-yielding, and climate-adapted varieties. Sorghum (*S. bicolor* L. Moench), a staple in semi-arid regions like Zimbabwe, exhibits remarkable genetic diversity across landraces and improved cultivars. This diversity is crucial for enhancing traits such as drought

tolerance, grain quality, pest resistance, and biomass production. According to ICRISAT (2020), evaluating 103 sorghum genotypes over two seasons revealed significant variation in agro-morphological traits, underscoring the potential for targeted selection and hybridization.

Landraces, often maintained by smallholder farmers, are particularly valuable due to their adaptation to local environments and stress conditions. These landraces harbor unique alleles that may be absent in commercial lines. A review by Menamo et al. (2021) highlights Ethiopia's sorghum germplasm as an example of rich diversity shaped by altitude and rainfall gradients, offering insights into breeding strategies for other regions. Similarly, ICRISAT global collection identifies taxonomic gaps and underrepresented ecotypes, suggesting that further exploration of neglected districts could enrich the genetic base of sorghum breeding programs. Improved varieties, while often more uniform, benefit from the introgression of traits from diverse germplasm pools. The integration of stay-green traits, deeper root systems, and enhanced nutrient-use efficiency has been facilitated by tapping into the variability found in landraces and wild relatives. This genetic divergence not only supports yield stability under stress but also broadens the adaptability of sorghum to emerging climatic challenges.

In conclusion, genetic variability in sorghum germplasm is essential for sustainable crop improvement. Continued characterization, conservation, and utilization of both landraces and improved varieties will empower breeders to develop cultivars that meet the nutritional, ecological, and economic needs of farmers in Zimbabwe and beyond.

HERITABILITY OF DROUGHT-TOLERANCE TRAITS

Heritability is a fundamental concept in plant breeding that

Table 2. Broad sense heritability of drought-tolerance traits in Sorghum.

Trait	Broad sense heritability (H^2)
Leaf rolling	0.45-0.62
Chlorophyll content	0.52-0.70
Stay green	0.60-0.78

Source: Mwamahonje et al. (2021)

quantifies the proportion of phenotypic variation in a trait attributable to genetic differences among individuals within a population. It serves as a predictive tool for breeders, indicating the potential success of selection for a given trait. In the context of drought tolerance in sorghum (*S. bicolor* L. Moench), understanding heritability is crucial for developing resilient cultivars suited to semi-arid environments like those in Zimbabwe. High heritability suggests that selection based on phenotypic performance will be effective, while low heritability implies a greater influence on environmental factors, necessitating more sophisticated breeding strategies. Several studies have estimated the heritability of key drought-tolerance traits in sorghum. Mwamahonje et al. (2021) evaluated traits such as leaf rolling, chlorophyll content, and stay-green under water-limited conditions and reported moderate to high broad-sense heritability estimates, ranging from 0.45 to 0.78. From Table 2, Leaf rolling results reflect drought avoidance and reduced water loss, chlorophyll content values indicate photosynthetic efficiency under stress, and stay green records highlight maintained leaf area and grain filling under drought. These findings suggest that genetic improvement of these traits through selection is feasible. Similarly, Enyew et al. (2022) analyzed genotype-by-environment interactions in sorghum landraces and found that traits like panicle exertion and root depth exhibited significant heritable variation, reinforcing the value of diverse germplasm in breeding programs. Another study by Tongoona et al. (2019) highlighted that physiological traits such as reduced transpiration rate and osmotic adjustment also showed moderate heritability, indicating their potential utility in selection indices for drought resilience.

The integration of heritability estimates into breeding pipelines enables the identification of superior genotypes and accelerates genetic gain. Marker-assisted selection and genomic prediction further enhance the precision of selecting drought-tolerant lines, especially when combined with multi-environment trials. In Zimbabwe, where drought is a recurrent constraint, leveraging heritable traits like stay-green, leaf area retention, and water-use efficiency can significantly improve sorghum productivity and stability. In summary, heritability provides a scientific basis for selecting drought-tolerant traits in sorghum. Studies consistently demonstrate that many physiological and

morphological traits associated with drought resilience possess moderate to high heritability, making them promising targets for breeding programs aimed at climate adaptation.

CONVENTIONAL BREEDING METHODS IN SORGHUM

Conventional breeding methods shown in Figure 2 remain foundational in sorghum improvement programs, particularly in resource-limited settings like Zimbabwe, where access to advanced genomic tools may be constrained. Among these methods, pedigree, bulk, and backcross approaches are widely used to develop cultivars with desirable traits such as drought tolerance, disease resistance, and improved grain quality. The pedigree method involves selecting superior individuals from segregating populations and tracking their lineage across generations. This approach allows breeders to monitor inheritance patterns and select specific traits with precision. According to ICRISAT (2016), pedigree breeding is especially effective when targeting complex traits like stay-green and grain yield, as it facilitates early generation selection and detailed record-keeping. However, it requires substantial labor and technical expertise, which may limit its scalability in smallholder contexts.

The bulk method, by contrast, involves growing a mixed population of F₂ or later generations without selection until advanced stages. This approach is less labor-intensive and allows natural selection to operate under local environmental conditions. Mamo et al. (2023) note that bulk breeding is particularly suitable for traits governed by additive gene action and for environments where field selection is difficult due to resource constraints. Its main limitation lies in the delayed selection, which may result in the loss of rare but valuable genotypes. Backcross breeding is used to introduce a specific trait from a donor parent into an elite variety while retaining the recipient's genetic background. This method is highly effective for transferring traits like disease resistance or drought tolerance. Begna et al. (2021) highlight its utility in improving sorghum's resistance to grain mold and Striga, especially when combined with marker-assisted selection. However, backcrossing can be time-consuming and

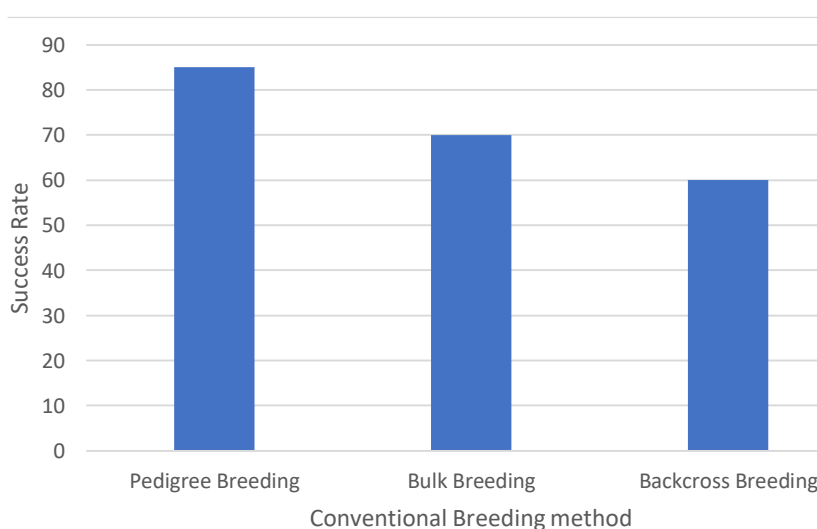


Figure 2. Performance of conventional breeding methods in sorghum
Source: Mamo et al. (2023).

requires repeated hybridization and selection cycles, which may be challenging in low-resource settings lacking controlled environments and molecular tools. In summary, conventional breeding methods, namely: pedigree, bulk, and backcross, offer valuable pathways for sorghum improvement. While each has distinct advantages, their effectiveness in resource-limited settings depends on the trait targeted, available infrastructure, and breeder expertise. Integrating these methods with participatory approaches and local germplasm can enhance their impact and relevance for smallholder farmers.

FIELD-BASED SCREENING TECHNIQUES

Field-based screening techniques are essential tools in sorghum breeding programs, particularly for evaluating drought tolerance under natural conditions. These methods allow breeders to assess plant performance *in situ*, using both visual scoring and quantitative indices to identify superior genotypes. In resource-limited settings like Zimbabwe, such techniques offer cost-effective and scalable approaches to selecting resilient cultivars. Visual scoring methods are widely used to evaluate morphological and physiological traits associated with drought tolerance. The stay-green trait, for instance, is assessed by observing the retention of green leaf areas during post-anthesis drought stress. Genotypes that maintain green foliage longer are considered more drought-tolerant, as they sustain photosynthesis and grain filling under water-limited conditions. According to Mwamahonje et al. (2021), stay-green scoring correlates strongly with yield stability and relative water content, making it a reliable selection criterion. Leaf rolling is

another visual trait, scored based on the degree of leaf curvature during midday stress. It serves as an indicator of water conservation, as rolled leaves reduce transpiration by minimizing exposed surface area (ICRISAT, 2020).

Beyond visual traits, breeders employ selection indices to quantify drought tolerance and yield performance. The Stress Tolerance Index (STI) compares yield under stress and non-stress conditions, identifying genotypes that perform well across environments. Mean Productivity (MP) calculates the average yield across both conditions, favoring genotypes with consistent performance. Yield Stability Index (YSI) measures the ratio of yield under stress to yield under optimal conditions, highlighting genotypes with minimal yield reduction. These indices are particularly useful in multi-environment trials, where genotype-by-environment interactions complicate direct comparisons. Mwamahonje et al. (2021) demonstrated that combining visual scoring with STI and MP improved the accuracy of selecting drought-tolerant sorghum lines.

In summary, field-based screening techniques, both visual and index-based, play a pivotal role in identifying drought-resilient sorghum genotypes. Their integration into breeding programs enhances selection efficiency and supports the development of cultivars suited to semi-arid regions. For Zimbabwean breeders and educators, these methods offer practical tools for participatory selection and curriculum enrichment.

PARTICIPATORY BREEDING AND FARMER PREFERENCES

Participatory breeding has emerged as a transformative approach in sorghum improvement, particularly in semi-

arid regions like Zimbabwe, where farmer engagement is critical to varietal adoption and agricultural resilience. This method involves farmers directly in the selection and evaluation of crop varieties, ensuring that breeding outcomes align with local preferences, agroecological realities, and socio-economic needs. Magaisa et al. (2022) highlights that participatory variety selection (PVS) conducted across five drought-prone districts in Zimbabwe significantly improved the stability and relevance of agronomic performance, as farmers were able to assess traits such as grain color, plant height, and drought tolerance under real field conditions. The role of farmers in varietal selection goes beyond simple feedback; it integrates indigenous knowledge, experiential insights, and context-specific criteria that formal breeding programs may overlook. By involving farmers in early-stage trials and decision-making, breeders can identify varieties that are not only high-yielding but also culturally acceptable and marketable. This approach enhances trust, accelerates adoption, and fosters innovation at the grassroots level.

Gender-responsive and community-based strategies further enrich participatory breeding by recognizing the differentiated roles and preferences of men and women in agriculture. Tongoona et al. (2019) emphasize that women often prioritize traits such as cooking quality, threshing ability, and early maturity, which are essential for household food security and labor efficiency. In contrast, men may focus more on marketability and biomass for livestock feed. Incorporating these diverse preferences into breeding objectives ensures that new varieties meet the needs of all community members. Moreover, community-based trials and farmer field schools create inclusive platforms for dialogue, learning, and collective decision-making.

In summary, participatory breeding and farmer-led varietal selection are vital for developing sorghum cultivars that are agronomically robust, socially acceptable, and economically viable. Gender-responsive and community-based approaches amplify the impact of breeding programs by embedding them within the lived realities of rural households, thereby promoting equity, sustainability, and resilience in sorghum farming systems.

CHALLENGES AND OPPORTUNITIES OF CONVENTIONAL BREEDING

Conventional breeding in Zimbabwe presents both significant challenges and promising opportunities, particularly in the context of climate-resilient crop development. One major challenge is the limited access to diverse germplasm and breeding infrastructure, which constrains the ability of researchers to exploit genetic variability for traits like drought tolerance and early maturity (Alidu et al., 2019). Additionally, inadequate

funding, poor mechanization, and a shortage of skilled personnel hinder the efficiency and scalability of breeding programs (Mashingaidze et al., 2013). Smallholder farmers, especially in districts like Buhera and Mutoko, often lack access to improved seeds, making it difficult to translate breeding gains into field-level impact (Mwamahonje et al., 2021). Despite these constraints, conventional breeding offers substantial opportunities. It remains a cost-effective and locally adaptable approach for selecting and recombining desirable traits without reliance on advanced molecular tools (ICRISAT, 2020). Moreover, the integration of participatory breeding frameworks allows researchers to align varietal development with farmer preferences, enhancing adoption and relevance (Enyew et al., 2022). With strategic investment in training, germplasm exchange, and multi-location trials, Zimbabwe can harness conventional breeding to develop resilient varieties that support food security and climate-smart agriculture.

DRAWBACKS OF THE CURRENT RESEARCH

Despite decades of research on sorghum in Zimbabwe, significant drawbacks persist that limit the effectiveness of breeding programs and the adoption of improved varieties. A major drawback lies in the overreliance on controlled research station trials, which prioritize agronomic performance under optimal input conditions. These trials often fail to simulate the low-input, stress-prone realities of communal farming areas, where most smallholder farmers operate. As Magorokosho et al. (2019) emphasize, this methodological disconnect has led to the release of cultivars that perform well in theory but falter under actual field conditions, contributing to low adoption rates. Another critical limitation is the narrow geographic scope of varietal evaluation. Regions such as southern Manicaland and Matabeleland South, which are highly vulnerable to drought and dependent on sorghum, remain underrepresented in breeding trials. This lack of location-specific data on soil fertility, rainfall variability, and farmer preferences undermines the development of contextually relevant varieties. Makuchete et al. (2024) argue that without tailored agroecological insights, breeding strategies risk being generic and misaligned with local needs.

Furthermore, existing research has underutilized the genetic diversity of local landraces in the context of Zimbabwe, which often possess adaptive traits suited to Zimbabwe's diverse microclimates. Limited efforts have been made to characterize these landraces or integrate them into formal breeding pipelines, resulting in a missed opportunity to harness indigenous resilience traits.

Social dimensions are also inadequately addressed. Many breeding programs overlook gender dynamics, cultural preferences, and farmer knowledge systems, which are crucial for varietal acceptance. Enyew et al. (2022) advocate for participatory breeding approaches

that incorporate community-based insights, enabling the co-creation of varieties that reflect farmers' lived realities.

In addition, the lack of integration of modern tools, such as Geographic Information System (GIS) mapping, climate modeling, and genotype-by-environment interaction analysis, has constrained the precision and scalability of breeding efforts. These tools are essential for tailoring varieties to specific farming systems and anticipating climate variability. In conclusion, the limitations of past sorghum research in Zimbabwe stem from methodological, geographic, genetic, and socio-cultural blind spots. Addressing these requires a shift toward holistic, decentralized, and participatory breeding strategies that embed scientific innovation within the socio-ecological fabric of Zimbabwean agriculture. By doing so, researchers can enhance the relevance, resilience, and adoption of sorghum cultivars among smallholder communities.

CONCLUSION

Drought tolerance remains a critical breeding objective for sorghum in semi-arid regions of Zimbabwe, where erratic rainfall and prolonged dry spells threaten food security and smallholder livelihoods. This review highlights the substantial genetic variability present in both landraces and improved sorghum lines, offering a rich foundation for selection. Heritability estimates for key traits such as stay-green, leaf rolling, and grain yield under stress conditions suggest that conventional breeding methods can achieve meaningful genetic gain when applied systematically.

The integration of farmer-preferred traits, multi-location trials, and participatory selection enhances the relevance and adaptability of emerging varieties. While molecular tools offer precision, conventional breeding remains indispensable in resource-limited contexts, especially when combined with robust field phenotyping and strategic selection environments. Future breeding programs should prioritize early-generation screening under managed stress, validation of selection efficiency, and alignment with local agro-ecological realities. Ultimately, the development of drought-resilient sorghum varieties through conventional breeding is not only feasible but essential for climate-smart agriculture in Zimbabwe. Strengthening institutional capacity, farmer engagement, and regional germplasm exchange will accelerate progress toward sustainable varietal release and adoption.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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