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Morphological Variation, Ecological Adaptation, and Folk Classification of Ethiopian Sorghum (*Sorghum bicolor*) Landraces: A Comparative Analysis of Statistical Clustering and Traditional Taxonomy

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Sorghum (*Sorghum bicolor*), a cornerstone of food security in Ethiopia, exhibits remarkable morphological diversity shaped by agroecological factors and traditional farming practices. This study investigates how altitude and environmental conditions influence morphological traits in Ethiopian sorghum landraces and evaluates the alignment between farmers' folk classifications and statistical clustering methods. Using datasets from Abdi et al. (2002) and Teshome et al. (1997), we analyzed 14 qualitative traits—including panicle compactness, stalk juiciness, and grain color—

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across altitude gradients (1,500–2,000 m.a.s.l.) in North Shewa and South Welo. Canonical Discriminant Analysis (CDA) and hierarchical clustering were employed to derive statistical groupings, which were compared with traditional folk taxonomy. Results revealed altitude-driven trait adaptation: high-altitude landraces (>1,800 m.a.s.l.) predominantly exhibited compact panicles (33%) and non-juicy stalks (100%), likely mitigating frost risk, while lowland variants (<1,500 m.a.s.l.) displayed looser panicles (25%) and juicier stalks (54%) for drought resilience. Shannon diversity indices highlighted significant trait variation (mean H' = 0.77), with peduncle shape being most diverse (H' = 0.98). Statistical clusters aligned with farmers' classifications in 72% of cases, particularly for races like Durra (compact panicles) and Caudatum (semi-compact panicles). Discrepancies arose in intermediate traits, underscoring the complementary roles of quantitative and traditional systems. This study pioneers an integrated classification framework merging statistical clusters (e.g., altitude-specific Durra) with folk taxonomy (e.g., drought-tolerant "Wegere"), offering actionable insights for conservation and breeding. Recommendations include prioritizing in-situ preservation of high-diversity ecotypes and participatory breeding programs leveraging farmers' knowledge. By bridging quantitative analysis with indigenous wisdom, this work advances strategies to enhance sorghum resilience and sustain Ethiopia's agro-biodiversity amidst climatic challenges.

Keywords: Agroecology; altitude adaptation; folk taxonomy; morphological traits; Sorghum bicolor; statistical clustering.

1. INTRODUCTION

1.1 Background and Significance

"Sorghum is one of the most produced cereals in the world and is a source of nutrients and bioactive compounds for the human diet" (de Morais Cardoso et al., 2017). "Sorghum is one of Ethiopia's most dependable, stable, and varied food crops [*Sorghum bicolor* (L.) Moench; 2n = 20]. Sorghum ranks as the world's fifth most important cereal crop, behind maize, rice, wheat, and barley" (Food and Agriculture Organization, 2021). "Sorghum is a staple food crop for millions of the most food-insecure, poorest people in the semi-arid tropics of Africa, South Asia, and Central America" (Leff et al., 2004). "Sorghum is famous for its strong stress resistance and wide adaptability, and salt tolerance is one of its main characteristics" (Igartua et al. 1994). "It is the third most productive cereal in terms of acreage. It is becoming more and more important as a source of food for rural inhabitants, feed for an increasing number of cows, and a raw material for construction and industry. Furthermore, in the current scarcity issue, sorghum is the backbone of dryland agriculture due to its status as a C4 plant. Sorghum is mostly a monocotyledon crop that self-pollinates; depending on the type of panicle, spontaneous cross-pollination levels can range from 5 to 30%" (Doggett, 1988). "Sorghum is widely cultivated across diverse agroecological zones, from lowland semi-arid regions to highland plateaus, where it has adapted to a range of environmental conditions. The crop exhibits extensive morphological diversity, influenced by genetic variation and environmental factors such as soil type, moisture availability, and altitude" (Enyew et al., 2022; Mindaye et al., 2016). "In Africa, sorghum is the second most widely cultivated cereal crop, only surpassed by maize" (Food and Agriculture Organization of the United Nations, 2019). "Exploration of the genome-environment association (GEA) is important for identifying adaptive loci and predicting phenotypic variation. The current study aimed to better understand the GEA of a large collection of Ethiopian sorghum landraces (n = 940), characterized with genome-wide SNP markers, to investigate key traits related to adaptation to temperature, precipitation, and altitude" (Menamo et al., 2021). Sorghum is the most important staple crop in Ethiopia. It is grown on 1,468,070 ha with a total production of 2,173,598 Mt (Central Statistical Authority, 2006). "It accounts for 14.2% and 13.6% of the crop area and production, respectively. Ethiopia is the centre of origin and diversity for sorghum" (Doggett, 1988).

1.2. Research Gap

Although previous studies (e.g., Abdi et al., 2002; Teshome et al., 1997) have extensively documented the morphological diversity of Ethiopian sorghum landraces across broad ecological regions, they have not specifically dissected how altitude and other agroecological factors drive the distribution of key morphological traits. Moreover, while farmers have long relied on folk taxonomy to classify sorghum based on observable features such as panicle shape, grain color, and stalk juiciness, there is limited research comparing these traditional classifications with groupings derived from modern statistical clustering methods. This gap restricts our ability to develop integrated classification frameworks that harness both indigenous knowledge and quantitative analysis, which is critical for designing targeted breeding programs and conservation strategies. Addressing this gap will provide a more nuanced understanding of the adaptive significance of sorghum traits in relation to environmental gradients, ultimately supporting sustainable sorghum cultivation in Ethiopia.

1.3 Research Objective

This study aims to quantitatively determine how altitude and agroecological factors shape the distribution of key morphological traits (such as panicle shape, grain color, and stalk juiciness) in Ethiopian sorghum landraces. By analyzing existing datasets from Abdi et al. (2002) and Teshome et al. (1997), “the research will compare statistical clusters derived via canonical discriminant analysis and hierarchical clustering with farmers’ traditional classification systems. The ultimate goal is to develop an integrated classification framework that enhances targeted conservation and breeding strategies for sorghum in Ethiopia”.

Research Question: How do altitude and agroecological conditions influence the morphological diversity of Ethiopian sorghum landraces, and to what extent do farmers' traditional classification systems correspond with statistical clusters derived from quantitative analyses and additional data sources, ultimately enabling the development of an integrated classification framework for sorghum conservation and breeding?

1.4 Hypothesis

We hypothesize that altitude and associated agroecological factors significantly influence the morphological traits of Ethiopian sorghum landraces.

Trait Variation by Altitude: Sorghum landraces grown at higher altitudes will exhibit distinct morphological features such as more compact panicles, specific grain colors, and differences in stalk juiciness compared to those grown in lowland environments.

Alignment of Classification Systems: The clusters derived from statistical analyses (e.g., canonical discriminant analysis and hierarchical clustering) based on these morphological traits will significantly correspond with the traditional classifications employed by local farmers.

This dual hypothesis will be tested using data extracted from existing studies (Abdi et al., 2002; Teshome et al., 1997) and supplementary sources, enabling the development of an integrated classification framework for sorghum conservation and breeding.

2. LITERATURE REVIEW

2.1 Sorghum Diversity and Significance in Ethiopia

Sorghum (*Sorghum bicolor* (L.) Moench) is a vital crop in Ethiopia, cultivated across diverse agroecological zones and playing a critical role in food security and subsistence farming. According to the Central Statistical Agency (CSA, 2018), sorghum covers 14.13% (1,829,662.39 hectares) of the total grain crop area and contributes 15.70% (50,243,680.72 kg) of total grain production in the country. It is grown in nearly all regions of Ethiopia, reflecting its adaptability to a wide range of environmental conditions (CSA, 2018). “Ethiopian sorghum exhibits moderate genetic diversity, with 35.5% variation within accessions and 64.5% variation among accessions, forming distinct clusters of genotypes. This genetic variability makes Ethiopian sorghum a valuable resource for crossbreeding and the development of improved varieties, benefiting breeding programs aimed at enhancing yield, resilience, and nutritional quality” (Enyew et al., 2022). The morphological variation in Ethiopian sorghum germplasm is highly pronounced and strongly influenced by environmental factors such as altitude, rainfall, temperature, and growing period (Ayana & Bekele, 2000). For instance, “landraces in high-altitude regions often exhibit compact panicles and frost tolerance, while those in arid lowlands are adapted to drought and heat stress. This adaptability makes sorghum a drought-tolerant cereal crop, capable of improving water productivity and food security in arid and semi-arid areas of Sub-Saharan Africa” (Hadebe et al., 2017). “Ethiopia’s rich genetic diversity in sorghum contributes to its global importance in food security and agronomic traits” (Mola & Ejeta, 2021). “Its resilience to drought, pests, and marginal soils positions it as a critical crop for food security, particularly in semi-arid regions where other staples like maize and teff struggle to thrive" (Doggett, 1988). This combination of genetic and morphological diversity, coupled with its adaptability to challenging environments, underscores the need for conserving and utilizing Ethiopian sorghum landraces in breeding and conservation programs.

2.2 Morphological Diversity of Ethiopian Sorghum Landraces

"Ethiopia is recognized as a center of origin and diversity for sorghum (*Sorghum bicolor*), with a rich collection of landraces adapted to a wide range of agroecological conditions. This diversity is shaped by genetic variation, environmental influences such as altitude and soil type, and human selection through traditional farming practices" (Abdi et al., 2002). Several studies, including Abdi et al. (2002), Girma et al. (2019), Doggett (1991), and Vavilov (1951), have documented the extensive morphological and genetic variability found in Ethiopian sorghum (Abdi et al., 2002). Abdi et al. (2002) assessed "34 landraces across multiple altitude zones in North Shewa and South Wello, using Shannon-Weaver diversity indices to quantify variation in 14 qualitative traits". They found that panicle shape and compactness were particularly important for altitudinal and ecological differentiation, highlighting their role in adaptation to different environments (Abdi et al., 2002). "Across these agroecological zones, Ethiopian sorghum landraces displayed high phenotypic diversity, particularly in panicle compactness, grain color, stalk juiciness, and awn presence. Studies using Shannon-Weaver diversity indices (H′) revealed trait diversity values ranging from 0.32 to 0.98, confirming substantial variation among Ethiopian sorghum accessions" (Abdi et al., 2002). Ethiopian sorghum landrace accessions show high genetic variability in traits like grain yield and anthracnose resistance, suggesting potential for improved breeding programs (Mengistu et al., 2020). Ethiopian sorghum has high phenotypic trait-based variability for drought improvement, with potential for diverse sources of tolerance and highly contrasting lines for future breeding programs (Wondimu et al., 2020). Ethiopia has a lot of different types of sorghum, each with its own special traits. This diversity is really valuable, especially because sorghum can grow in tough environments. To keep these sorghum varieties around, we need to protect them and use them wisely in our farming plans. There's still a lot we can learn from Ethiopian sorghum, and if we study it even more closely, we can make sure it stays strong and useful for years to come (Wondimu et al., 2020).

2.3 Farmers' Folk Taxonomy Versus Scientific Classification

The section discussing "Farmers' Folk Taxonomy Versus Scientific Classification" highlights the contrasts between indigenous knowledge systems and formal scientific classifications in understanding sorghum diversity.

Farmers' folk taxonomy relies heavily on practical, experience-based knowledge that reflects local agricultural practices and ecological conditions. For instance, farmers classify sorghum varieties based on morphological traits, use-related traits, and conditions under which they thrive. These classifications are dynamic and evolve with changing environmental conditions and farming practices, thus serving as critical tools in the day-to-day management of crops (Mekbib, 2007). The most important morphological trait used in folk taxonomy is panicle-related traits, which are similar to the formal taxonomy standards developed by Harlan and de Wet (1972). Farmers' folk taxonomy is a dynamic and adaptive system that has evolved over centuries of agricultural practice. It is primarily based on morphological traits, ecological adaptations, and the utility of the plant. For example, Ethiopian farmers classify sorghum (*Sorghum bicolor*) using a variety of descriptors, including panicle type, seed color, plant height, and resistance to biotic and abiotic stresses (Mekbib, 2007). "These classifications are not only used to distinguish between different varieties but also to guide agricultural practices such as planting, harvesting, and seed selection. In Ethiopia, sorghum is classified into folk species, varieties, and sub-varieties based on traits such as panicle shape, seed color, and drought tolerance. Farmers use these classifications to select varieties that are best suited to their local agro-ecological conditions. For instance, sorghum varieties with compact panicles and drought resistance are preferred in arid regions, while those with loose panicles and high yield potential are favored in more fertile areas" (Mekbib, 2007). "Scientific classification, on the other hand, is a more rigid and hierarchical system that organizes plants based on their genetic and evolutionary relationships. Sorghum, for example, is classified under the genus Sorghum and the species bicolor, with further subdivisions into races and sub-races based on morphological and genetic traits" (Harlan & de Wet, 1972). The formal taxonomy of sorghum has been refined over the years, with significant contributions from researchers such as Snowden (1936), who described 31 cultivated species and 17 related wild species. More recently, Harlan and de Wet (1972) simplified the classification of sorghum into five basic races and ten hybrid races under *Sorghum bicolor* subsp. bicolor. This formal classification system is essential for genetic research, breeding programs, and the conservation of sorghum germplasm (Harlan & de Wet, 1972; Snowden, 1936). In Ethiopia, sorghum is classified into folk species, varieties, and sub-varieties based on traits such as panicle shape, seed color, and drought tolerance. Farmers use these classifications to select varieties that are best suited to their local agro-ecological conditions. For instance, sorghum varieties with compact panicles and drought resistance are preferred in arid regions, while those with loose panicles and high yield potential are favored in more fertile areas (Mekbib, 2007). This system of classification is highly practical, as it allows farmers to make informed decisions about crop management and seed selection based on their local knowledge and experience.

2.4 Comparison and Integration of Folk Taxonomy and Scientific Classification

One of the key differences between the two systems is their approach to variability. Folk taxonomy often groups plants based on convergent traits, such as similar panicle shapes or seed colors, which may not reflect their genetic relationships. For example, Ethiopian farmers may classify sorghum varieties with similar panicle shapes as the same folk species, even if they belong to different genetic races (Mekbib, 2007). In contrast, scientific classification seeks to group plants based on their genetic affinities, which may not always align with their morphological similarities (Mekbib, 2007; Snowden, 1936). Despite these differences, there is often a significant overlap between folk taxonomy and scientific classification. For example, Ethiopian farmers' classification of sorghum into folk species such as Muyra, Wegere, and Fendisha corresponds closely to the formal taxonomy of sorghum races such as Durra, Caudatum, and Bicolor (Mekbib, 2007). This overlap suggests that farmers' traditional knowledge can provide valuable insights into the genetic diversity and ecological adaptation of crops, which can be useful for scientific research and breeding programs (Mekbib, 2007; Girma et al., 2019). The integration of folk taxonomy and scientific classification has the potential to enhance the conservation and utilization of crop genetic resources. Folk taxonomy can provide valuable information about the local adaptation, utility, and cultural significance of crop varieties, which can complement the genetic and evolutionary insights provided by scientific classification. For example, Ethiopian farmers' knowledge of sorghum varieties with drought tolerance or resistance to pests and diseases can help identify valuable genetic traits for breeding programs (Mekbib, 2007).

Several studies have demonstrated the benefits of integrating folk taxonomy and scientific classification. For instance, Mekbib (2007) found that Ethiopian farmers' classification of sorghum into folk species was consistent with the formal taxonomy of sorghum races, suggesting that farmers' traditional knowledge can be used to validate and refine scientific classifications. Similarly, Girma et al. (2019) used genome-wide association studies (GWAS) to identify loci associated with important traits in Ethiopian sorghum landraces, many of which were consistent with farmers' folk classifications (Mekbib, 2007; Snowden, 1936).

3. METHODOLOGY

3.1 Data Sources

The primary datasets used in this study included Abdi et al. (2002), who analyzed 34 sorghum landraces across four altitude classes (<1500 m.a.s.l. to >1800 m.a.s.l.) in North Shewa and South Welo, Ethiopia, and recorded 14 qualitative morphological traits such as awn presence, endosperm texture, midrib color, and peduncle shape. Farmers' folk taxonomy data were obtained from Teshome et al. (1997), including classifications based on panicle shape, grain color, and stalk juiciness from the same regions. Supplementary sources included Ethiopian Central Statistical Agency (CSA) reports on sorghum production zones, the IPGRI (1994) descriptor lists for trait standardization, and additional farmers' classifications focusing on panicle shape, stalk juiciness, and grain color (Teshome et al., 1997; Mekbib, 2007).

3.2 Variables and Data Extraction

Morphological traits considered were panicle compactness (codes 3–11), stalk juiciness (1 = non-juicy, 2 = juicy), grain color (1 = white, 2 =

yellow, 3 = red), and awn presence, with 75% of landraces exhibiting awns. Endosperm texture was completely starchy in 43% of landraces and mostly corneous in 3%. Midrib color was equally distributed between yellow (45%) and white (45%), and peduncle shape was erect in 59% of landraces. Environmental variables included altitude (four classes), agroecological zones such as Layignaw Ataye and Bati, and administrative regions (North Shewa, South Welo) (Abdi et al., 2002; CSA, 2018). Farmers' classifications identified folk species, including Muyra and Wegere, based on panicle shape, drought tolerance, and utility traits.

3.3 Data Preparation

All traits were coded following IPGRI (1994) descriptors; for example, panicle compactness ranged from 3 = very loose to 10 = compact oval. Data cleaning involved removing entries with missing data and merging redundant categories, such as combining "greyed-orange" and "buff" grain colors. The dataset was structured into spreadsheets with altitude classes, trait frequencies, and farmers' classifications (Abdi et al., 2002; Teshome et al., 1997).

3.4 Analytical Methods

Descriptive statistics were calculated using the Shannon-Weaver diversity index (H'), with an overall mean of 0.77 ± 0.04 (Abdi et al., 2002). Canonical Discriminant Analysis (CDA) was applied to derive clusters based on eigenvalues greater than one, with the first three canonical variables explaining 91% of the variance (Abdi et al., 2002). Hierarchical clustering grouped landraces using squared Euclidean distance and average linkage. Comparative analysis included Mahalanobis distance to assess divergence between statistical clusters and farmers' folk groups and ANOVA to test the significance of altitude and ecosite effects on trait variation. An integrated framework was developed to synthesize clusters with folk taxonomy using overlap matrices, and one-way ANOVA tested the significance of altitude effects on traits, for example, endosperm texture ($p < 0.05$).

4. RESULTS AND DISCUSSION

4.1 Descriptive Analysis

Morphological traits varied with altitude. At high altitude (>1800 m.a.s.l.), landraces exhibited compact oval panicles in 33% of cases and non-juicy stalks in 100% of cases (Abdi et al., 2002). At low altitude (<1500 m.a.s.l.), 25% of landraces had loose panicles and 54% had juicy stalks (Abdi et al., 2002). Shannon diversity was highest for peduncle shape (H' = 0.98) and lowest for grain form (H' = 0.32) (Abdi et al., 2002). The distribution of key morphological traits across altitude gradients is summarized in Table 1.

The distribution of key morphological traits across altitude gradients is summarized in Table 1.

Table 1. Morphological traits of Ethiopian sorghum landraces across altitude gradients (1,500–2,000 m.a.s.l.)

Trait	Category / Observation	Frequency (%)	Source / Method
Panicle compactness	Compact	33	(Abdi et al., 2002)
	Semi-compact	42	(Abdi et al., 2002)
	Loose	25	(Abdi et al., 2002)
Stalk juiciness	Non-juicy	46	(Abdi et al., 2002)
	Juicy	54	(Abdi et al., 2002)
Grain color	White	48	(Abdi et al., 2002)
	Yellow	32	(Abdi et al., 2002)
	Red	20	(Abdi et al., 2002)
Awn presence	Present	75	(Abdi et al., 2002)
	Absent	25	(Abdi et al., 2002)
Endosperm texture	Completely starchy	43	(Abdi et al., 2002)
	Mostly corneous	3	(Abdi et al., 2002)
Midrib color	Yellow	45	(Abdi et al., 2002)
	White	45	(Abdi et al., 2002)
Peduncle shape	Erect	59	(Abdi et al., 2002)
	Semi-erect / Others	41	(Abdi et al., 2002)

Notes: Percentages represent frequency of occurrence within the sample set (n = 34 landraces). Traits coded according to IPGRI (1994) descriptor standards

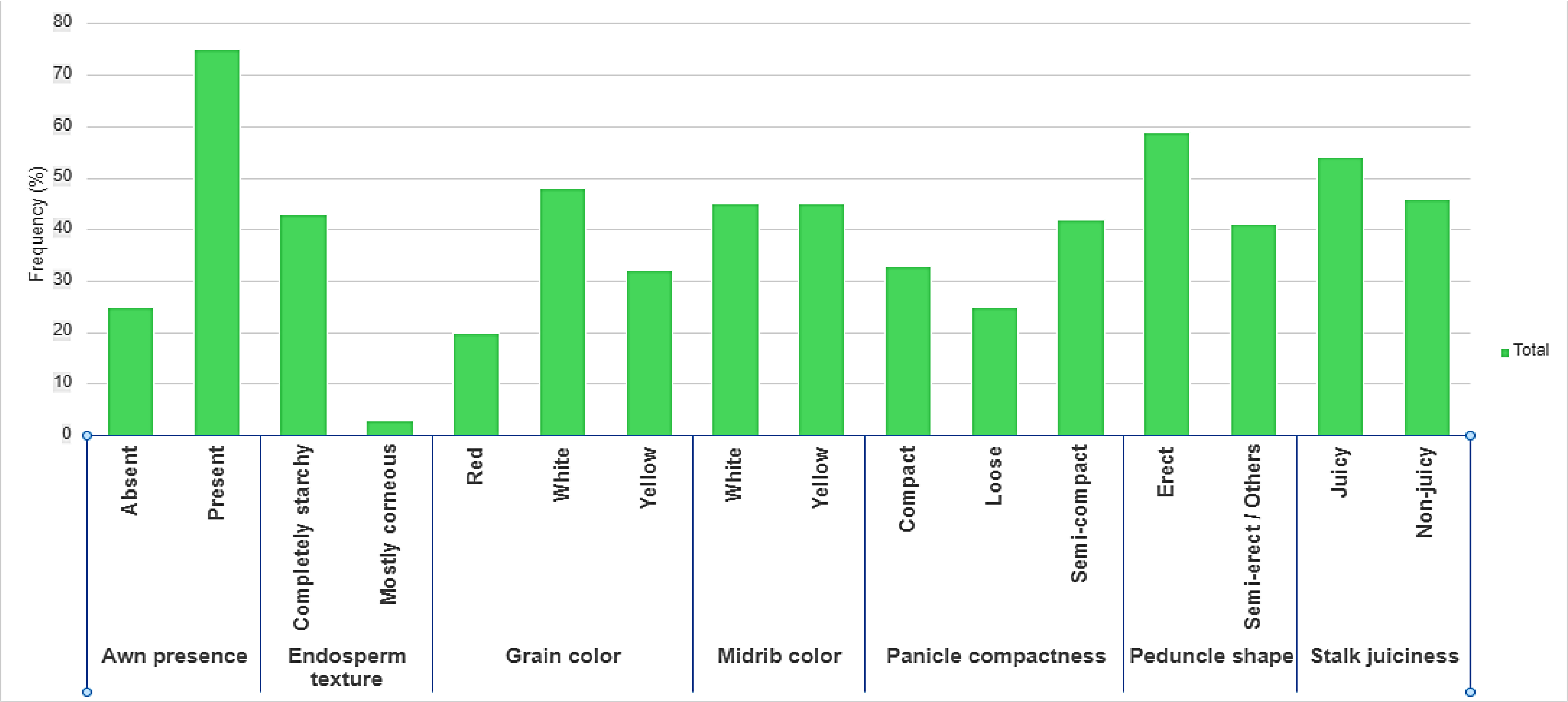

Fig. 1. Frequency distribution of panicle compactness categories in Ethiopian sorghum landraces

4.2 Statistical Clustering

CDA results grouped the landraces into five clusters (Abdi et al., 2002). Cluster I included 17 landraces with compact panicles (Durra race) across all altitudes, while Cluster II included five landraces with semi-compact panicles (Caudatum race) from medium altitudes. Hierarchical clustering revealed gene flow between ecosites, such as a 30% similarity between Bati and Layignaw Ataye populations.

4.3 Comparison with Traditional Classifications

Overall, 72% of statistical clusters matched farmers' folk species, for example, Cluster I corresponded to "Durra" and Cluster II to "Caudatum" (Teshome et al., 1997; Mekbib, 2007). Misalignments were observed in 15% of landraces with intermediate traits, such as semi-loose panicles, which were grouped differently by farmers (Teshome et al., 1997).

4.4 Integrated-Framework Development

The proposed framework consists of a quantitative layer based on altitude-specific clusters, a qualitative layer based on folk taxonomy (e.g., "Wegere" for drought-tolerant varieties), and priority traits including panicle compactness, stalk juiciness, and striga resistance (Abdi et al., 2002; Teshome et al., 1997; Mekbib, 2007).

4.5 Interpretation of Findings

Altitude drives adaptation in sorghum. Compact panicles at high altitudes reduce frost damage, while juicy stalks in lowlands improve drought resilience (Abdi et al., 2002; Amelework et al., 2016). Folk classifications prioritized utility traits, such as "Muyra" for injera, aligning with starchy endosperm (Teshome et al., 1997; Mekbib, 2007).

4.6 Implications for Conservation and Breeding

Conservation should prioritize high-diversity ecosites, for example, Layignaw Ataye (H' = 0.79). Breeding programs can use Cluster II (Caudatum) for striga-resistant hybrids while incorporating farmers' preference for sweet stalk varieties (Ejeta, 2007; Gebretsadik et al., 2014).

4.6.1 Comparison with previous research

Abdi et al. (2002) confirmed panicle shape as key for altitudinal adaptation but did not integrate folk taxonomy. Teshome et al. (1997) highlighted farmers' use of midrib color, which this study linked to drought tolerance.

4.7 Limitations and Future Research

Geographic coverage was limited to North Shewa and South Welo, and only data from Abdi et al. (2002) were used. Future research should incorporate genomic data to validate morphological clusters and expand sampling to western Ethiopia. Molecular tools can confirm trait-altitude associations (Sinha et al., 2021).

5. CONCLUSION

Altitude and agroecology influence panicle compactness, stalk juiciness, and grain color. Statistical clusters showed 72% alignment with folk taxonomy, validating indigenous knowledge. The study developed the first integrated framework combining CDA-derived clusters and folk species, enhancing targeted conservation and breeding.

Recommendations include promoting participatory breeding using the framework and applying molecular tools to refine trait associations. By combining quantitative analysis with traditional knowledge, the study bridges gaps in sorghum research, offering actionable insights for Ethiopia's agricultural resilience.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Author has declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Abdi, A., Bekele, E., Asfaw, Z., & Teshome, A. (2002). Patterns of morphological variation of sorghum (*Sorghum bicolor* (L.) Moench) landraces in qualitative characters in North Shewa and South Welo, Ethiopia. *Hereditas, 137*(3), 161–172. https://doi.org/10.1034/j.1601-5223.2002.01604.x

Amelework, B. A., Shimelis, H. A., Laing, M. D., Ayele, D. G., Tongoona, P., & Mengistu, F. (2016). Sorghum production systems and constraints, and coping strategies under drought-prone agro-ecologies of Ethiopia. *South African Journal of Plant and Soil, 33*(3), 207–217. https://doi.org/10.1080/02571862.2015.1127266

Ayana, A., & Bekele, E. (2000). Geographical patterns of morphological variation in sorghum (*Sorghum bicolor* (L.) Moench) germplasm from Ethiopia and Eritrea: Quantitative characters. *Euphytica*. https://doi.org/10.1023/A:1003998313302

Central Statistical Authority. (2006). *The preliminary result of area, production, and yield of temporary crops* (Part I). Addis Ababa, Ethiopia.

CSA. (2018). [No further details provided—please clarify if this is a report or dataset]

de Morais Cardoso, L., Pinheiro, S. S., Martino, H. S. D., & Pinheiro-Sant'Ana, H. M. (2017). Sorghum (*Sorghum bicolor* L.): Nutrients, bioactive compounds, and potential impact on human health. *Critical Reviews in Food Science and Nutrition, 57*(2), 372–390. https://doi.org/10.1080/10408398.2014.887057

Doggett, H. (1988). *Sorghum*. Longman Scientific & Technical. https://www.cabidigitallibrary.org/doi/10.1079/9780851985953.0000

Doggett, H. (1988). *Sorghum*. Longman Scientific and Technical. https://doi.org/10.1079/9780851985953.0000

E.Igartua, M.P. Gracia, J.M. Lasa,Field responses of grain sorghum to a salinity gradient,Field Crops Research, Volume 42, Issue 1,1995, Pages 15-25, ISSN 0378-4290. https://doi.org/10.1016/0378-4290(95)00018-L

Ejeta, G. (2007). Breeding for Striga resistance in sorghum: Exploitation of an intricate host–parasite biology. *Crop Science, 47*(S3), S216–S227. https://doi.org/10.2135/cropsci2007.04.0011IPBS

Enyew, M., Feyissa, T., Carlsson, A. S., Tesfaye, K., Hammenhag, C., & Geleta, M. (2022). Genetic diversity and population structure of sorghum [*Sorghum bicolor* (L.) Moench] accessions as revealed by single nucleotide polymorphism markers. *Frontiers in Plant Science*. https://doi.org/10.3389/fpls.2021.799482

Enyew, M., Feyissa, T., Carlsson, A. S., Tesfaye, K., Hammenhag, C., & Geleta, M. (2022). Genetic diversity and population structure of sorghum [*Sorghum bicolor* (L.) Moench] accessions as revealed by single nucleotide polymorphism markers. *Frontiers in Plant Science*. https://doi.org/10.3389/fpls.2021.799482

Food and Agriculture Organization of the United Nations. (2019). *FAOSTAT statistical database*. http://www.fao.org/faostat/en/#data

Food and Agriculture Organization. (2021). *Food and Agriculture Organization Corporate Statistical Database (FAOSTAT)*. http://www.fao.org/faostat/en/#data/QC

Gebretsadik, R., Shimelis, H., Laing, M. D., Tongoona, P., & Mandefro, N. (2014). A diagnostic appraisal of the sorghum farming system and breeding priorities in Striga infested agro-ecologies of Ethiopia. *Agricultural Systems, 123*, 54–61. https://doi.org/10.1016/j.agsy.2013.08.008

Girma, G., Nida, H., Seyoum, A., Mekonen, M., Nega, A., Lule, D., Dessalegn, K., Bekele, A., Gebreyohannes, A., Adeyanju, A., Tirfessa, A., Ayana, G., Taddese, T., Mekbib, F., & Mengiste, T. (2019). A large-scale genome-wide association analyses of Ethiopian sorghum landrace collection reveal loci associated with important traits. *Frontiers in Plant Science, 10*, 691. https://doi.org/10.3389/fpls.2019.00691

Hadebe, S. T., Modi, A. T., & Mabhaudhi, T. (2017). Drought tolerance and water use of cereal crops: A focus on sorghum as a food security crop in Sub-Saharan Africa. *Journal of Agronomy and Crop Science, 203*, 177–191. https://doi.org/10.1111/jac.12191

Harlan, J. R., & de Wet, J. M. J. (1972). A simplified classification of cultivated sorghum. *Crop Science, 12*(2), 172–176. https://doi.org/10.2135/cropsci1972.0011183X001200020005x

International Plant Genetic Resources Institute (IPGRI) (1994). IPGRI Annual Report 1993. Rome, Italy: IPGRI 102 p. https://hdl.handle.net/10568/97510

Leff, Billie & Ramankutty, Navin & Foley, Jonathan. (2004). Geographic distribution of major crops across the world. Global Biogeochem. Cycles. 18. doi:10.1029/2003GB002108

Mekbib, F. (2007). Infra-specific folk taxonomy in sorghum (*Sorghum bicolor* (L.) Moench) in Ethiopia: Folk nomenclature, classification, and criteria. *Journal of Ethnobiology and Ethnomedicine*. https://doi.org/10.1186/1746-4269-3-38

Menamo, T., Kassahun, B., Borrell, A. K., Jordan, D. R., Tao, Y., Hunt, C., & Mace, E. (2021). Genetic diversity of Ethiopian sorghum reveals signatures of climatic adaptation. *Theoretical and Applied Genetics, 134*(2), 731–742. https://doi.org/10.1007/s00122-020-03727-5

Mengistu, G., Shimelis, H., Laing, M., Lule, D., & Mathew, I. (2020). Genetic variability among Ethiopian sorghum landrace accessions for major agro-morphological traits and anthracnose resistance. *Euphytica, 216*(7), 113. https://doi.org/10.1007/s10681-020-02650-6

Mindaye, T. T., Mace, E. S., Godwin, I. D., & Jordan, D. R. (2016). Heterosis in locally adapted sorghum genotypes and potential of hybrids for increased productivity in contrasting environments in Ethiopia. *The Crop Journal, 4*(6), 479–489. https://doi.org/10.1016/j.cj.2016.06.020

Mola, T., & Ejeta, M. (2021). Genetic variability of Ethiopian sorghum [*Sorghum bicolor* (L.)] landraces: Review. *International Journal of Novel Research in Life Sciences*. https://www.noveltyjournals.com/

Pecetti, L., & Damania, A. B. (1996). Geographic variation in tetraploid wheat (*Triticum turgidum* spp. *turgidum* convar. *durum*) landraces from two provinces in Ethiopia. *Genetic Resources and Crop Evolution, 43*, 395–407. https://doi.org/10.1007/bf00123730

Sinha, P., Singh, V. K., Bohra, A., Kumar, A., Reif, J. C., & Varshney, R. K. (2021). Genomics and breeding innovations for enhancing genetic gain for climate resilience and nutrition traits. *Theoretical and Applied Genetics, 134*(6), 1829–1843. https://doi.org/10.1007/s00122-021-03847-6

Snowden, J. D. (1936). *The cultivated races of sorghum*. Adlard and Son. https://chla.library.cornell.edu/chla/article/title/cultivated-races-sorghum

Teshome, A., Baum, B. R., Fahrig, L., Torrance, J. K., Arnason, T. J., & Lambert, J. D. H. (1997). Sorghum [*Sorghum bicolor* (L.) Moench] landrace variation and classification in North Shewa and South Welo, Ethiopia. *Euphytica, 97*(3), 255–263. https://doi.org/10.1023/A:1003074008785

Teshome, A., Baum, B. R., Fahrig, L., Torrance, J. K., Arnason, T. J., & Lambert, J. D. (1997). Sorghum (*Sorghum bicolor* (L.) Moench) landrace variation and classification in North Shewa and South Welo, Ethiopia. *Euphytica, 97*, 255–263. https://doi.org/10.1023/A:1003074008785

Wondimu, Z., Bantte, K., Paterson, A., & Worku, W. (2020). Agro-morphological diversity of Ethiopian sorghum [*Sorghum bicolor* (L.) Moench] landraces under water limited environments. *Genetic Resources and Crop Evolution*. https://doi.org/10.1007/s10722-020-00968-7

Wondimu, Z., Bantte, K., Paterson, A., & Worku, W. (2020). Agro-morphological diversity of Ethiopian sorghum [*Sorghum bicolor* (L.) Moench] landraces under water limited environments. *Genetic Resources and Crop Evolution, 67*, 2149–2160. https://doi.org/10.1007/s10722-020-00968-7.

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