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Original Research

The Impact of Plant Spacing and Landraces on the Growth and Yield Traits of Bambara Groundnut (*Vigna subterranea*) in the Field

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Abstract

Bambara groundnut production and research ignored at one's risk, considering that this hardy crop yields well in mixed cropping, marginal lands, and off-season. To investigate effect of plant spacing x landraces, a replicated randomized complete block design was utilized. The treatment set consisted of two Bambara groundnut landraces (i.e., Ikwo Landrace-1 = V1 and Nsukka Landrace-2 = V2) and three plant spacing: P1 = 12 x 45 cm^2, P2 = 20 x 45 cm^2, and P3 = 55 x 45 cm^2 equivalent to 182,149; 111,334, and 40,485 plants ha^{-1}, respectively. Shoot height and petiole length were not significantly different. Significant differences existed between the number of leaves at 4 and 6 weeks after sowing. Plant spacing2 x Landrace-1 interaction produced significantly more 100-seed weight (287.6 g), followed by Plant spacing1 x Landrace-1 (248.1 g) and Plant spacing2 x Landrace2 (190.6 g). Landrace-1 produced a higher 100-seed weight (239.19 g), compared to Landrace-2 (126.63 g). Plant spacing 2 produced more 100-seed weight (239.08 g) followed by Plant spacing 3 (196.87 g). Seed yield from Plant spacing2 x Landrace-1, Plant spacing3 x Landrace-1, and Plant spacing1 x Landrace-1 (2330.4, 2127.2, and 1049.4 kg ha^{-1}, respectively) were significantly higher compared to the other treatments. Landrace-1 produced a higher seed weight (1835.66 kg ha^{-1}) compared to Landrace-2 (911.2 kg ha^{-1}). Plant spacing 2 produced more seed weight (1638.8 kg ha^{-1}), followed by Plant-spacing 3 (1586.52 kg ha^{-1}). Finally, Plant spacing2 followed by plant spacing3 and Landrace-1 are highly recommended for Ebonyi State, southeastern Nigeria.

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INTRODUCTION

When given optimal agronomic attention, Bambara groundnut (*Vigna subterranea* syn. *Voandzeia subterranea*) can return to the popular prominence that it enjoyed before the coming of oil-rich legumes like groundnut and soybean (Goli *et al*., 1991; Obidiebube *et al*., 2019). Bambara groundnut was popular because it fed the natives, while oil-rich legumes feed the industry and exotic demand. Thus, Bambara groundnut became an orphan crop, yet it is still widely cultivated from the edge of the Sahara desert through the Kalahari desert down to the grasslands of South Africa, Asia, and the Americas (Ntundu *et al*., 2004; Rungnoi *et al*., 2012; Mayes *et al*., 2019; Obidiebube *et al*., 2022; Temege *et al.,* 2018; Wongwichaiwat *et al*., 2023).

Bambara groundnut is the third most important grain legume after groundnut and cowpea in Sub-Saharan Africa. The global yield of Bambara groundnut in 2006 was 330,000 metric tonnes, and West Africa accounted for 45-50% of this yield (Brink *et al*., 2006). The world seems to have produced less Bambara groundnut in 2018-2021, with only 200 000 metric tonnes of seeds harvested (Majola *et al*., 2021). Bambara groundnut is a hardy legume that can thrive effectively in low rainfall and soil fertility (Adzawla *et al*., 2016; Olayide *et al*., 2018; Boukar *et al*., 2019; Olanrewaju *et al*., 2021; Ajilogba *et al*., 2022; Bitire *et al*., 2023; Khan *et al*., 2024; Ndifon *et al*., 2025).

Bambara groundnut is a complete foodstuff that can be cooked, toasted, fried, steamed, or used to enrich other diets. Its seeds contain lots of carbohydrates, protein, fibre, fat, calories, alkaloids, flavonoids, saponins, phenols, carotenoids, and anthocyanins. Moreover, it is rich in calcium, iron, potassium, phosphorus, manganese, and methionine. Bambara groundnut is a common beverage seed, hay, and traditional medicinal resource (Bamshaiye *et al.*, 2011; Olukolu *et al*., 2012; Mazahib *et al*., 2013; Marcel *et al*., 2014; Mune and Sogi, 2015; Gerrano *et al*., 2021; Wongwichaiwat *et al*., 2023; Khan *et al*., 2024). This crop fixes nitrogen nutrients in association with root-nodulating bacteria (Babalola *et al*., 2017; Halimi *et al*., 2019; Bitire *et al*., 2023).

In spite of its various accolades, this crop is plagued with severe biotic, abiotic, and socio-economic constraints stemming from sub-optimal agronomic practices, pest and disease pressure, inadequate soil nutrients, unimproved varieties, stigmatization as food for the poor or crop for women, low research interest, and high rate of self-pollination (Boukar *et al*., 2019; Ndifon *et al*., 2025).

Some researchers have observed that increasing plant population density results in high Bambara groundnut pod and grain yield. Obidiebube *et al*. (2019) reported that a spacing of 15 x 30 cm^2 resulted in the highest yield of 3,920 kg ha^{-1} while a spacing of 45 x 30 cm^2 produced the least yield of 2,478 kg ha^{-1}. The closely spaced plants produced more number of pods, pod and seed weights per plant, and seed yield kg ha^{-1}, as well as better suppression of weeds by the canopy. Obidiebube *et al.* (2019) reported that the spacing of 45 x 30 cm^2 had the least pod and seed weights per plant, with the mean value of 23.3 and 21.7 g, respectively.

Gunri *et al*. (2010) reported that plant spacing of 30 x 10 cm^2 significantly increased both the pod and kernel yield of Bambara groundnut. Berchie (2010) also recounted pod and seed yields of 4,600 and 3,400 kg ha^{-1}respectively. Normally, Bambara groundnut yield vary between 650-850 kg ha^{-1}, but, Collinson *et al*. (1996) reported Bambara groundnut yields of up to 4,100 kg ha^{-1}.

Berchie (2010) reported that the Nav-4 Landrace (at 50 x 20 cm^2) produced significantly more pod yield. Research on Bambara groundnut plant spacing in the rainforest zone in West Africa is rare since its cultivation there is new (Obidiebube *et al*., 2019; Feldman *et al*., 2019).

A good understanding of the role of plant population density is vital in determining factors influencing growth and yield parameters of Bambara groundnut with respect to various varieties' nutrient utilization and yield optimization. An optimum plant population is necessary for achieving increased seed yield. Based on this background information, this research was embarked on to assess the effect of plant spacing x landraces on the growth and yield parameters of Bambara groundnut landraces.

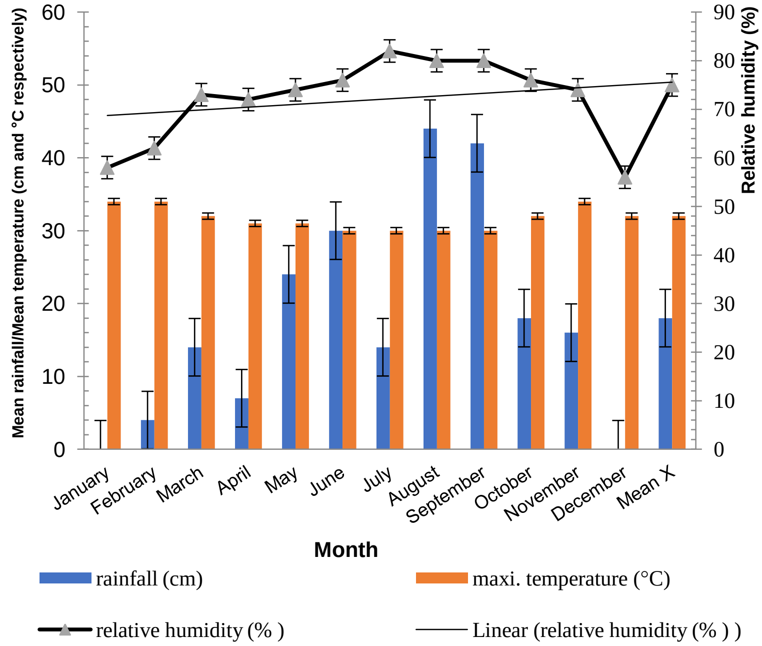
Materials and Methods

Study area

This rain-fed study was carried out at the Faculty of Agriculture Teaching and Research Farm, Alex Ekwueme Federal University, Ndufu-Alike, Abakaliki (area: 6.069˚N by 8.199˚E), Ebonyi State. Abakaliki soils are hydromorphic and contain lots of ironstone concretions derived from shales. The soils are red-brown coloured nevertheless gradually turning towards pale-clayey-coloured soils. In this study, the soil at the study sites had the following physical properties: sand amounted to 59.6%, silt accounted for 24.8%, and clay constituted 15.6% of the soil.

While the chemical properties of the soil included pH of 6.30, Nitrogen was 0.112%, Organic Carbon was 1.01%, Phosphorus stood at 06.50 mg/kg, Organic matter at 1.74%, Calcium was 1.65 mg/kg, Magnesium was 0.98 mg/kg, Potassium stood at 0.612 mg/kg, Sodium was at 0.251 mg/kg, Exchangeable Anions at 0.24 mg/kg, Exchangeable Cation Exchange Capacity stood at 3.733 mg/kg, and Base Saturation stood at 94%. The soil type in Ebonyi State was classified as Inceptisol (USDA) or Cambisol (FAO).

The essential vagaries of climate for crop production in the site are presented in Figure 1. Ebonyi State is located in the derived semi-humid savannah ecological zone with lush tropical vegetation.



Source:: modified from Ndifon (2022)

Figure 1: Climate pattern for Abakaliki showing temperature and rainfall distributions

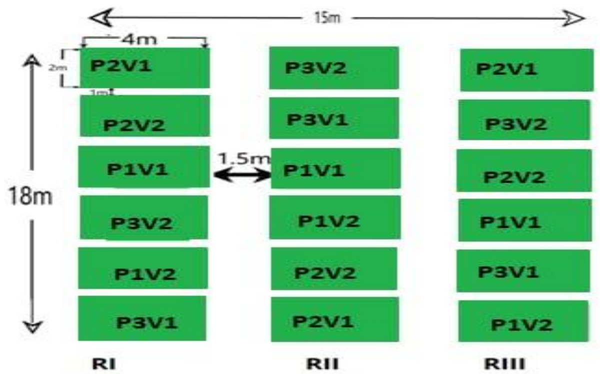
Ecological requirements for Bambara groundnut production

Bambara groundnut prefers warm, dry, marginal soils, from sea level up to 2,000 m above sea level. Bambara groundnut has an optimal temperature requirement between 30-35°C for germination and 20-28°C for normal growth. It is a sun-loving crop. It does well at even low rainfall of 600-750 mm per annum, but the most acceptable yields are obtained at higher rainfall, even up to above 2,000 mm annual rainfall. Thus, in well-drained soils, Bambara groundnut yields well. Bambara groundnut requires enough phosphorus and potassium in the soil. Mild sandy loam soil with a pH of 5.0-6.5 is preferable (Brink *et al*., 2006).

Land Preparation and Materials

The site was cleared with a tractor, and a composite soil sample was collected from different mapped units from the site, air dried for a week, and taken to the soil science laboratory for physical and chemical soil analysis. The seed beds were made manually using a 90 cm width per bed within each plot measuring 4 x 2 m^2.

The seeds were obtained from Eungu and Ebonyi State (i.e., Nsukka Bambara groundnut landrace 2 (V2) and Ikwo Bambara groundnut landrace 1 (V1), respectively). Seed viability and germination tests were carried out on the seeds to determine the suitability of the seed lot. Two seeds were sown per hill and thinned to one seedling per hill two weeks later. All recommended agronomic practices for high yield of Bambara groundnut were adopted. Seeds were sown on the beds at different plant spacing for each variety: P1 was 12 x 45 cm^2, P2 was 20 x 45 cm^2, and P3 was 55 x 45 cm^2 per plot, equivalent to 182,149; 111334, and 40,485 plants ha^{-1}, respectively (Figure 2).



P = plant spacing, V = landrace

Figure 2. The layout of the field plots shows the combinations of the two factors.

Experimental design

The rain-fed field utilized for the experiment was pegged out using a randomized complete block design (RCBD). The six treatments consisted of factorial combinations of the two landraces/varieties x the three plant spacing. Each plot had a 1 m pathway around it, as shown in Figure 2.

Data Collection

Data were collected on the following parameters. Five plants were randomly selected/tagged from the centre of each experimental unit. Plant height (cm) was measured from the ground level (at the base of the plant) to the tip of the highest point, including the terminal leaflet. The number of leaves per plant was recorded by counting from 4-12 weeks after sowing (WAS). The total number of pods per plant was taken by counting the pods after harvest. The seed fresh weight (g) per treatment was obtained at harvest using Mettler weighing balance, and the dry seed weight was recorded after drying the pods to 12% moisture content.

The days to 50% flowering was determined by counting the total number of plants-in-flower on each plot. It varied from 37-45 days after sowing, with the first flowers appearing 1 week earlier.

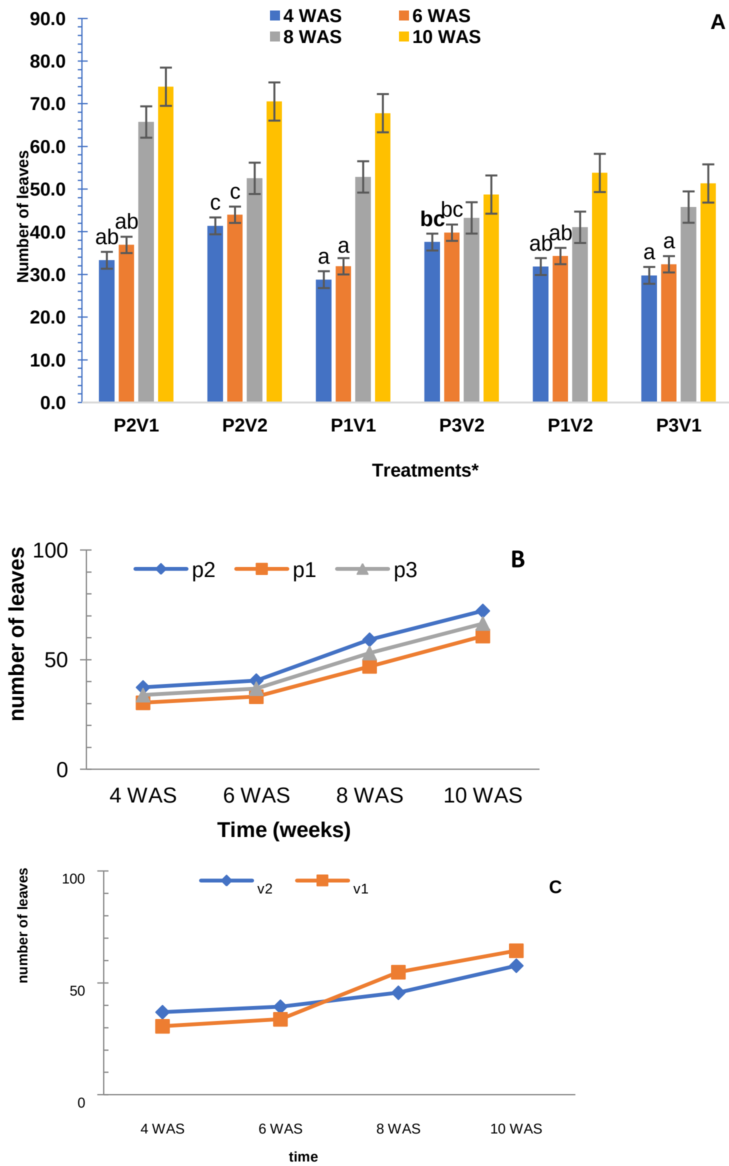
Data analysis

All the data were subjected to analysis of variance (ANOVA) using Genstat Release 11.1 (PC/Windows), and Duncan's multiple range test (DMRT) ($p \leq 0.05$) was used to separate the treatment means. Descriptive statistics were also utilized to illustrate the trends in the data for impact reckoning.

Results

The days to 50% flowering were determined by counting the total number of flower-bearing plants among the five tagged plants. It varied from 37-45 days after sowing, with the first flowers appearing at 30 days after sowing.

At 4 and 6 weeks after sowing (WAS), the number of leaves produced was significantly different. However, the latter intervals revealed no significant difference in terms of the number of leaves (Figure 3). This could be tied to branching and an additional number of leaves, which almost doubled by 12 WAS. Plant spacing 2 x Landrace 1 had significantly more leaves than the other treatment combinations. Early production of leaves was more in Plant spacing 2 x Landrace 2, followed by Plant spacing 3 x Landrace 2, then Plant spacing 2 x Landrace1 in descending order of magnitude. The best plant spacing in terms of the number of leaves was Plant-spacing2 followed by Plant spacing 3 (as a factor in the experiment). The better landrace in terms of the number of leaves was Landrace 2 during the early growth stages. It seems that the significant difference in the number of leaves is tied to the interaction of plant spacing and type of landrace rather than to one factor alone.



*P1, P2, and P3 stands for plant spacing: 0.0549 m^2, 0.08982 m^2 and 0.247005 m^2 (circa 182,149, 111334, and 40,485 plants/ha) respectively while V1 and V2 stands for Ikwo Bambara groundnut landrace1 and Nsukka Bambara groundnut landrace2 respectively.

Figure 3. Effect of plant spacing x landraces on the number of Bambara groundnut leaves

The shoot height was recorded and presented in Figure 4. The shortest plants were produced by Plant spacing 2 x Landrace 2, while the tallest plants were obtained in Plant spacing 2 x Landrace 1 and

Plant spacing 3 x Landrace 1. There were no significant differences between the different interactions, plant spacing, or varieties in terms of shoot height as time passed.

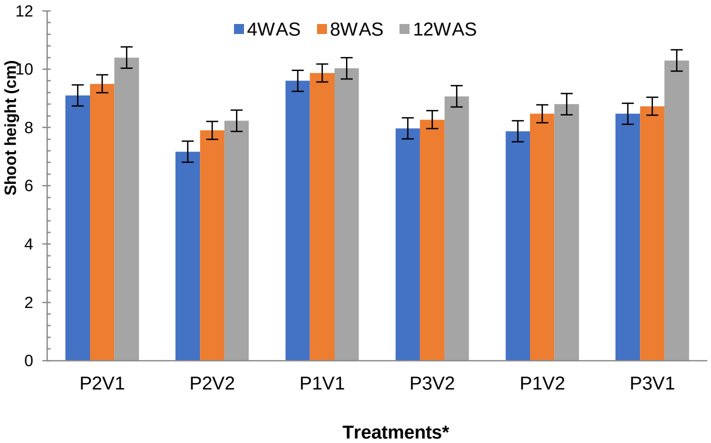


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Figure 4. Effect of plant spacing x landraces on shoot height of Bambara groundnut

The petiole length was recorded and presented in Figure 5. The longest petioles were produced by Plant spacing 2 x Landrace 1, while the shortest petioles were obtained in Plant spacing 3 x Landrace 2. There were no significant differences between the different interactions, plant spacing, or varieties in terms of petiole lengths as time passed.

Figure 4. Effect of plant spacing x landraces on shoot height of Bambara groundnut

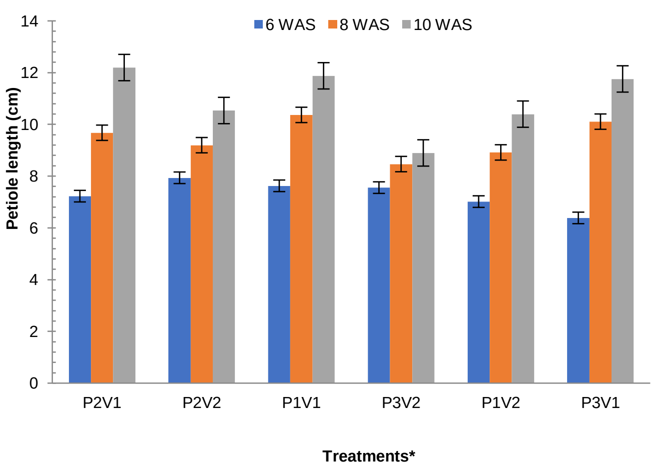

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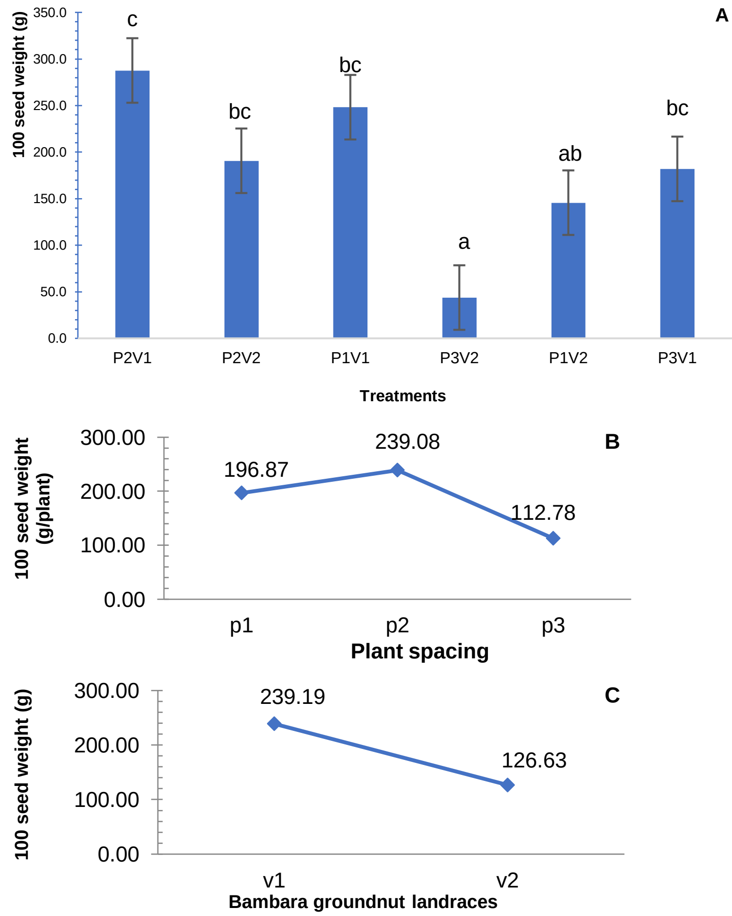
Figure 5. Effect of plant spacing x landraces on petiole length of Bambara groundnut

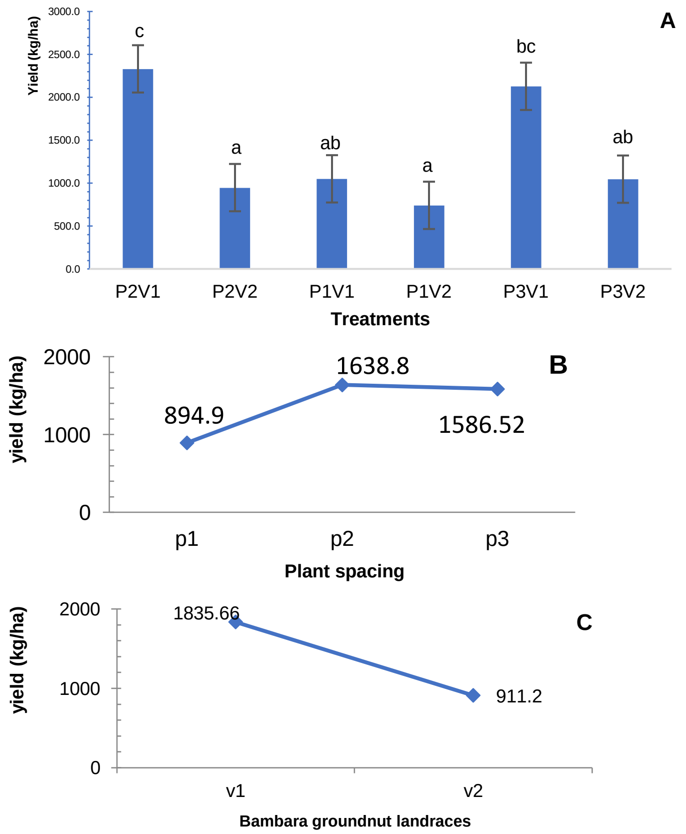
The 100-seed weight of Bambara groundnut was recorded and presented in Figure 6. The highest 100-seed weight of Bambara groundnut was produced by Plant spacing 2 x Landrace 1, while the lowest 100-seed weight of Bambara groundnut was obtained in Plant spacing 3 x Landrace 2. There were significant differences between the different interactions in terms of 100-seed weight of Bambara groundnut. Plant spacing 2 plant spacing produced the highest 100-seed weight, followed by Plant spacing 1 likewise, Landrace 1 produced a higher 100-seed weight compared to Landrace 2



*P1, P2, and P3 stands for plant spacing: 0.0549 m^2, 0.08982 m^2 and 0.247005 m^2 (circa 182,149, 111,334, and 40,485 plants/ha) respectively, while V1 and V2 stands for Ikwo Bambara groundnut landrace1 and Nsukka Bambara groundnut landrace2 respectively

Figure 6. Effect of plant spacing x landraces on 100-seed weight of Bambara groundnut

The seed yield of Bambara groundnut was recorded and presented in Figure 7. The highest seed weight of Bambara groundnut was produced by Plant spacing 2 x Landrace 1, while the lowest seed weight of Bambara groundnut was obtained in Plant spacing 1 x Landrace 2. There were significant differences between the yields produced by different interactions in terms of dry seed yield of Bambara groundnut. Plant spacing 2 plant spacing produced the highest dry seed weight, followed by Plant spacing 3, likewise, Landrace 1 produced a higher dry seed weight compared to Landrace 2



*P1, P2, and P3 stands for plant spacing: 0.0549 m^2, 0.08982 m^2 and 0.247005 m^2 (circa 182,149, 111,334, and 40,485 plants/ha) respectively, while V1 and V2 stands for Ikwo Bambara groundnut landrace 1 and Nsukka Bambara groundnut landrace2 respectively

Figure 7. Effect of plant spacing x landraces on the yield of Bambara groundnut

Discussion

Wongwichaiwat *et al*. (2023) reported that four Bambara groundnut genotypes took 32-34 days to reach 50% flowering, while the two varieties in this study took 37-45 days after sowing. Thus, wide variability exists amongst Bambara groundnut landraces. They reported a negative correlation between shoot/plant height and petiole length, as well as between plant height and number of seeds per plot.

Harry *et al*. (2023) reported that shoot/plant height, number of leaves, and leaf area were all significantly different ($p \leq 0.05$) up to 12 WAS. These findings only partially confirmed the significant differences observed in the number of leaves herein. The two varieties utilized herein came from about 90 km apart. Determining true differences between landraces could be difficult since farmers obtain their seeds from any available source, market, or friend.

Wassouo *et al*. (2024) reported that higher plant densities (40 x 20 cm^2 i.e., 125,000 plants/ha; 40 x 25 cm^2 i.e., 100,000 plants/ha) yielded more pods/ha than lower plant densities. They observed highly significant interactions between planting densities and landraces of Bambara groundnut. This corroborates the findings of the current study relating to significant differences between yields of different interactions.

Obidiebube *et al*. (2019) utilized very low planting densities. They thus reported that spacing 15 x 30 cm^2 with 222,222 plants/ha gave the highest yield of 3920 kg/ha. They reported that the number of pods plants^{-1} and grain yield/ha^{-1} of Bambara groundnuts increased with increased planting density.' This agrees with the general theorem that 'Bambara groundnuts performed better at high densities for growth and yield than at low densities in a very rich soil in the forest zone.

Obidiebube *et al*. (2022) further reported that the number of pods, pod weight, and grain yield of Bambara groundnut increased with a decrease in plant spacing (45 x 30 cm^2, 35 x 30 cm^2, 25 x 30 cm^2, and 15 x 30 cm^2). They confirmed that 15 x 30 cm^2 (with 222,222 plants/ha) is the best plant spacing for Bambara groundnut landraces they utilized in the area covered. In principle, the findings of Wassouo *et al*. (2024) and Obidiebube *et al*. (2019) reported that higher populations of Bambara groundnut produce more yields, which agree with the current study.

Bambara groundnut yield could be as low as 650-850 kg/ha^{-1} in very poor soil, although yields of 4,100 kg ha^{-1} have been reported (Collinson *et al*., 1996). Obidiebube *et al.* (2019) reported that the spacing of 45 x 30 cm^2 (i.e.; 74,074 plants/ha) had the least pod and seed weights per plant with the mean value of 21.7 g per plant which could amount theoretically to 1,703 kg seeds per ha and 15 x 30 cm^2 (with 222,222 plants/ha at 23.3 g per plant) amounts theoretically to 5,111 kg seeds per ha

Wongwichaiwat *et al*. (2023) reported significant differences amongst treatments in terms of the number of pods per plant, seed weight, and 100-seed weight. They reported that the yield differed significantly between landraces (1,624.67-2,853.33 kg/ha). These findings corroborate the findings of this current study.

Nwagwu *et al*. (2023) pointed out that some crops like maize, are sensitive to the population density of an associated intercrop. For instance, Nwagwu *et al*. (2023) intercropped maize with Bambara groundnut at 71,428 plants per hectare, optimizing maize grain yield. That means that even intercropping plant densities are also important, and more research should be carried out on this key growth and yield factor.

CONCLUSION

The cultivation of Bambara groundnut is widespread and is expanding to hostile territory due to its imbalance between demand and supply. Its yield can be improved by overcoming constraints like a lack of improved varieties. This improvement will need to be carried out with a good understanding of the number of plants that can be cultivated per hectare to obtain optimal yield. This study showed that plant spacing x landrace can affect the yields of Bambara groundnut. The spacing of 20 x 45 cm^2 (i.e. 111,334 plants ha^{-1}) is recommended based on the performance of the plants in terms of number of leaves, 100 seed weight per plant, and yield per hectare. The Nsukka landrace 2 (V2) gave a higher yield even though the yield from both landraces is acceptable.

Data Availability

The datasets supporting the findings of this study are available from the corresponding author upon reasonable request.

Conflict of Interest Statement

The authors declare that they have no conflicts of interest

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