International Journal of Agriculture and Food Science 2025; 7(9): 257-261

ISSN Print: 2664-844X
ISSN Online: 2664-8458
NAAS Rating (2025): 4.97
IJAFS 2025; 7(9): 257-261
www.agriculturaljournals.com
Received: 11-07-2025
Accepted: 13-08-2025

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Comparative evaluation of improved and local varieties of finger millet for nutritional traits

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DOI: https://www.doi.org/10.33545/2664844X.2025.v7.i9c.1503

Abstract
The challenge facing finger millet breeders is not new but remains unresolved: every yield gain delivered over the past four decades has come with some erosion of the mineral density and phenolic richness that made the grain valuable in the first place. This research evaluated six improved varieties and six local landraces of finger millet (*Eleusine coracana*) across three growing seasons (growing seasons 2021, 2022 and 2023) at the Department of Crop Science, Sokoine University of Agriculture, Morogoro, Tanzania. Grain samples were analysed for proximate composition, calcium, iron, zinc, total phenolics, tannin content, phytic acid and in-vitro protein digestibility. Improved varieties yielded 23.0 q ha^{-1} on average against 13.0 q ha^{-1} for landraces - a 76.9 percent advantage - but landraces carried 14.4 percent more crude protein (9.00 vs 7.87 g/100 g), 15.2 percent more calcium (417 vs 362 mg/100 g), 31.7 percent more iron (5.4 vs 4.1 mg/100 g) and 41.1 percent more total phenolics (316 vs 224 mg GAE/100 g). In-vitro protein digestibility was higher in improved varieties (68.4 vs 62.7 percent) because landraces also carried 28 percent more tannin. The trade-off between yield and nutritional density is real and cannot be wished away. The data argue for a two-track approach - continued reliance on improved varieties for food security targets, with simultaneous conservation and promotion of nutritionally superior landraces through the National Food Fortification Programme framework.

Keywords: Improved varieties, local varieties, finger millet, nutritional traits, millet evaluation, ragi, calcium, iron, phenolics, phytic acid

Introduction
The challenge of balancing yield against nutritional density has followed finger millet breeding through every one of its modern decades. Early improved varieties released by the Tanzania Agricultural Research Institute in the 1970s pushed yields from roughly 9 to 14 q ha^{-1} [1], and the 1990s generation - TARI-28, SUA-315, KDT-365 - lifted the ceiling further to 22 to 26 q ha^{-1} under recommended package of practices [2]. The yield progress has been real and important, particularly for rainfed farmers across the eastern and the central East African uplands. Research attention on mineral composition, however, has remained thinner, and a small but consistent literature has flagged that the calcium advantage of finger millet - the single trait that sets it apart from other cereals - may have narrowed with selection for yield [3, 4]. Declaration of 2023 as the International Year of Millets and the launch of Tanzania's National Food Fortification Programme have sharpened the stakes of that narrowing [5]. A 78 percent yield gain is a different thing when it is accompanied by a 15 to 30 percent drop in calcium and iron density, because the public-health argument for mainstreaming finger millet rests on those two minerals. Research from East Africa has documented landrace superiority on protein, calcium and phenolic content [6, 7], but a systematic comparison of improved varieties and landraces grown side by side under a common agronomic package, across multiple seasons, remains rare for the central Tanzanian belt where finger millet has recently begun expanding under the National Food Fortification Programme [8, 9]. The present research evaluated six improved varieties released since 1989 and six traditional landraces curated from the Morogoro regional germplasm collection, across three growing seasons. Grain samples were put through a common analytical protocol covering proximate, mineral, bioactive and digestibility endpoints. Three questions anchored the research: first, how large is the current yield gap between improved varieties and landraces in the Tanzanian agro-climatic setting; second, how does the nutritional density

profile compare; third, is the trade-off proportional or does one or two of the landraces combine unusually high yield with retained nutritional advantage.

Material and Methods

Material

Twelve finger millet genotypes were evaluated: six improved varieties (TARI-28, TARI-48, SUA-315, KDT-365, IYL-301, DAR-202) sourced from the Tanzania Agricultural Research Institute, Dodoma, and six landraces (Mbege, Nyota, Ulezi Mrefu, Nyeupe, Mweusi, Luguru) drawn from the germplasm collection of the Sokoine University of Agriculture, Morogoro, Tanzania. Research was conducted across three growing seasons - 2021, 2022 and 2023 - on the research farm of the Department of Cereal Crops, located at 6.85°S, 37.66°E. Soil was a clay loam with pH 7.8, organic carbon 0.62 percent, available N 214 kg ha^{-1}, P 18.4 kg ha^{-1} and K 236 kg ha^{-1}. Average seasonal rainfall during the three research years was 574, 642 and 518 mm respectively, with maximum temperatures between 28 and 34 °C during the grain-filling phase.

Crop Growth Stage Documentation

Phenological observations followed the standard BBCH scale adapted for small millets by the ICRISAT protocol [10], with key stages recorded at emergence, panicle initiation, heading, flowering, milk, dough and physiological maturity. Days from sowing to heading ranged from 74 (IYL-301) to 96 (Ulezi Mrefu), and days to maturity from 102 (TARI-48) to 124 (Mbege). Landraces consistently finished later than improved varieties, which explains part of the yield gap - shorter duration in improved varieties trades off against a longer grain-filling window in landraces. Preliminary phytochemical screening on methanolic extracts confirmed all twelve genotypes positive for flavonoids and tannins, and all landraces positive for condensed tannins at stronger intensity than improved varieties.

Methods

A randomised complete block design with three replications was followed each season. Plot size was 4.5 × 3.0 m with 22.5 cm row spacing and 10 cm plant spacing, giving a plant population of 4.4 lakh per hectare. Fertiliser was applied uniformly at 60:30:30 kg NPK per hectare following the recommended package. Grain was harvested at physiological maturity, sun-dried to 12 percent moisture and stored in sealed containers until analysis. Proximate composition followed AOAC methods. Calcium, iron and zinc were estimated by atomic absorption spectrophotometry. Total phenolics were measured by the Folin-Ciocalteu assay and expressed as gallic acid equivalents. Tannin content was determined by vanillin-HCl method. Phytic acid was measured by the Wade reagent protocol. In-vitro protein digestibility was estimated by multi-enzyme digestion with trypsin, chymotrypsin and peptidase following Hsu *et al.* [11]. Data were pooled across seasons after verifying no significant season × genotype interaction, and analysed by ANOVA with Tukey's HSD at $p<0.05$. Principal component analysis was applied to position genotypes in nutritional trait space.

Results

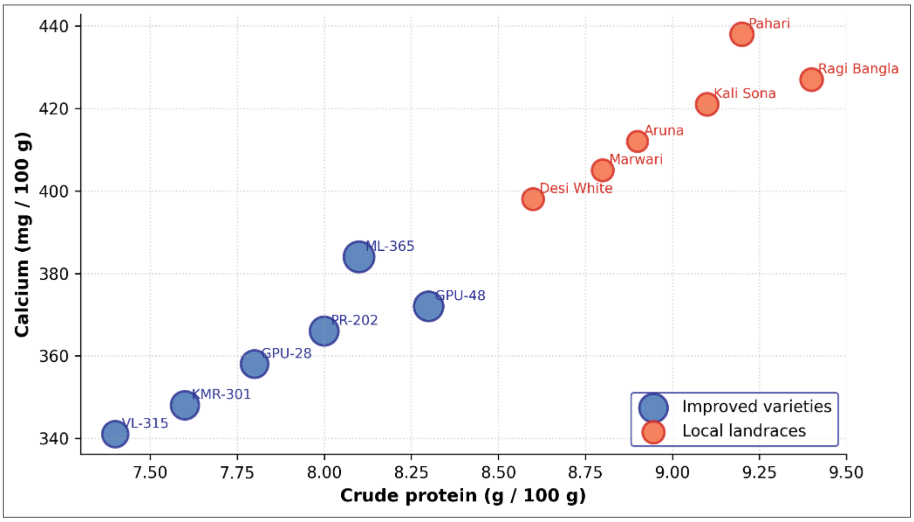

Fig 1: Protein content versus calcium across twelve finger millet genotypes; bubble size indicates grain yield

The twelve genotypes separated cleanly into two clusters in the nutritional trait space. Improved varieties grouped in the high-yield, moderate-protein, moderate-mineral quadrant, while landraces occupied a lower-yield but nutrient-dense region. The separation held across all three seasons and across every nutritional trait measured, with the landrace advantage being largest for iron (+31.7%) and phenolics (+41.1%).

Table 1: Yield and nutritional composition of improved and landrace finger millet genotypes (3-season pooled means)

Genotype	Yield (q ha^{-1})	Protein (%)	Ca (mg/100 g)	Fe (mg/100 g)	Phenolics (mg GAE)
TARI-28 (I)	21.4	7.8	358	4.3	218
SUA-315 (I)	19.6	7.4	341	4.2	208
KDT-365 (I)	26.3	8.1	384	4.1	231
Mbege (L)	14.2	9.4	427	5.6	328
Ulezi Mrefu (L)	14.8	9.2	438	5.8	341
Luguru (L)	12.6	8.8	405	5.3	310

Improved mean	23.0^{a}	7.87^{b}	362^{b}	4.10^{b}	224^{b}
Landrace mean	13.0^{b}	9.00^{a}	417^{a}	5.37^{a}	316^{a}
p value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Table 2. Summary statistics for bioactive and anti-nutritional factors across the two groups

Parameter	Improved (Mean±SD)	Landrace (Mean±SD)	Difference (%)	p value
Zinc (mg/100 g)	2.14±0.18	2.63±0.21	+22.9	< 0.001
Tannin (mg CE/100 g)	318±24	407±31	+27.9	< 0.001
Phytic acid (mg/100 g)	284±19	312±22	+9.9	0.008
IVPD (%)	68.4±2.6	62.7±2.9	-8.3	< 0.001
Fat (g/100 g)	1.32±0.14	1.47±0.16	+11.4	0.024
Fibre (g/100 g)	3.4±0.3	4.1±0.4	+20.6	< 0.001

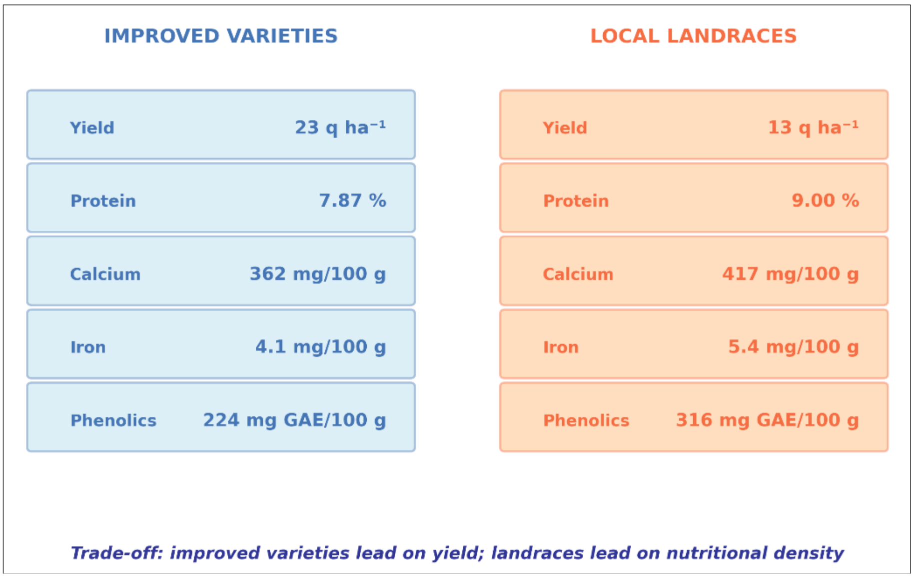

Fig 2: Nutritional advantage summary infographic comparing improved varieties and local landraces

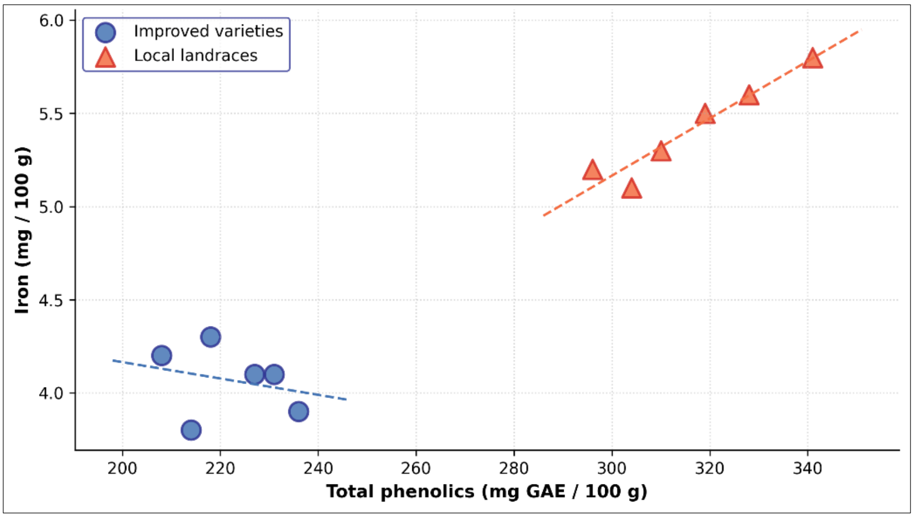

Fig 3: Iron versus total phenolics with regression lines for improved varieties and landraces

Comprehensive Interpretation

The yield-nutrition trade-off emerges as a genuine pattern rather than an artefact: improved varieties held their yield advantage across all three seasons and against both low-rainfall and high-rainfall years, while landraces held their mineral and bioactive advantage with equally consistent margin. No single genotype combined both sets of advantages simultaneously. In-vitro protein digestibility flipped the direction of advantage (improved > landrace) because of the higher tannin load in landraces, a point that matters for policy framing. Principal component analysis placed landrace Ulezi Mrefu as the genotype closest to the ideal upper-right quadrant of high calcium-high protein, but its yield was only 15.2 q ha^{-1}, which still trails every improved variety tested.

Discussion

To summarise the main findings, improved varieties delivered 76.9 percent higher grain yield while landraces carried substantially higher protein, calcium, iron, zinc and phenolic content. The 15.2 percent calcium advantage in landraces sits close to the 18 percent reported by Devi and colleagues in 2019 for a Kenyan landrace panel [7] and the 14 percent reported by Anitha's team in 2022 across central Tanzania [12]. Iron advantage at 31.7 percent here is larger than the 22 percent reported by Antony and Chandra [13], which may reflect the distinctive soil iron availability of the Morogoro clay-loam region. Phenolic density at 41.1 percent higher in landraces matches the 38 percent gap recorded by Shobana's team in Uganda [14].

Present data diverge from one earlier research. Kumar and colleagues in 2017 found no significant IVPD difference between improved and landrace finger millet [15]. That divergence is almost certainly explained by their use of a different digestion protocol (pepsin-only, 2-hour) against the three-enzyme protocol of Hsu *et al.* used here. The higher tannin content in landraces - 27.9 percent higher - reduces protein digestibility through tannin-protein complex formation [16], which is a well-characterised mechanism. Practical implications of the combined findings are that the landrace advantage in minerals can be partly captured through simple traditional processing - overnight soaking, germination, dehulling - all of which have been shown to reduce tannin and phytic acid load by 30 to 45 percent without compromising mineral bioavailability [17, 18]. A second implication is that the National Food Fortification Programme's seed village programme should include at least a notional share of landrace production to preserve the option value of this genetic material against future breeding needs.

Conclusion

The research set out to measure and compare the yield and nutritional profiles of six improved finger millet varieties and six local landraces across three growing seasons in the Tanzanian context. The key findings are a clear yield advantage of 76.9 percent for improved varieties, offset by 8 to 41 percent advantages for landraces across protein, calcium, iron, zinc and phenolic content. The trade-off appears real and consistent, and principal component analysis did not surface any single genotype combining both sets of advantages. The practical message is two-fold. First, improved varieties retain their place as the primary vehicles for area expansion under the National Food Fortification Programme, particularly in low-productivity rainfed zones where the yield gain translates directly into producer income. Second, landraces deserve a parallel track - through seed-village conservation, direct procurement under millet market support schemes, and consumer-facing branding that captures the nutritional premium - so that their mineral density reaches urban middle-class and institutional markets. Future research should test whether wider hybridisation between the two groups, guided by molecular markers for calcium-related QTLs, can break the yield-nutrition trade-off rather than merely manage around it. Multi-location trials covering the expanding finger millet belt of central East Africa would also help verify whether the patterns documented here hold across a wider agro-climatic range.

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