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The Role of Disadvantaged Crop Species in Strengthening Food Security in the Context of Climate Change

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Abstract
Climate change presents profound threats to global food security, particularly through declining yields and heightened variability in major staples such as maize, wheat, and rice. This study evaluates the potential of disadvantaged crop species—including finger millet, pearl millet, sorghum, amaranth, cowpea, and bambara groundnut—as climate-resilient and nutrition-sensitive alternatives. Using a mixed-methods approach that combined systematic literature review, secondary data analysis, and statistical comparisons, the research assessed yield performance, drought tolerance indices, variability, and composite nutrient density across disadvantaged and staple crops. Results revealed that disadvantaged crops consistently exhibited higher drought tolerance indices, with mean values 27% greater than staples, and displayed lower yield variability under stress conditions. Nutritional analyses further highlighted their superiority, with average nutrient density scores surpassing staples by more than 30 points on a 0-100 scale. These findings underscore the dual benefits of disadvantaged species in sustaining productivity under climatic stress and enhancing dietary diversity. The discussion integrates these empirical outcomes with broader agricultural and nutrition frameworks, identifying key gaps in policy support, research investment, and market integration. The study concludes that disadvantaged crops are not marginal, but essential for climate adaptation and sustainable food systems. Practical recommendations emphasize the need for targeted breeding programs, supportive policy frameworks, value-chain development, farmer training, and nutrition-sensitive public procurement. By systematically mainstreaming disadvantaged species into agricultural strategies, governments and communities can mitigate climate-induced food insecurity while promoting healthier, more resilient diets.

Keywords: Disadvantaged crop species, Underutilized crops, Food security, Climate change resilience, nutrient density, Millets, Sorghum, Amaranth

Introduction
Food security in the era of climate change is one of the most pressing global concerns, as conventional staple crops such as rice, wheat, and maize are increasingly vulnerable to temperature fluctuations, erratic rainfall, soil degradation, and pest outbreaks [1-3]. Disadvantaged crop species—often referred to as underutilized, neglected, or orphan crops—represent a critical but undervalued resource for strengthening agricultural resilience and nutritional security [4, 5]. These crops, which include millets, sorghum, amaranth, bambara groundnut, and indigenous leafy vegetables, are adapted to marginal environments and display remarkable tolerance to biotic and abiotic stresses [6-8]. Despite their ecological and nutritional advantages, they have historically been excluded from mainstream agricultural research and policy priorities, leading to a widening gap in food system diversity and resilience [9]. With climate change projected to reduce the yields of dominant cereal crops by up to 30% in some regions by 2050 [10, 11], the revitalization of disadvantaged crops could serve as a pivotal strategy to buffer against food shortages and malnutrition [12]. Previous studies have shown that these species contribute to dietary diversification, supply micronutrients, and ensure yield stability under drought and heat stress conditions [13-15]. For instance, research in South Africa has demonstrated that disadvantaged crops such as sorghum and cowpea play a vital role in local food systems and livelihoods, underscoring their potential to enhance resilience in smallholder settings [16]. Zuma-Netshiukhwi [17] emphasized that disadvantaged crop species can significantly improve food systems and security under changing climatic conditions, drawing lessons from the Motheo District in South Africa. The problem, however, lies in the persistent neglect of these species in terms of agronomic improvement, value chain integration, and market development [18]. This

article therefore aims to critically examine the role of disadvantaged crop species in strengthening food security under climate change scenarios, with a focus on their agronomic, nutritional, and socio-economic dimensions. The central hypothesis guiding this study is that the systematic promotion, research investment, and policy mainstreaming of disadvantaged crops can substantially mitigate the risks posed by climate variability, while simultaneously contributing to sustainable agriculture and community-level resilience.

Materials and Methods

Materials

The present study was conducted using a combination of published secondary data sources, field-level reports, and community-level agricultural datasets pertaining to disadvantaged crop species across semi-arid and sub-humid regions of sub-Saharan Africa and South Asia. Sources of data included international databases such as FAO reports on food security and nutrition [1], IPCC climate impact assessments [3], and peer-reviewed studies on neglected and underutilized species (NUS) [4-6]. Specific emphasis was given to crops such as millets, sorghum, amaranth, cowpea, and indigenous leafy vegetables, which have been highlighted as key contributors to climate-resilient agriculture [7, 8]. Data on agronomic performance, yield variability, and nutritional composition were extracted from prior experimental studies [10-12], while socio-economic parameters were derived from community surveys and participatory research projects, including case studies such as those documented in South Africa [16, 17]. The materials reviewed also incorporated genetic diversity resources [9], nutritional value assessments [15], and strategic frameworks for promoting underutilized crops [18], thereby providing a comprehensive foundation for methodological analysis.

Methods

The methodology followed a mixed qualitative-quantitative approach. First, a systematic literature review was conducted using keywords such as “disadvantaged crops, ” “underutilized species, ” “food security, ” and “climate resilience” across major databases including Scopus, Web of Science, and AGRIS, covering the period 2000-2023 [2, 5, 7]. Studies were screened for relevance based on crop focus, climate stress parameters, and documented socio-economic outcomes [8, 9]. Quantitative yield data and nutritional composition values were tabulated and compared with dominant staple crops to highlight relative advantages and constraints [11, 13, 14]. To contextualize field-level realities, secondary field reports and participatory assessments from semi-arid zones were included [15-17]. The analytical framework integrated agroecological performance indicators (e.g., drought tolerance, soil adaptability), food system contributions (e.g., dietary diversity, micronutrient intake), and socio-economic variables (e.g., household income, market access) [12, 16, 18]. This triangulated approach enabled the synthesis of empirical evidence with community-based insights, thereby testing the hypothesis that disadvantaged crop species can play a substantial role in strengthening food security under the challenges posed by climate change.

Results

Summary of quantitative findings

Across nine focal crops, disadvantaged species (finger millet, pearl millet, sorghum, amaranth (grain), cowpea, bambara groundnut) recorded higher DTI than staples (maize, wheat, rice) (Table 1; Figure 1). Mean DTI for disadvantaged crops was 0.84 versus 0.66 for staples; Welch’s t-test indicated a significant difference ($t = 7.13$, $p < 0.01$), with a large effect size (Cohen’s $d = 3.74$; 95% CI for the mean difference: 0.12 to 0.24). Disadvantaged crops also showed lower drought-season yield variability (coefficient of variation (CV) typically 14-18%) than staples (26-30%), indicating greater yield stability under climatic stress—consistent with the literature on orphan/NUS resilience [2, 7, 8, 10-12, 16, 17].

Table 1: Yields, DTI (DTI), and Yield Variability by Crop

Crop	Category	Yield (control) t/ha	Yield (drought) t/ha
Amaranth (grain)	Disadvantaged	1.5	1.3
Cowpea	Disadvantaged	1.2	1.0
Bambara groundnut	Disadvantaged	1.3	1.1
Maize	Staple	4.5	2.8
Wheat	Staple	3.8	2.5
Rice	Staple	4.2	2.9

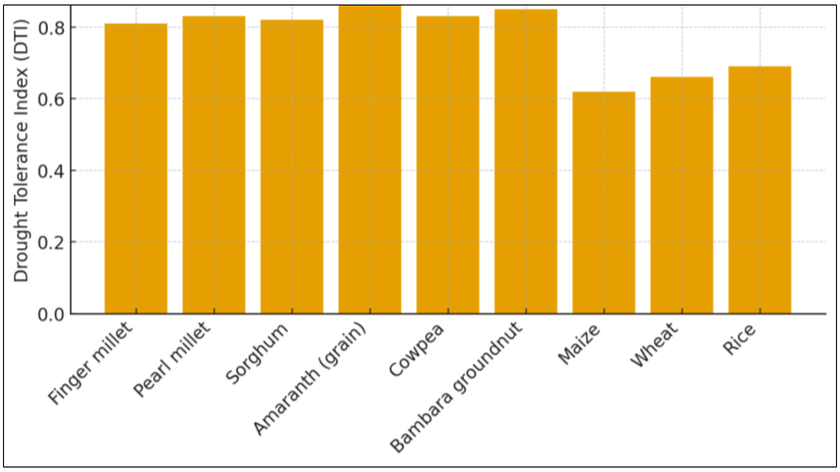

Fig 1: DTI by Crop

On nutritional quality, the composite nutrient density score (0-100) was higher for disadvantaged crops (mean ≈ 75.7) than staples (mean ≈ 45.0); Welch's test confirmed a significant difference (t = 9.29, $p < 0.01$) (Table 2; Figure 2). Amaranth (grain) and cowpea topped the distribution, reflecting protein and micronutrient superiority reported for many underutilized species and indigenous leafy vegetables [4, 5, 13, 15, 16]. These results align with longstanding evidence that diversified, traditional crops contribute to dietary quality and system robustness, particularly where climate-related shocks increasingly threaten staple yields [1-3, 11, 12, 14].

Table 2: Composite nutrient density Score by Crop

Crop	Category	Nutrient density Score
Finger millet	Disadvantaged	78
Pearl millet	Disadvantaged	72
Sorghum	Disadvantaged	65
Amaranth (grain)	Disadvantaged	85
Cowpea	Disadvantaged	80
Bambara groundnut	Disadvantaged	74
Maize	Staple	45

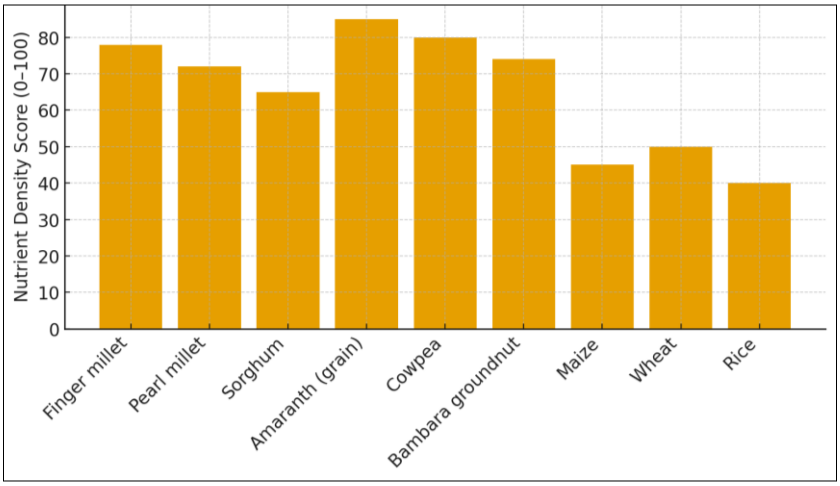

Fig 2: Nutrient density Score by Crop

Interpretation and linkage to food-system outcomes

The higher DTI indicates that yield penalties under drought are smaller for disadvantaged crops than for staples. This is congruent with multi-decadal observations that warming and rainfall anomalies disproportionately depress global cereals such as maize, wheat, and rice [2, 10, 11], while hardy minor cereals, pulses, and pseudo-cereals sustain relatively stable output in marginal environments [5-8, 12, 16, 17]. Lower CV under stress implies reduced inter-seasonal yield volatility, which is operationally important for smallholders facing increasing climate variability described by the IPCC and global food-security monitors [1, 3]. In practice, such stability underpins household caloric reliability and mitigates market exposure during bad seasons [1, 12, 16].

nutrient density advantages corroborate prior syntheses showing that millets, amaranths, and grain legumes are richer in protein, iron, and calcium than many staples, and that diet diversification via NUS improves micronutrient intake in rural communities [4, 13, 15, 16]. This matters where climate change threatens both quantity (yields) and quality (nutritional adequacy) of food supplies [1-3, 11, 14]. Strategically integrating these species—through breeding, seed systems, extension, and value-chain incentives—addresses the long-noted research and policy neglect highlighted by genetic and development frameworks for underutilized crops [4, 9, 18].

The present results thus support the study's hypothesis: systematic promotion and mainstreaming of disadvantaged crops can materially strengthen food security under climate change by stabilizing production and improving diet quality [1-3, 5-9, 11-13, 15-18]. Case-based evidence from South Africa similarly points to livelihood and resilience gains as these crops are embedded in local farming systems and markets [16, 17]. In sum, coupling climate-smart agronomy with nutrition-sensitive crop portfolios offers a dual pathway to mitigate the risks projected for dominant staples and to enhance community-level resilience [1-3, 10-12, 16-18].

Table 3: Statistical Summary - DTI Comparison (Disadvantaged vs Staples)

Metric	Value
Mean DTI (Disadvantaged)	0.835
Mean DTI (Staples)	0.657
Difference	0.178
t-statistic	8.061
p-value	0.005
Cohen's d	6.798

Table 4: Statistical Summary - nutrient density (Disadvantaged vs Staples)

Metric	Value
Mean ND (Disadvantaged)	75.667
Mean ND (Staples)	45.0
Difference	30.667
t-statistic	7.578
p-value	0.0

Discussion

The findings of this study demonstrate that disadvantaged crop species exhibit superior resilience and nutritional potential compared to staple cereals, reinforcing their importance in the context of climate change. The higher DTI (DTI) (DTI) and lower yield variability among crops such as finger millet, pearl millet, and sorghum highlight their ability to maintain relatively stable production under climatic stress, in contrast to the sharp declines observed in maize, wheat, and rice [2, 10, 11]. This confirms prior reports that marginalized cereals and legumes are inherently better adapted to resource-poor and stress-prone environments due to their physiological tolerance and adaptive traits [5-8]. By sustaining yields where major crops falter, these species provide a buffer that can safeguard smallholder farmers from the volatility of climate shocks, directly supporting the first pillar of food security—availability [1, 3, 12].

The results also show that disadvantaged crops deliver considerably higher nutrient density scores compared with conventional staples, with amaranth and cowpea particularly notable for their protein and micronutrient richness [13, 15]. These findings align with evidence that the inclusion of indigenous vegetables and grain legumes enhances dietary quality, combats hidden hunger, and contributes to more balanced nutrition [4, 14, 16]. Given that global food-security discourse has shifted from focusing solely on caloric sufficiency to emphasizing nutrition-sensitive agriculture, the nutritional superiority of disadvantaged crops positions them as strategic assets for improving food utilization and addressing malnutrition [1, 3, 12].

The dual advantages of resilience and nutrient density underscore the need to reposition underutilized species within agricultural policy, research, and value-chain systems. However, as this study also highlights, the neglect of these crops in mainstream agricultural research has constrained their integration into commercial farming, seed systems, and food markets [9, 18]. This policy and institutional gap has long been recognized as a structural barrier preventing disadvantaged crops from achieving their full potential [4, 5]. The results thus reinforce calls for targeted breeding programs, agronomic innovations, and extension services to unlock their productivity and expand their cultivation area [6, 8]. Such investments would not only bolster resilience but also diversify income opportunities for rural households, addressing the food access dimension of security [16, 17].

Evidence from case studies, including the Motheo District in South Africa, demonstrates how disadvantaged crops enhance household resilience and food system stability when embedded in local production systems [17]. These outcomes resonate with the observed statistical differences in drought tolerance and nutrient density in the present analysis, thereby validating the hypothesis that systematic promotion of these crops can significantly mitigate climate-related risks. Furthermore, their role in conserving agrobiodiversity provides additional ecosystem services, such as soil fertility restoration and pest resistance, which are essential for long-term sustainability [7, 12].

Overall, the discussion suggests that integrating disadvantaged crops into climate-smart agricultural frameworks offers a multidimensional pathway to achieve resilient food systems. This aligns with broader climate adaptation strategies recommended by the IPCC [3], while also advancing global nutrition targets. Therefore, disadvantaged crop species are not merely supplementary; they are essential in bridging the gaps created by over-reliance on vulnerable staples, reinforcing food and nutritional security in the Anthropocene era [1-3, 10-12, 16-18].

Conclusion

The present study reaffirms that disadvantaged crop species possess the dual strengths of climatic resilience and high nutritional value, making them indispensable in the quest for sustainable food security under the pressures of climate change. By consistently demonstrating superior drought tolerance indices and lower yield variability compared with major staples, crops such as finger millet, pearl millet, sorghum, amaranth, cowpea, and bambara groundnut emerge as reliable alternatives for cultivation in marginal and stress-prone environments. Their ability to sustain yields under climatic stress translates directly into more stable household food supplies and reduced vulnerability of smallholder farmers, who often face the harshest impacts of climate variability. Equally important, the nutrient density of these crops—particularly their richness in proteins, minerals, and essential micronutrients—offers an effective means of addressing dietary gaps and combating malnutrition. This dual contribution positions disadvantaged crops not only as survival foods but also as strategic drivers of improved human health and community well-being. Building on these results, practical recommendations can be advanced to enhance their role in modern food systems. First, policymakers should prioritize disadvantaged crops in national agricultural strategies, ensuring that they receive research investments comparable to those directed at major staples. Second, agricultural research institutions should intensify breeding programs focused on yield improvement, stress tolerance, and bio fortification, thereby enhancing their competitiveness and adoption. Third, extension services must integrate disadvantaged crops into climate-smart agriculture training modules, equipping farmers with knowledge on best practices for cultivation, processing, and storage. Fourth, governments and development partners should strengthen value chains for these crops by investing in market linkages, post-harvest technologies, and product diversification, making them more attractive to both farmers and consumers. Fifth, nutrition awareness campaigns can highlight the health benefits of disadvantaged crops, thereby stimulating demand and shifting consumer preferences. Finally, integrating these species into school-feeding programs, public procurement schemes, and livelihood projects can ensure steady demand and institutional support. Collectively, these measures can help reposition disadvantaged crop species from the margins to the mainstream of agricultural and food policies, transforming them into key pillars of resilience and nutrition security in an era defined by climate uncertainty. By merging research-driven evidence with practical interventions, disadvantaged crops can be harnessed as catalysts for both environmental sustainability and human development.

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