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Research Article

Genetic Improvement and Drought Tolerance Breeding in Sorghum in Sub-Saharan Africa: Stay-Green, Marker-Assisted Selection, Hybrids and Farmer Adoption

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Abstract

Sorghum (Sorghum bicolor (L.) Moench) is a staple food crop in drought-prone areas of sub-Saharan Africa (SSA), where it is characterised by erratic rainfall with poor distribution, yet it is drought-tolerant by nature with reasonable yield compared with other cereals (Rosenow and Clark, 1995; FAO, 2023). Drought is a major cause of sorghum yield losses in rain-fed agriculture, especially in the semi-arid and arid zones of Africa and Asia, and enhancing drought tolerance through the stay-green trait remains a key breeding objective to improve productivity under water-limited conditions (Borrell et al., 2014; Jordan et al., 2012). This article synthesises peer-reviewed evidence published between 2000 and 2025 on sorghum breeding for drought tolerance in SSA, with emphasis on stay-green, marker-assisted selection (MAS), hybrids, and farmer adoption. Evidence shows that under subsistence farming, sorghum yields are 0.7 to 0.9 t ha-1, while improved hybrid cultivars give 3 to 4 t ha-1 in better-endowed environments (Rai et al., 1999). In Ethiopia, 37 improved lowland varieties released between 1976 and 2016 yielded an average of 2,644.7 kg ha-1, exceeding older varieties by 607.1 kg ha-1, a 30.9 percent gain. Stay-green QTL Stg3A and Stg3B, introgressed with SNP markers, accounted for 30 percent of grain yield increase and stay-green in water-stressed conditions, and Stg3B alone improved grain yield by 16 percent and total dry matter by 9 percent under water stress. In Ethiopia, the stay-green genotype ETSC16140 gave maximum grain yield of 4,037.9 kg ha-1 under drought stress. Hybrids such as P-9534 x Melkam gave 6.32 t ha-1, a 32.49 percent advantage over the check ESH-4 (4.77 t ha-1). In northern Nigeria, SAMSORG 52, 53 and 54, developed by ICRISAT, mature in three months and help farmers cope with declining rainfall. The article reviews mechanisms, breeding methods, genomics, seed systems, and adoption, and it proposes a practical, farmer-centred breeding and seed strategy for SSA. The central argument is that sorghum breeding should not chase maximum yield under optimal conditions, but should breed for stable yield under drought, with stay-green, early maturity, and farmer-preferred grain quality, delivered through seed systems that farmers can actually access.

Keywords: sorghum; drought tolerance; stay-green; marker-assisted selection; hybrids; sub-Saharan Africa

Abbreviations: SSA, sub-Saharan Africa; MAS, marker-assisted selection; QTL, quantitative trait locus; SNP, single-nucleotide polymorphism; GWAS, genome-wide association study; NIL, near-isogenic line.

1. Introduction

Sorghum is the crop that survives when maize fails. In the Sahel, Sudan Savanna, and semi-arid East and Southern Africa, sorghum is grown on soils too dry, too poor, or too hot for maize, and it provides grain for food, fodder for livestock, and income for millions (Rosenow and Clark, 1995; FAO, 2023). It is predominantly grown in semi-arid and arid tropics of Africa and South Asia, with significant production also in China, Southeast Asia, and the Americas (Venkateswaran et al., 2019). In SSA, sorghum is a staple for over 100 million people, especially in Nigeria, Ethiopia, Sudan, Burkina Faso, Mali, and Niger.

Yet sorghum yields in SSA remain low. Under subsistence farming, yields are 0.5 to 0.7 t ha-1 for pearl millet and 0.7 to 0.9 t ha-1 for sorghum, while improved hybrids give 3 to 4 t ha-1 in better-endowed environments (Rai et al., 1999). The gap is not only due to poor soil and low inputs, but also due to drought, Striga, pests, and the use of landraces with low yield potential. Breeding has made progress: in Ethiopia, 37 improved lowland varieties released between 1976 and 2016 yielded 2,644.7 kg ha-1, exceeding older varieties by 607.1 kg ha-1, a 30.9 percent gain, but adoption remains low because improved varieties often lack farmer-preferred traits, such as grain colour, taste, stover quality, and adaptation to local soils.

This article asks three questions. First, how does drought reduce sorghum yield, and how does stay-green tolerance work? Second, how have conventional, marker-assisted, and genomic breeding improved drought tolerance, yield, and quality? Third, why do some farmers adopt improved sorghum varieties while others do not, and what seed systems make adoption more likely? The synthesis concentrates on grain sorghum, while drawing on sweet and forage sorghum where relevant.

2. Drought, Stay-Green and How Sorghum Tolerates Water Stress

Drought in sorghum is of two types: pre-flowering drought, which reduces leaf area, tillering, and panicle size, and post-flowering or terminal drought, which reduces grain filling, grain mass, and causes lodging (Rosenow and Clark, 1995; Borrell et al., 2014). Terminal drought is the most damaging, because it occurs when grain is filling, and it is also the most common in SSA, where rains end early or are erratic at the end of the season. Sorghum tolerates drought through several mechanisms: deep roots that extract water from depth, waxy leaves that reduce transpiration, osmotic adjustment that maintains cell turgor, and stay-green, which maintains green functional leaves under post-anthesis drought (Jordan et al., 2012).

Stay-green is an integrated drought adaptation trait characterised by a distinct green leaf phenotype during grain filling under terminal drought (Borrell et al., 2014; Jordan et al., 2012). Stay-green genotypes are able to maintain grain filling under drought, resulting in increased grain yield, grain mass, and lodging resistance. The trait has been employed in selection and breeding for post-flowering drought resistance, even though the genes regulating it are still being elucidated. In a glasshouse experiment, stay-green lines B35, KS19, and E36-1 maintained chlorophyll and grain filling under water-limited conditions, while the senescent control R16 senesced early and yielded less. In Ethiopia, stay-green genotype ETSC16140 gave maximum grain yield of 4,037.9 kg ha-1 under drought stress, and chlorophyll maintenance showed a direct positive effect on grain yield.

The original sources of the most widely used stay-green genotypes B35 and SC56 are Ethiopia and Sudan, showing that African landraces are the source of the world's most important drought tolerance genes. Three hundred and twenty sorghum landraces and four improved varieties grown at Melkassa, Mieso, and Mehoni in Ethiopia revealed novel sources of drought tolerance, with variation in chlorophyll at flowering and maturity, green leaf number, stay-green, and panicle exertion, which can be used for breeding.

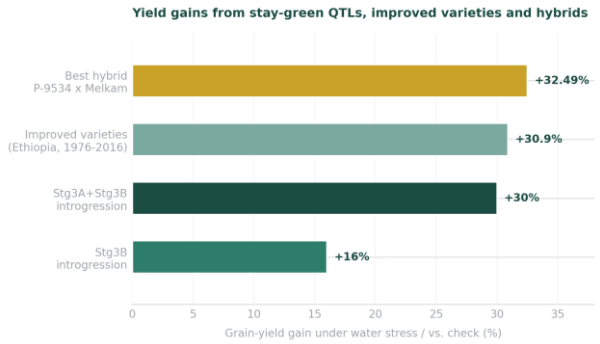


Figure 1 — Yield gains reported for stay-green introgressions, improved varieties and hybrids. Stg3B alone improved grain yield by 16% under water stress; Stg3A + Stg3B accounted for 30% of the yield increase; improved varieties in Ethiopia gained 30.9% over older varieties; the best hybrid gained 32.49% over the check. Values are as reported in the text (Borrell et al., 2014; Jordan et al., 2012; Rai et al., 1999).

3. Marker-Assisted Selection and Stay-Green QTLs

Marker-assisted selection (MAS) uses DNA molecular markers to map quantitative trait loci (QTL) associated with stay-green, to supplement conventional breeding (Jordan et al., 2012; Borrell et al., 2014). Stay-green has been mapped to key chromosomal regions, including Stg1, Stg2, Stg3, and

Stg4, with Stg3 split into Stg3A and Stg3B. Near-isogenic lines (NILs) of RTx7000 were characterised in seven experiments and 14 environments to determine the influence of four individual stay-green QTLs on canopy development, water use, and grain yield under post-anthesis drought. The Stg QTLs decreased canopy size, reduced water use before flowering, and increased water availability for grain filling, thereby increasing yield under drought.

Introgression of Stg3A and Stg3B with SNP markers snpSB00049, snpSB00053, and snpSB00054 for Stg3A and snpSB00101, snpSB00102, and snpSB00103 for Stg3B accounted for 30 percent of grain yield increase and stay-green in water-stressed conditions. Stg3B was the key QTL in enhancing green leaf area, particularly under water stress, and introgressions with Stg3B improved grain yield by 16 percent and total dry matter by 9 percent under water stress. QTL pyramiding, combining multiple Stg QTLs in one variety, has emerged as a strategic breeding approach, but effects depend on recipient parent background, as shown by Vadez et al. (2011), where stay-green QTL effects on water extraction, transpiration efficiency, and seed yield depended on the recipient parent.

Genomics-assisted breeding for drought adaptation in the Sahel has identified QTLs that contributed to high phenotypic variance and colocalised with known stay-green QTLs. Modern tools, including genome-wide association studies (GWAS), genomic selection, and gene editing, are now being used to identify drought genes, such as those for root architecture, transpiration efficiency, and stay-green, and to accelerate breeding. However, genomics should supplement, not replace, field phenotyping, because drought tolerance is a complex, polygenic trait that depends on environment, soil, and management.

4. Hybrids, Early Maturity and Other Traits

Hybrids offer a step-change in sorghum yield. In Ethiopia, best hybrids such as P-9534 x Melkam gave 6.32 t ha-1, B6 x ICRS-14 gave 5.92 t ha-1, TX-623 x ICRS-14 gave 5.88 t ha-1, and P9511 x Melkam gave 5.78 t ha-1, with yield advantages of 32.49 percent, 24 percent, 23 percent, and 21 percent respectively over the standard check ESH-4 (4.77 t ha-1). Guinea-race based hybrids, developed by ICRISAT and partners for West African smallholders, were evaluated in on-farm farmer-managed trials and showed satisfactory grain yield and quality under farmers' cultivation conditions, even in low-input environments.

Early maturity is another key trait for drought escape. In northern Nigeria, SAMSORG 52, 53, and 54, developed by ICRISAT, mature in three months, enabling farmers in drought-prone areas to produce grain within a shorter period while also providing fodder for livestock. SAMSORG 52, formerly 12KNICSV-297, Yar Gwuiwa, was released in 2023 after multilocation testing and farmer evaluations, derived from a cross between Zabuwa and Grinkan-7-3-1, as an open-pollinated, compact, resilient variety adapted to the Sahel and Sudan Savanna. Early maturity allows farmers to escape terminal drought, to plant late if rains are late, and to fit sorghum into double-cropping systems.

Other traits matter for adoption: grain quality, including colour, hardness, and taste for tuwo, tô, and other foods, stover quality for fodder, Striga resistance, and phosphorus-use efficiency. In West Africa, sorghum is grown in low-input systems with serious soil phosphorus deficiencies, and selection for phosphorus-limited environments has identified genotypes that yield well under low phosphorus. Breeding for low phosphorus, Striga resistance, and grain quality should be prioritised alongside drought tolerance, because a drought-tolerant variety that tastes bad, is susceptible to Striga, or yields poorly on low phosphorus will not be adopted.

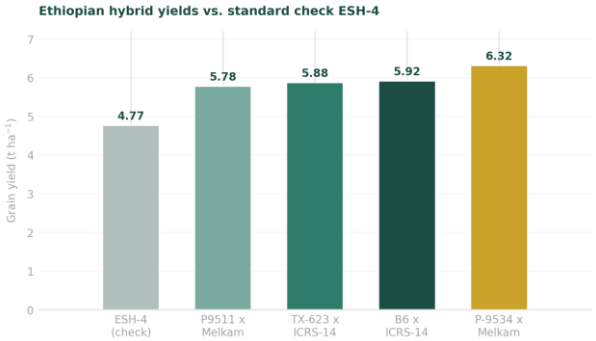


Figure 2 — Grain yield of leading Ethiopian hybrids compared with the standard check ESH-4 (4.77 t ha−1). P-9534 × Melkam gave 6.32 t ha−1, a 32.49% advantage. Values are as reported in the text.

Table 1. *Key sorghum breeding traits and their use.*

Trait / QTL	What it does	Breeding use
Stay-green Stg1–4	Maintains green leaves, grain filling	MAS, QTL pyramiding
Stg3B	Key QTL, +16% yield under stress	Introgress with SNP markers
Early maturity	Escapes terminal drought	Select for 90–100 day varieties
Deep roots / TE	Extracts water, efficient use	Phenotype, GWAS, selection
Striga resistance	Reduces parasite damage	Screen, MAS, combine
Low-P tolerance	Yields on poor soils	Multi-environment trials

Note: TE = transpiration efficiency; MAS = marker-assisted selection; GWAS = genome-wide association study. Summary of traits discussed in Sections 2–4.

5. Seed Systems, Adoption and Gender

Breeding is useless without seed. In SSA, most sorghum seed is farmer-saved, exchanged, or bought in informal markets, with low use of certified seed. Formal seed systems, including public breeding, private seed companies, and community seed production, are weak for sorghum, because sorghum is often open-pollinated, low-value, and grown by poor farmers, so seed companies have little incentive to produce it. Hybrids require annual seed purchase, which is a barrier if seed is unavailable or expensive, while open-pollinated varieties, such as SAMSORG 52, can be saved by farmers, but yield gains may be lower.

Adoption depends on farmer-preferred traits, seed availability, and extension. Farmers adopt varieties that are early, drought-tolerant, high-yielding, and have good grain and stover quality, and they reject varieties that are late, low-yielding, or have poor taste, even if they are drought-tolerant in trials. Participatory variety selection, where farmers evaluate varieties in their own fields and choose what they like, has been shown to improve adoption, because it ensures that breeding targets match farmer needs. Community seed production, where farmer groups multiply and sell quality seed, can fill the gap between formal and informal systems.

Gender matters. Women often manage sorghum for food, especially for porridge and brewing, yet they may not control decisions about variety choice or seed purchase. Programmes that involve women in variety selection, that ensure women have access to seed and extension, and that breed for traits women value, such as grain quality, cooking time, and stover for fodder, are more likely to reach those who actually grow and process sorghum.

6. Research and Policy Priorities

Several gaps remain. First, long-term, multi-location trials that measure not only grain yield but also stover, nutrition, and income over multiple seasons are still scarce. Second, research on QTL pyramiding, on genomic selection, and on gene editing for drought, Striga, and low phosphorus should be prioritised, but with field validation in SSA. Third, research on seed systems, on community seed production, and on hybrid seed economics should be embedded in breeding programmes, not treated as separate. Fourth, research on climate, on early warning, and on agronomy, such as planting date, spacing, and soil fertility, should be combined with breeding, because variety alone cannot overcome poor agronomy.

Policy should align incentives with drought-tolerant sorghum. Public investment should support national breeding programmes, genebanks, and phenotyping, with funding for long-term trials. Seed policy should support both formal and community seed systems, with quality assurance that is simple and affordable. Regional coordination, through ICRISAT, CORAF, and national programmes, can ensure that varieties bred in one country can be tested and released in others, reducing duplication and speeding adoption (FAO, 2023).

7. Conclusion

Sorghum breeding for drought tolerance offers a practical, low-cost, and locally available way to improve food security in SSA. Stay-green QTLs can increase grain yield by 16 to 30 percent under water stress, improved varieties can increase yield by 30.9 percent over older varieties, and hybrids can increase yield by 32 percent over checks, with early-maturing varieties such as SAMSORG 52 enabling farmers to escape terminal drought (Borrell et al., 2014; Jordan et al., 2012; Rai et al., 1999). The challenge is not a lack of genes; it is the challenge of combining stay-green, early maturity, Striga resistance, low-phosphorus tolerance, and farmer-preferred grain quality in varieties that farmers can actually access through seed systems. If that is achieved, sorghum can turn from a low-yielding fallback crop into a reliable, climate-resilient staple that sustains millions in the face of drought and climate change.

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Conflict of Interest

The authors declare no conflict of interest.

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