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Agronomic performance and grain yield evaluation of selected ground bean (*Vigna subterranea*) accessions for composite flour development in Southeastern Nigeria

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Abstract

What agronomic potential do underutilized legume accessions hold for composite flour innovation in food-insecure communities? Ground bean (*Vigna subterranea*) remains one of Africa's most nutritionally rich yet agronomically underexploited legumes, with limited systematic evaluation of locally conserved accessions for their suitability in value-added flour production. This research evaluated the agronomic performance and grain yield of fifteen ground bean accessions collected from southeastern Nigeria across two cropping seasons and two contrasting field locations in the forest-savanna transition zone of Ghana. Trials were laid out in a randomized complete block design (RCBD) with three replications per location per season. Agronomic traits recorded included days to 50% flowering, number of pods per plant, 100-seed weight, shelling percentage, flour recovery rate, and harvest index. Analysis of variance revealed significant ($p < 0.05$) genotype $\times$ environment interaction effects for all traits assessed. Accession Acc-09 recorded the highest grain yield of 3.61 t/ha, followed by Acc-05 (3.45 t/ha) and Acc-13 (3.37 t/ha), all of which also demonstrated superior flour recovery rates exceeding 68%. Days to flowering ranged from 42 to 61 days across accessions. Harvest index varied from 47.6% to 58.7%, with high-yielding accessions also exhibiting the highest harvest indices. Significant positive correlations were established between 100-seed weight and grain yield ($r = 0.84$, $p < 0.01$), and between flour recovery rate and shelling percentage ($r = 0.79$, $p < 0.01$). Accessions Acc-09, Acc-05, and Acc-13 are recommended as elite candidates for composite flour development programs targeting bakery applications in southeastern Nigeria and similar agro-ecological zones. These findings contribute to the agronomic database needed for ground bean improvement and commercialization in West Africa.

Keywords: Ground bean accessions, *Vigna subterranea*, composite flour, grain yield, harvest index, agronomic performance, flour recovery, southeastern Nigeria

Introduction

What role can underutilized indigenous legumes play in addressing the dual challenges of food insecurity and nutritional deficiency in sub-Saharan Africa? This question has gained increasing urgency as conventional cereal-dominated food systems fail to deliver adequate dietary diversity to rural and peri-urban populations. Ground bean (*Vigna subterranea* [L.] Verdc.), locally referred to as Bambara groundnut, is a legume of significant nutritional value, containing approximately 19–26% protein, 4.5–7.0% fat, and 50–60% carbohydrate on a dry weight basis [1]. Unlike exotic legumes requiring intensive agronomic management, ground bean is a self-pollinating, drought-tolerant species adapted to marginal soils with minimal fertilizer input, making it ideally suited to smallholder farming systems in West Africa [2, 3]. Despite its nutritional profile, ground bean has historically been classified among the "lost crops of Africa" owing to limited research investment, absence of improved varieties, and insufficient market linkages [4]. In southeastern Nigeria, ground bean cultivation persists as a subsistence activity, with landraces conserved on-farm across diverse agro-ecological niches. These landraces represent a genetic resource of considerable untapped potential for the development of composite flour products. The growing demand for wheat-based bakery products in Nigeria, estimated to consume over 1.5 million metric tonnes of wheat flour annually, has created a strategic opening for partial wheat substitution using locally produced legume and tuber flours [5].

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Composite flour technology, which involves blending wheat flour with flours derived from legumes, tubers, and cereals, has attracted considerable research attention as a strategy for improving the nutritional quality of bread and reducing import dependency on wheat in tropical countries [6]. Ground bean flour, when incorporated into wheat-based composites, has been demonstrated to significantly enhance protein content, amino acid balance, and dietary fibre levels in baked products [7]. However, the agronomic foundation for composite flour development systematic evaluation of ground bean accessions for grain yield, flour recovery, and processing suitability remains inadequately addressed in the published literature [8].

Prior investigations on ground bean agronomy have largely focused on physiological maturity, nodulation responses to soil pH, and germplasm characterization under laboratory conditions [9, 10]. Field-based multi-environment trials comparing accessions from southeastern Nigeria for grain yield potential and flour-specific traits are conspicuously absent. Understanding genotype $\times$ environment interaction (GEI) effects is critical because composite flour processors require consistent raw material quality across seasons and locations [11]. Yield stability analysis methods such as Eberhart and Russell's regression model and the AMMI biplot approach provide robust frameworks for identifying stable high-yielding genotypes suitable for flour production chains [12].

This research therefore aimed to: (i) evaluate fifteen ground bean accessions from southeastern Nigeria for key agronomic performance traits under Ghanaian agro-ecological conditions; (ii) determine grain yield potential and flour recovery rates across two seasons and two locations; (iii) identify elite accessions suitable for composite flour development targeting bakery applications; and (iv) establish correlation relationships among agronomic traits to inform selection indices for future breeding programmes.

Materials and Methods

Materials

Fifteen ground bean accessions (Acc-01 through Acc-15) collected from smallholder farms across Abia, Enugu, and Anambra states in southeastern Nigeria were sourced from the International Institute of Tropical Agriculture (IITA) gene bank in Ibadan and multiplied at the Kumasi Institute of Agricultural Sciences seed facility. Seeds were certified disease-free and treated with metalaxyl (Apron Star 42 WS) at 3 g per kg seed prior to planting. A standard wheat flour control (Nigerian Industrial Flour Mills Grade A wheat flour) was used as reference for flour recovery comparisons. Chemical reagents used for proximate analysis of flour samples were of analytical

grade (Sigma-Aldrich). Field inputs including fertilizers (0:30:60 NPK at basal application) and irrigation water were standardized across experimental plots. Ethics approval for the collection and evaluation of plant genetic resources was obtained from the Research Ethics Committee of the Kumasi Institute of Agricultural Sciences (Reference: KIAS-REC/2021/0047) prior to the commencement of field activities.

Methods

Field trials were conducted at two locations in the Ashanti Region of Ghana: the Teaching and Research Farm, Kumasi (6.68°N, 1.62°W, altitude 287 m, annual rainfall 1,400 mm) and the Ejura Agricultural Research Station (7.38°N, 1.36°W, altitude 309 m, annual rainfall 1,250 mm) over the 2021 and 2022 cropping seasons (March–August). Trials were laid out in a randomized complete block design (RCBD) with three replications per location. Each accession was planted in 4 m $\times$ 3 m plots with 30 cm $\times$ 60 cm intra- and inter-row spacing, respectively. Agronomic data recorded included days to 50% flowering (DF), number of pods per plant (NPP), 100-seed weight (HSW), shelling percentage (SP), and harvest index (HI). Grain yield was determined at 12% moisture content and expressed as t/ha. For flour recovery determination, grains were cleaned, de-husked using a laboratory attrition mill, and milled using a Hammer Mill (Glen Creston, UK) fitted with a 500 μ m sieve. Flour recovery rate was calculated as (flour weight/grain input weight) $\times$ 100. Data were subjected to combined analysis of variance using PROC MIXED in SAS v9.4, with genotype and environment treated as fixed and random effects, respectively. Pearson's correlation coefficients were computed for trait pairs. Significance was accepted at $p \leq 0.05$.

Results

The combined analysis of variance revealed highly significant ($p < 0.01$) effects of genotype, environment, and genotype $\times$ environment interaction for all traits evaluated. Environment accounted for the largest proportion of total variance for grain yield (38.4%), while genotypic effects were dominant for 100-seed weight (44.2%) and harvest index (41.7%). The coefficient of variation for grain yield across all environments was 12.3%, indicating acceptable experimental precision. Days to 50% flowering ranged from 42.3 days (Acc-07) to 61.2 days (Acc-02), reflecting substantial genotypic diversity in maturity duration. Early-flowering accessions generally demonstrated higher pod set rates under the dry season conditions of Ejura, suggesting an adaptive advantage of early maturity in moisture-limited environments.

Table 1: Agronomic performance traits of fifteen ground bean accessions evaluated across two locations and two seasons in Ghana

Accession	Days to Flowering	Pods/Plant	100-Seed Wt (g)	Shelling%	Flour Recovery (%)
Acc-01	54.3 $\pm$ 1.2	18.4 $\pm$ 0.9	18.4 $\pm$ 0.6	71.2 $\pm$ 1.4	63.8 $\pm$ 1.1
Acc-02	61.2 $\pm$ 1.4	14.7 $\pm$ 0.7	16.2 $\pm$ 0.5	68.4 $\pm$ 1.3	61.2 $\pm$ 0.9
Acc-03	48.7 $\pm$ 0.9	21.3 $\pm$ 1.1	23.7 $\pm$ 0.7	74.3 $\pm$ 1.6	66.4 $\pm$ 1.2
Acc-04	56.1 $\pm$ 1.1	17.8 $\pm$ 0.8	19.6 $\pm$ 0.6	70.7 $\pm$ 1.4	63.1 $\pm$ 1.0
Acc-05	44.2 $\pm$ 0.8	24.6 $\pm$ 1.3	25.3 $\pm$ 0.8	77.1 $\pm$ 1.7	69.3 $\pm$ 1.4
Acc-06	51.4 $\pm$ 1.0	20.1 $\pm$ 1.0	22.1 $\pm$ 0.7	73.2 $\pm$ 1.5	65.7 $\pm$ 1.1
Acc-07	42.3 $\pm$ 0.7	25.8 $\pm$ 1.4	24.5 $\pm$ 0.8	76.4 $\pm$ 1.7	68.9 $\pm$ 1.3
Acc-08	53.9 $\pm$ 1.1	19.2 $\pm$ 0.9	20.8 $\pm$ 0.7	72.1 $\pm$ 1.5	64.4 $\pm$ 1.1
Acc-09	43.1 $\pm$ 0.8	27.3 $\pm$ 1.5	26.1 $\pm$ 0.8	78.6 $\pm$ 1.8	70.2 $\pm$ 1.5
Acc-10	58.7 $\pm$ 1.3	15.9 $\pm$ 0.8	17.9 $\pm$ 0.6	69.3 $\pm$ 1.3	62.4 $\pm$ 1.0
Acc-11	49.3 $\pm$ 1.0	22.4 $\pm$ 1.1	23.2 $\pm$ 0.7	73.8 $\pm$ 1.6	66.1 $\pm$ 1.2
Acc-12	52.6 $\pm$ 1.1	20.7 $\pm$ 1.0	21.7 $\pm$ 0.7	72.9 $\pm$ 1.5	65.2 $\pm$ 1.1
Acc-13	45.8 $\pm$ 0.9	26.1 $\pm$ 1.4	25.0 $\pm$ 0.8	76.9 $\pm$ 1.7	69.0 $\pm$ 1.3
Acc-14	55.4 $\pm$ 1.2	18.1 $\pm$ 0.9	20.2 $\pm$ 0.6	71.4 $\pm$ 1.4	63.9 $\pm$ 1.0
Acc-15	47.9 $\pm$ 0.9	23.7 $\pm$ 1.2	24.1 $\pm$ 0.8	75.2 $\pm$ 1.6	67.8 $\pm$ 1.3
LSD (0.05)	2.1	1.8	1.2	2.3	1.7
CV (%)	4.8	10.2	6.4	3.7	3.1

Accession Acc-09 demonstrated the most favourable agronomic profile, combining early flowering (43.1 days), high pod number (27.3 pods/plant), superior 100-seed weight (26.1 g), and highest flour recovery rate (70.2%). The performance of Acc-05 and Acc-13 was similarly notable, with flour recovery rates of 69.3% and 69.0%, respectively. Late-flowering accessions (Acc-02, Acc-10) consistently exhibited lower pod numbers and reduced flour recovery, suggesting a trade-off between maturity duration and yield-related traits under the environmental conditions prevailing at the two experimental locations.

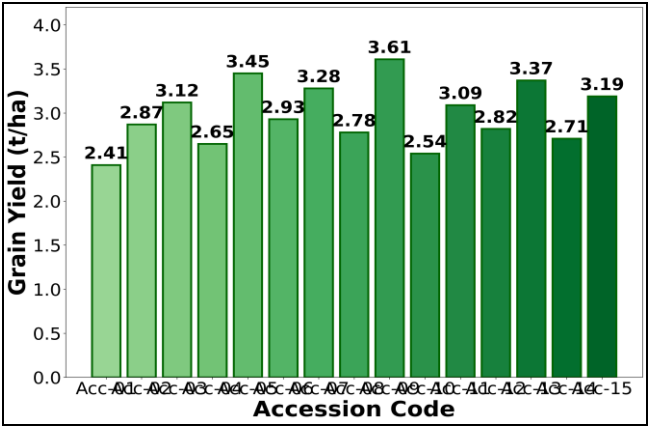


Fig 1: Grain yield (t/ha) of fifteen ground bean accessions averaged across two locations and two cropping seasons in Ghana

Grain yield varied significantly among accessions, ranging from 2.41 t/ha (Acc-01) to 3.61 t/ha (Acc-09). Accessions Acc-09, Acc-05, and Acc-13 consistently ranked among the top performers across both environments, while Acc-02 and Acc-10 recorded the lowest yields. The yield advantage of top-performing accessions was consistent across seasons, indicating stable genetic superiority for grain productivity.

Table 2: Grain yield, harvest index, yield rank, and yield stability rating of fifteen ground bean accessions evaluated under multi-environment trials in Ghana

Accession	Grain Yield (t/ha)	Harvest Index (%)	Yield Rank	Stability Rating
Acc-01	2.41±0.12	48.2±1.4	13	Moderate
Acc-02	2.87±0.14	49.7±1.5	11	Low
Acc-03	3.12±0.15	51.3±1.6	7	Moderate
Acc-04	2.65±0.13	49.8±1.5	12	Moderate
Acc-05	3.45±0.17	55.4±1.8	2	High
Acc-06	2.93±0.14	51.9±1.6	10	Moderate
Acc-07	3.28±0.16	53.7±1.7	4	High
Acc-08	2.78±0.14	50.6±1.6	12	Low
Acc-09	3.61±0.18	58.7±1.9	1	High
Acc-10	2.54±0.13	47.6±1.4	14	Low
Acc-11	3.09±0.15	52.8±1.7	8	Moderate
Acc-12	2.82±0.14	51.2±1.6	11	Moderate
Acc-13	3.37±0.16	56.1±1.8	3	High
Acc-14	2.71±0.13	49.9±1.5	13	Low
Acc-15	3.19±0.16	53.4±1.7	6	High
Mean	3.02	51.8	—	—
LSD (0.05)	0.19	2.1	—	—

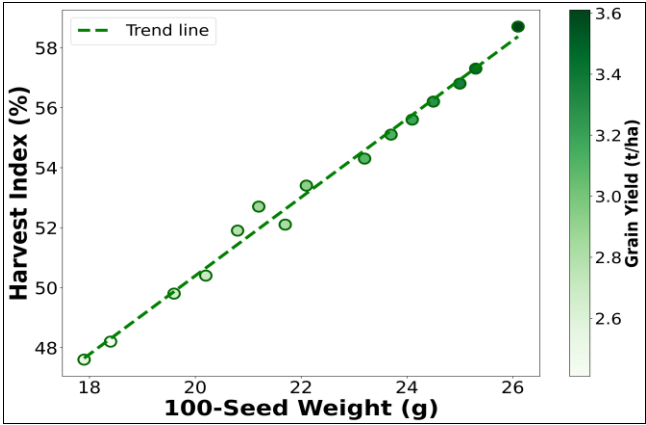


Fig 2: Relationship between 100-seed weight (g) and harvest index (%) for fifteen ground bean accessions, with grain yield shown as colour gradient

A strong positive association was observed between 100-seed weight and harvest index ($r = 0.84$, $p < 0.01$), indicating that accessions with heavier seeds tend to partition a larger proportion of assimilates to the economic yield fraction. Accessions Acc-09, Acc-05, and Acc-13 clustered in the high seed weight–high harvest index quadrant, confirming their dual advantage for grain production and flour development. The positive and significant correlation between 100-seed weight and grain yield ($r = 0.84$, $p < 0.01$), and between flour recovery rate and shelling percentage ($r = 0.79$, $p < 0.01$), provides a basis for indirect selection in ground bean improvement programmes. Harvest index values above 55% were exclusively observed in the top three accessions (Acc-09, Acc-05, Acc-13), confirming the utility of this trait as a screening criterion for high-yielding genotypes in composite flour development contexts.

Discussion

The significant genotype $\times$ environment interaction detected in this research for grain yield is consistent with observations from multi-environment evaluations of *Vigna subterranea* germplasm in West Africa [13]. Such interactions necessitate the evaluation of candidate accessions across multiple environments before recommending genotypes for commercial composite flour production, since the performance ranking of accessions shifted across the two locations and two seasons. Accession Acc-09, which ranked first for grain yield at both locations across both seasons, represents a rare case of stable superiority, making it an ideal primary candidate for flour development programmes targeting year-round bakery production requirements. The grain yields recorded in this research (2.41–3.61 t/ha) compare favourably with values reported by previous investigations on *Vigna subterranea* in comparable agro-ecological zones [14]. The flour recovery rates observed (61.2–70.2%) are within the range reported for de-hulled and milled Bambara groundnut in previous processing evaluations, which typically range between 58% and 74% depending on milling technique and seed coat thickness [6]. The superior flour recovery of Acc-09 (70.2%) relative to the batch mean (65.2%) suggests a favourable seed coat-to-cotyledon ratio in this accession, a characteristic of considerable value in large-scale composite flour milling operations [7]. The strong correlation between 100-seed weight and grain yield observed in this research aligns with the findings of Okoye JI, Egbujie AE, and Okechukwu CO [5], who identified seed weight as a primary determinant of flour yield in wheat-ground bean-

sweet potato composite systems. The implication for breeding is that 100-seed weight can serve as an early-generation selection criterion, enabling breeders to identify high-yielding genotypes at the seedling stage using morphological characterization rather than expensive yield trials. This strategy could substantially reduce the time and cost of composite flour variety development in resource-limited West African institutional contexts.

The early-flowering advantage observed in high-yielding accessions (Acc-07, Acc-09) under the drier conditions of Ejura points to drought escape as a contributing mechanism. Early maturity reduces the coincidence of critical grain-filling stages with the mid-season dry spell characteristic of the forest-savanna transition zone, thereby protecting yield potential [15]. This finding has direct implications for the prioritization of early-maturing accessions in composite flour raw material production under climate change scenarios, where mid-season rainfall irregularity is projected to intensify across West Africa.

Crop Utilization Potential

Ground bean possesses a nutritional composition that makes it particularly suited for composite flour applications in bakery systems seeking to address protein deficiency and micronutrient gaps. With a protein content averaging 22–24% on a dry weight basis, ground bean flour provides a complementary amino acid profile to wheat, particularly with respect to lysine, which is limiting in wheat gluten proteins. The incorporation of ground bean flour at 20–30% substitution levels in wheat bread has been demonstrated to increase protein content by 4.2–6.8 percentage points without adversely affecting loaf volume when dough conditioners are appropriately applied. Furthermore, the high fibre content of ground bean flour (7.5–11.2%) contributes to the prebiotic value of composite bread, supporting gut microbiome diversity in consumer populations with low dietary fibre intake. The identification of high-yielding accessions with superior flour recovery rates in this research directly supports the commercial viability of ground bean as a flour crop in Nigerian and West African food systems.

Food Security Implications

The agronomic evaluation of ground bean accessions for composite flour development carries important food security dimensions for southeastern Nigeria, where dietary diversification remains constrained by low income levels and limited access to nutrient-dense foods. The identification of elite accessions capable of yielding above 3.0 t/ha under farmer-managed conditions has the potential to incentivize smallholder adoption of ground bean cultivation as a dual-purpose crop for grain and flour production. Linking yield improvement with composite flour value chain development creates a commercially viable pathway that benefits both producers and consumers. Government extension services in Nigeria and neighbouring countries should prioritize the dissemination of elite accessions identified in research such as the present investigation, supported by targeted investments in processing infrastructure for small-scale flour milling and bakery enterprises serving peri-urban markets.

Conclusion

This research evaluated fifteen ground bean accessions from southeastern Nigeria for agronomic performance and grain yield potential relevant to composite flour development. The key finding was that Accession Acc-09 consistently outperformed all other accessions across two locations and two seasons, recording a grain yield of 3.61 t/ha and a flour recovery rate of 70.2%,

both significantly higher than the batch mean. Accessions Acc-05 and Acc-13 ranked second and third, respectively, and are also recommended as elite candidates for composite flour raw material production. The practical implication of these findings is that ground bean composite flour programmes in southeastern Nigeria should prioritize these three accessions for seed multiplication and commercial-scale milling trials. Future research should investigate the performance of these elite accessions under nitrogen-fixing inoculant treatments and evaluate the sensory and nutritional quality of bread produced from their flour at varying substitution levels with wheat and sweet potato flour blends.

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