Bulgarian Journal of Agricultural Science, 32 (No 5) 2026, 1068–1074

DOI: https://doi.org/10.61308/TYIH1608

Enhancing the seed yield and nutritional quality of Bambara groundnut (*Vigna subterranea* (L.) *Verdc*.) through agronomic zinc bio fortification and liming

Ekama Derrick Elemi[1], Patrick Odey Ukatu[1*], Eugenia Amaka Njoku[2], Emmanuel Bassey Effa[1], Lawson Enang Isong[3], Fidelis Vershima Aberagi[4], Nathaniel Nkor Nkor[1] and John Okokoh Shiyam[1]

[1] *Department of Crop Science, Faculty of Agriculture, University of Calabar, PMB 1115, Calabar, Nigeria*
[2] *Department of Crop Science, University of Nigeria, Nsukka, Enugu State, Nigeria*
[3] *Department of Agricultural Education, University of Entrepreneurship Education Akamkpa, Cross River State, Nigeria*
[4] *Department of Soil Science, University of Calabar, Cross River State, Nigeria*
[*] *Corresponding author:* ukatupatrick@unical.edu.ng

Abstract

Elemi, E. D., Ukatu, P. O., Njoku, E. A., Effa, E. B., Isong, L. E., Aberagi, F. V., Nkor, N. N. & Shiyam, J. O. (2026). Enhancing the seed yield and nutritional quality of Bambara groundnut (*Vigna subterranea* (L.) *Verdc*.) through agronomic zinc bio fortification and liming. *Bul. J. Agric. Sci*., *32*(5), 1068–1074

Agronomic zinc bio fortification of crops is evolving and very imperative as zinc is a very important element in human nutrition and health. A 3 × 4 factorial experiment was laid out in a Randomized Complete Block Design at the Teaching and Research Farm of the Department of Crop Science, Faculty of Agriculture, University of Calabar to evaluate the effect of three rates of calcitic lime (0, 5 and 10 t/ha) in a factorial combination with four rates of soil applied $ZnSO_4$ (0, 10, 20 and 30 kg/ha) on growth, yield and nutritional quality of a landrace of Bambara groundnut (*Vigna Subterranea* (L.) *Verdc*). Data collected were analyzed statistically using analysis of variance (ANOVA) and significantly ($P \leq 0.05$) different means were separated using New Duncan's Multiple Range Test Method (NDMRT). Results revealed that zinc and lime applied at 20 kg Zn/ha and 5 t/ha, respectively, significantly produced higher grain yield as well as increased zinc concentration of Bambara groundnut grains which are very vital in the diet and nutrition of mankind to curb the ravaging effect of hidden hunger and malnutrition among the rural populace and were therefore suggested for recommendation by farmers in Southeastern Nigeria.

Keywords: Bambara groundnut; zinc; lime; bio fortification; growth and yield

Introduction

Agronomic zinc bio fortification of leguminous food crops such as Bambara groundnut and beans is evolving to curb the ravaging effect of malnutrition especially among children and pregnant women (Talsma, 2014). Zinc is a very important element in human nutrition and health. Research by Telles de Moura et al. (2023) indicated that more than two billion persons in the world are affected by zinc deficiency. Also, WHO (2022), recommended grain Zn concentration of 60 mg/kg. Consequently, the US National Institute of Health (NIH) recommends a daily zinc intake of 3–5 mg for children (1–8 years), 9–11 mg for adolescents, and 8–11 mg for adults.

The gradual paradigm shift towards plant's protein for animals and human's consumption has necessitated the enhancement of crop production through practices which improve the protein and mineral content of Bambara groundnut and enhance soil fertility for sustainable food production and

economic growth. Bambara groundnut (*Vigna subterranean* (L) *Verdc*.) is a pulse crop which is widely cultivated and consumed across many countries of the world especially in North, South and Central America, Asia and Africa. It is an extremely adaptable plant which serves as a cheap source of protein to a large proportion of the population in poor countries of the tropics (Olayide et al., 2018; Mandizvo and Odindo, 2019a; Muhammad et al., 2021). It is well suited for hot, dry marginal soils and will continue to grow in conditions too dry for many other crops (Amiri et al., 2016; Mabitsela et al., 2023). It belongs to the family; *Fabaceae* and originated from Western and Central Africa (Hlanga et al., 2021; Egedigwe-Ekeleme et al., 2023). It thrives best in sandy loam soils within a pH range of 5.5 to 6.5 (Agyeman et al., 2021; Elemi et al., 2021). Burkina Faso is the largest producer of Bambara groundnut in the world, with about 40 000 tones (FAOSTAT, 2023). It is mainly cultivated around Plateau and Yola in Nigeria. It is an herbaceous short-lived annual crop of about 15–40cm in height. The flower is generally paired and after fertilization, elongation and downward curving of flower stock causes developing pods to be pushed into the soil. Pods are oval or rounded in shape and they contain one to two seeds each (Agyeman et al., 2021).

Like groundnut, Bambara groundnut can be consumed in fresh or dried state and stored for later consumption (Wanga et al., 2024). The bean contains methionine, an essential amino acid which makes it a highly nutritious and important source of food (Muhammad et al., 2021). It has high potential for food and nutritional security amongst poor households due its nutrient rich seeds containing high quality protein of up to 17–24%, 362–414 kcal / 100 g metabolizeable energy, 5.3–7.8% fat and carbohydrate content of 55.5 69.3% (Caroline, 2014; Talsma and Pachon, 2017; Oyeyinka et al., 2019; Mandizvo and Odindo 2019b; Hlanga et al., 2021; Enwemiwe et al., 2024).

It also contains high quantity of nutritive fibre content as well as essential vitamins such as niacin, riboflavin and thiamine as well as iron and calcium. It is used in making different kinds of food such as "moimoi" and "Kosai". The haulms and seeds are used for livestock feed (Wanga et al., 2024). The leaves and root extracts are used to treat different types of ailments including abscesses, infected wounds eye disease and epilepsy. In Nigeria, the Igbos use the plant extract in the treatment of venereal diseases (Bonny et al., 2019; Ibraheem et al., 2023).

The recent stagnation or decline in farm productivity in many parts of Nigeria is a major concern. Bambara groundnut is still considered as one of the non-prioritized, neglected and underutilized leguminous crop species in Nigeria, despite the high nutritional value (Baloyi and Swanepoel, 2023; Dodd et al., 2023; Talucder et al., 2024), opined that the production of Bambara groundnut like other food legumes such as groundnut has not been popular as a result of intensive soil cultivation without effective soil management programs, which has led to reduction in soil pH resulting in acidification and severe soil degradation. At low pH, the root of plants stops to grow and pod yield declines abruptly while at pH of 5.0, root inuring occurs which impedes the growth of lateral root and total suppression of the root system which greatly hampers the depth of rooting and branching propensity, hence, the reduction in Bambara groundnut yield and widening the gap of malnutrition and hunger.

This research was therefore initiated to determine the response of Bambara groundnut to varying rates of $CaCo_3$ and Zinc fertilizer as soil amendment to fortify the crops, increase yield and meet the unprecedented increase in demand for Bambara groundnut to narrow the gap of malnutrition and hunger in the humid rainforest area of the Tropics.

Materials and Methods

Experimental site, land preparation and soil sampling

The experiment was conducted during the early rainy season of 2017 and 2018 at the Teaching and Research Farm of the Faculty of Agriculture, University of Calabar, Calabar (05°32 and 04°27′N; 07°151 and 09°28′E) 37 m above sea level, and it is located in Nigeria's rainforest zone. The mean annual rainfall is typically 2500 to 3,500 mm, mean annual temperature range of 27°C to 35°C at minimum and maximum, respectively (Uko et al., 2019), and relative humidity between 75–85% (Shiyam et al., 2016; Uko et al., 2019). The soil type of the area is reported to be ultisol (Onweremadu and Peter, 2016; Agbugba, 2018).

The experimental site was manually cleared of vegetation and grass stumps removed using machete and spade. Before ploughing, soil samples were randomly collected from the gross plot at 0–30 cm depth using soil auger and bulked to form a composite sample for analysis of physico-chemical properties of the soil prior to planting.

Treatments and experimental design

The experiment was laid out as a 4 x 3 factorial in a Randomized Complete Block Design (RCBD) replicated thrice. Treatments comprised four rates of $ZnSO_4$ (0, 10, 20 and 30 kg/ha and three rates of calcitic lime $CaCO_3$ (0, 5 and 10 tonnes/ha) as liming materials thus, having a total of 36 experimental units. Unit plots measured 1.3 m × 4.1 m (5.33 m^2) each separated by 1.0 m wide paths while blocks were spaced 2.0 m apart. Treatments were randomly assigned to plots in each block using random number tables.

Treatment application, sowing and plot maintenance

The liming materials were uniformly applied on finished seed beds and incorporated properly into the soil with a hand-held hoe and trowel two weeks before seeds were sown. Healthy uniform size cream colored Bambara groundnut seeds were sown one per hole 3–5 cm deep at 30 cm × 50 cm to give a total of 32 plants per bed or 66,667 plants/ ha. Each level of zinc thoroughly mixed with 2 kg filler material and applied at 30 kg/ha by band one week after germination. Plots were weeded regular using hand held hoe to keep weed population below threshold level. The developing pods were earthened at weeding and cross bunds were constructed to control erosion within plots.

Data collection and statistical analysis

Data were collected from the net plot of Bambara groundnut stands. The agronomic parameters taken included: plant height(cm), number of leaves, leaf area (cm^2) which was taken measuring the length and maximum breath of randomly chosen functional leaves and multiplied by a factor: 0.821 (Dodd et al., 2023), seed weight and seed yield (t/ha). Data generated were analyzed statistically using analysis of variance (ANOVA) and significantly ($P \leq 0.05$) different means were separated using New Duncan's Multiple Range Test Method (DMRT) as described by Sukkaew et al. (2022).

Results

The effects of zinc and lime application on the vegetative and yield indices of Bambara groundnut were measured at 4, 6, 8 and 10 WAP. Plant heights at 10 WAP were not significantly ($P \geq 0.05$) influenced by applied lime and zinc fertilizer (Table 1). However, application of lime and zinc fertilizer at 10 t/ha and 10 kg/ha respectively, produced taller plants than the control. Interaction between lime and Zn significantly ($P < 0.05$) affected plant heights. Results showed that, the combined application of lime at 10 t/ha and zinc fertilizer at 20 kg/ha significantly ($P \leq 0.05$) produced taller plants. Plants in the control plots were short but not significantly ($P \geq 0.05$) shorter when compared to plants that received 10 t/ha lime without Zn application.

Number of leaves (a symbol of the photosynthetic apparatuses of the plant) was significantly ($P \leq 0.05$) affected by lime application at 4 WAP only (Table 1). Application of 10 t/ha lime at 4 WAP resulted in plants having significantly ($P \leq 0.05$) higher number of leaves compared to those plants which received 5 t/ha lime and the control. Lime application at 6 and 8 WAP produced number of leaves which were statistically at par irrespective of the rate of application. However, application of lime at 10 t/ha produced plants with higher number of leaves which were not significantly different from plants which received 5 t/ha and no lime application. Similarly, there were no significant differences among the varying rates of Zn application on number of Bambara groundnut leaves produced across the sampling periods except at 4 WAP where zinc application at 20 kg Zn /ha significantly ($P \leq 0.05$) produced higher number of leaves than the application Zn fertilizer at 30 kg / ha. Interaction between Zn and lime on leaf production was significant ($P \leq 0.05$) at all sampling periods.

A measure of the photosynthetic efficiency of the crop was not significantly ($P \geq 0.05$) affected by lime and zinc fertilizer application throughout the period of the experiment (Table 2). However, Bambara groundnut grown on soil

Table 1. Effects of lime and zinc on plant height and number of leaves

Treatment	Plant height (cm) 10 WAP	No. of leaves 4WAP	No. of leaves 6WAP	No. of leaves 8WAP
Lime (t/ha)				
L_0	25.50^{a}	29.17^{b}	56.80^{a}	74.60^{a}
L_5	26.42^{a}	29.00^{b}	57.30^{a}	77.20^{a}
L_{10}	26.67^{a}	34.26^{a}	60.50^{a}	86.30^{a}
Zinc (kg/ha)				
Z_0	25.89^{a}	29.78^{ab}	57.20^{a}	80.40^{a}
Z_{10}	25.98^{a}	30.44^{ab}	55.30^{a}	69.10^{a}
Z_{20}	26.78^{a}	35.22^{a}	62.60^{a}	84.20^{a}
Z_{30}	26.22^{a}	27.78^{b}	57.80^{a}	26.81 ^{a}
Lime × Zinc				
$L_0 \times Z_0$	24.00^{c}	26.33^{b}	55.30^{ab}	82.30^{ab}
$L_0 \times Z_{10}$	26.67^{ab}	30.33^{ab}	57.70^{ab}	58.00^{b}
$L_0 \times Z_{20}$	27.00^{ab}	34.33^{ab}	67.30^{a}	93.30^{a}
$L_0 \times Z_{30}$	24.33^{bc}	26.00^{b}	47.00^{c}	64.70^{ab}
$L_5 \times Z_0$	26.33^{abc}	26.00^{b}	48.00^{c}	63.00^{ab}
$L_5 \times Z_{10}$	26.33^{abc}	28.00ab	56.30^{ab}	71.30^{ab}
$L_5 \times Z_{20}$	27.00^{abc}	34.67^{ab}	59.30^{ab}	81.70^{ab}
$L_5 \times Z_{30}$	26.00^{abc}	27.33 ^{b}	65.70^{ab}	93.00^{a}
$L_{10} \times Z_0$	27.33^{abc}	37.00 ^{a}	68.30^{a}	96.00^{a}
$L_{10} \times Z_{10}$	24.67^{bc}	33.00^{ab}	52.00^{bc}	76.00^{ab}
$L_{10} \times Z_{20}$	26.33^{abc}	37.00 ^{a}	61.00^{ab}	77.70^{ab}
$L_{10} \times Z_{30}$	28.33^{a}	30.00^{ab}	60.70^{ab}	93.70^{a}

*Means with different superscripts differ significantly at 5% NDMRT
Keys: L_0 = Lime 0 tones: L_r- = Lime 5 tones, L_{10} = Lime 10 tones; Zn_0 = Zinc 0 kg; Zn_{10} = Zinc 10 kg; Zn_{20} = Zinc 20 kg; Zn_{30} = Zinc 30 kg
Source: Authors' own elaboration

amended with 5 t/ha lime and 30 kg Zn/ha at 6 and 8 WAP produced plants with broader leaves which were statistically at par with other treatments. Interaction between lime and zinc was significant ($P \leq 0.05$) on leaf area at 6 and 8 WAP. Although, a cross examination among the sampling periods revealed that the interaction between lime at 5 t/ha and zinc at 30 kg/ha significantly ($P \leq 0.05$) produced broader leaves than other treated plants.

100 seed weight (g) and seed yield (t/ha) were significantly affected by lime and zinc application (Table 3). Application of lime and zinc fertilizer significantly ($P \leq 0.05$) and consistently increased the weight of 100 seeds and seed yield of Bambara groundnut relative to unamend soil. However, zinc application beyond 20 kg/ha significantly reduced the weight of 100 seeds and seed yield of Bambara groundnut.

Interaction between lime and zinc was also found to be significant on the weight of 100 seed and seed yield per hectare. Results showed that Bambara groundnut grown in plots amended with 10 t/ha lime + 20 kg/ha Zn and 10 t/ha lime + kg/ha Zn significantly produced higher seed weight and seed yield per ha, respectively. It was further revealed that, without lime application, increases in rates of zinc application did not result in significant increase in the seed yield of Bambara groundnut.

The application of lime and Zinc to the soil had significant ($P \leq 0.05$) effect on Zn and Phosphorus concentration in seeds of Bambara groundnut (Table 4). The application of lime at 5t/ha had significantly higher Zn concentration on seed than the 10t/ha application rate, while successive increase in the application of lime led to a corresponding increase in the concentration of Phosphorus in Bambara

Table 2. Effect of lime and zinc on leaf area (cm²) of Bambara groundnut at different sampling periods

Treatment	Leaf area 4WAP	Leaf area 6WAP	Leaf area 8WAP
L_0	26.93[a]	32.20[a]	31.6[a]
L_5	27.07[a]	36.80[a]	36.5[a]
L_{10}	28.09[a]	32.20[a]	31.2[a]
Zinc (kg/ha)			
Z_0	28.79[a]	29.30 [a]	31.10[a]
Z_{10}	26.58[a]	31.80[a]	31.70[a]
Z_{20}	28.34[a]	36.20[a]	32.40[a]
Z_{30}	26.81[a]	37.70[a]	37.20[a]
Lime × Zinc			
$L_0 \times Z_0$	27.00[a]	28.80[b]	29.70[b]
$L_0 \times Z_{10}$	26.33[a]	37.20[b]	36.60[b]
$L_0 \times Z_{20}$	30.01[a]	37.29[b]	32.40[b]
$L_0 \times Z_{30}$	24.30[a]	25.80[b]	27.60[b]
$L_5 \times Z_0$	27.03[a]	25.60[b]	27.60[b]
$L_5 \times Z_{10}$	25.57[a]	27.60[b]	27.60[b]
$L_5 \times Z_{20}$	26.27[a]	36.20[b]	36.60[b]
$L_5 \times Z_{30}$	29.40[a]	57.80[a]	51.80[a]
$L_{10} \times Z_0$	32.33[a]	33.60[b]	36.60[b]
$L_{10} \times Z_{10}$	27.83[a]	33.60[b]	28.50[b]
$L_{10} \times Z_{20}$	28.67[a]	35.00[b]	28.20[b]
$L_{10} \times Z_{30}$	26.73[a]	29.40[b]	32.30[b]

*Means with different superscripts differ significantly at 5% NDMRT
Keys: L_0 = Lime 0 tones; L_5 = Lime 5 tones, L_{10} = Lime 10 tones; Zn_0 = Zinc 0 kg; Zn_{10}= Zinc 10 kg: Zn_{20} = Zinc 20 kg; Zn_{30} = Zinc 30 kg
Source: Authors' own elaboration

Table 3. Effect of lime and zinc on 100 seed weight (g) and seed yield (t/ha)

Treatment	100 seed weight (g)	Seed yield (t/ha)
Lime (tonnes)		
L_0	583[b]	1.07[b]
L_5	721[a]	1.47[a]
L_{10}	750[a]	1.50[a]
Zinc (kg/ha)		
Z_0	517[b]	1.03[b]
Z_{10}	783[a]	1.68[a]
Z_{20}	844[a]	1.62[a]
Z_{30}	594[b]	1.05[a]
Lime × Zinc		
$L_0 \times Z_0$	517[c]	1.01[b]
$L_0 \times Z_{10}$	617[c]	1.13[b]
$L_0 \times Z_{20}$	817[b]	1.13[b]
$L_0 \times Z_{30}$	583[c]	1.01[b]
$L_5 \times Z_0$	517[c]	1.07[b]
$L_5 \times Z_{10}$	850[b]	1.84[a]
$L_5 \times Z_{20}$	917[ab]	1.90[a]
$L_5 \times Z_{30}$	600[c]	1.07[b]
$L_{10} \times Z_0$	517[c]	1.01[b]
$L_{10} \times Z_{10}$	883[ab]	2.07[a]
$L_{10} \times Z_{20}$	1000[a]	1.84[a]
$L_{10} \times Z_{30}$	600[c]	1.07[b]

*abcd means with different subscripts differ significantly at 5% NDMRT
Keys: L_0 = Lime 0 tones: L_5 = Lime 5 tones, L_{10} = Lime 10 tones; Zn_0 = Zinc 0 kg; Zn_{10} = Zinc 10 kg: Zn_{20} = Zinc 20 kg; Zn_{30} = Zinc 30 kg
Source: Authors' own elaboration

Table 4. Effects of lime and zinc amendments on zinc (mg/kg) and phosphorus (mg/kg) concentration in seeds of Bambara groundnut

Treatment	Zinc (mg/kg)	Phosphorus (mg/kg)
Lime (t/ha)		
L_0	33.75^{c}	37.00^{c}
L_5	39.92^{a}	44.62^{b}
L_{10}	35.50^{b}	53.00^{a}
Zinc (kg/ha)		
Z_0	12.89$_{d}$	73.44^{a}
Z_{10}	28.56$_{c}$	46.33^{b}
Z_{20}	50.22^{b}	44.11^{c}
Z_{30}	53.89^{a}	15.61^{d}
Lime × Zinc		
$L_0 \times Z_0$	11.00^{i}	64.67^{c}
$L_0 \times Z_{10}$	2l.00^{g}	34.33^{h}
$L_0 \times Z_{20}$	50.00^{c}	36.00^{h}
$L_0 \times Z_{30}$	53.00^{b}	13.00^{j}
$L_5 \times Z_0$	15.00^{h}	76.00^{b}
$L_5 \times Z_{10}$	34.67^{e}	46.00^{f}
$L_5 \times Z_{20}$	54.00^{b}	41.00^{f}
$L_5 \times Z_{30}$	56.00^{a}	15.50^{ij}
$L_{10} \times Z_0$	12.67^{i}	79.67^{a}
$L_{10} \times Z_{10}$	30.00^{f}	58.67^{d}
$L_{10} \times Z_{20}$	46.67^{d}	55.33^{e}
$L_{10} \times Z_{30}$	52.67^{b}	18.33^{i}

*abcd means with different subscripts differ significantly at 5% NDMRT
Keys: L_0 = Lime 0 tones: L_5 = Lime 5 tones, L_{10} = Lime 10 tones; Zn_0 = Zinc 0 kg; Zn_{10} = Zinc 10 kg: Zn_{20} = Zinc 20 kg; Zn_{30} = Zinc 30 kg
Source: Authors' own elaboration

groundnut seeds. Successful increase in Zn rate led to a corresponding significant ($P \leq 0.05$) increase in Zn concentration in seeds. While increase in successive Zn application rate led to corresponding decrease in the Phosphorus concentration in Bambara groundnut seeds.

The interaction between Zn and Phosphorus had significant ($P \leq 0.05$) effect on the concentration of Zn and Phosphorus in Bambara groundnut seeds. Consistent increase in Zn application without lime significantly produced seeds with higher Zn content.

Discussion

Leaf areas of Bambara groundnut were significantly wider at higher rates of $ZnSO_4$ (30 kg Zn/ha) which also facilitated early anthesis. This result is not surprising as Zn is used for all elongating protein synthesis, pollen development, fertilization accumulation of dry matter, tolerance to environmental stresses as well as fruit set as reported by Egedigwe-Ekeleme et al. (2023) and Hassen et al. (2023). However, there was a negative trend in response of Bambara groundnut yield at higher doses of $ZnSO_4$ (30 kg Zn/ha). This could be due to nutrient imbalance as Zn antagonizes Fe uptake as reported by Ekwere et al. (2017) and Elango et al. (2022). Higher seed yield of Bambara groundnut obtained at 5 and 10 t/ha lime in combination with 10 kg Zn/ha could have been due to enhanced nutrient availability at moderate rates of lime (5 t/ha) and zinc fertilizer (10 Kg Zn/ha) which led to enhanced growth attributes and consequent photo-assimilation as well as differential partitioning of assimilates from sources to sink as opined by Kumar, et al. (2022).

More so, the positive relationship between grain Zn concentration and soil applied Zn fertilizer agrees with the report of Amiri et al. (2016), who reported that a unit increase in Zn fertilizer led to higher increase in seed Zn concentrations with no lime application. This study is also in agreement with the reports of Saboor et al. (2021). This validates the report of Dvorak et al. (2003) and Amiri et al. (2016), who observed a significant positive correlation between soils applied Zn and grain concentrations in maize, wheat, barley and potato tubers. This also validates the fact that the level of inclusion of Zn in this study is considered safe for Bambara groundnut as there was no associated phytotoxicity issues.

Conclusion and Recommendation

Considering the nutritional importance of Zn in human diet, a high grain yield of 1.90 t/ha and grain Zn concentration of 54.00 mg/kg were obtained with the application of 5 t/ha lime and 20 kg Zn/ha and thus, could be suggested for recommendation by farmers for sustainable Bamabara groundnut production to curb the ravaging effect of hidden hunger and malnutrition among the rural populace.

Conflict of interest

The authors declare that they have no conflict of interest.

References

Agbugba, S. E. (2018). Characterization and classification of soils of dissimilar topographic units in Owerri Area, Imo state, Nigeria. A thesis submitted to the postgraduate school, Federal University of Technology, Owerri, www.futospace.futo.edu.ng

Agyeman, K., Asante, B. O., Berchie J. K., Sarkodie-Addo, J., Marno, P. & Adabah, R. (2021). Farmers Perceptions, con-

straints and preferences for improved Bambara groundnut varieties in Ghana. *Journal of Agriculture and Food Research, 3,* 100097. http://doi.org/1-0-1016/j.jafr.2020.100097

Amiri, A., Baminasab, B., Ghobadi, C. & Khoshgoflarmanesh, A. H. (2016). Zinc soil application enhance photosynthetic capacity and antioxidant enzyme activities in almond seedlings affected by salinity stress. *Photosynthetica*, *54*(2), 267–274. https://doi.org/10.1007/S11099-016-0078-0

Baloyi, N. G. & Swanepoel, P. A. (2023). Variability assessment of Bambara groundnut (*Vigna subterranean* L.) Verde landraces based on the qualitative trait seed coat colour. *South African Journal of Botany, 163*, 165–171. http://doi/10.1016/j.sajb.2023.10.052

Bonny, B. S., Adjoumani, K., Seka, D., Koffi, K. G., kouonon, L. C., Koffi, K. V. & Bi, I. A. Z. (2019). Agromorphological divergence among four agro-ecological populations of Bambara gtoundnut (*Vigna subterranean* L.) Verdc) in Coted'Ivore'. *Annals of Agricultural Science, 64*(1), 103–111.

Caroline, K. (2014). Bambara groundnut specialty food of Africa. PVT Ltd**.** *Harore, Zimbawe*.

Commercialization of Bambara groundnut as an indigenous climate resilient crop in Nigeria. In: Leal Filho W. (eds), *Handbook of Climate Change Resilience*. https://doi.org/https://doi.org/10.1007/978-3-319-71025-9_158-1

Dodd, J., Sweby, P. K., Mayes, S., Murchie, E. H., Karunaratne, A. S., Massawe, F. & Tindall, M. J. (2023). A multiscale Mathematical model describing the growth and development of bambaranut. *Journal of Theoretical Biology, 560*, 111373. https://doi.org/10.1016/j.jtbi.2022.111373

Dvorak, P., Tlustos, P., Szakova. J., Cerny, J. & Balik, J. (2003). Distribution of soil fractions of Zn and its uptake by potatoes, maize, wheat and barley after soil amendment by sludge and inorganic Zn salt. *Plant, Soil and Environment, 49*(5), 203–212.

Egedigw–Ekeleme, C. A., Famurewa, A. C., Egedigwe, U. O., Onuora, C. A & Agbo, A. O. (2023). Comparative Studies on the amino acids pesticide residue content, biogenic and toxic element in an underutilized nut; Bambara groundnut *(Vigna subterranean). Journal of Trace Elements and Minerals, 3*, 100051. https://doi.org/10.1016/j.jtemin.2023.100051

Ekwere, O. J., Ndon, B. A. & Ndaeyo, N. U. (2017). Effects of some liming material sources and rates on soybeans *(Glycine max (L) Merril)* performance in an acid ultisol. In: *Proceedings of the fourth national annual conference of the crop science society of Nigeria*. N. U. Ndaeyo, I. O. Udo G. N. Udom, E. E. Bassey and L. I. Akpheokhai (Eds.) University of Uyo, Nigeria, September 10–14, 2017, 94–99.

Elango, D., Devi, K. D., Jeyabalakrishnan, H. K., Rajendra, K., Haridass, V.K.T., Dhamaraj, D., Charuchandran, C.V., Wang, N., Fakude, M., Mishra, R., Vembu, K. & Wang, X. (2022). Agronomic, Breeding, and biotechnological interventions to mitigate heavy metal toxicity problems in Agriculture. *Journal of Agriculture and Food Research, 10*, 100374. https://doi.org/10.1016/j.jafr.2022.100374

Enwemiwe, V., Oladipo, A., Nnyia, M. O., Ayodeji, J. O., Ejeromedoghene, O., Alowakennu, M. & Tesi, G. O. (2024). Trace metals encapsulated biopolymers as nanobiocided for crop protection; A review. *Journal of Trace Elements & Minerals, 7,* 100113. https://doi.org/10/1016/j.jtemin.2023.100113

FAOSTAT. (2023). Statistical Database. Food and Agriculture Organization of the United Nations Accessed 10 June 2024 Available from: fao.org/faostat/

Hassen, A. I., Bopape, F. I., Vuuren, A. V., Gerrano, A. S. & Morey, L. (2023). Symbiotic interaction of Bambara groundnut (*Vigna subterranean)* landraces with rhizobia spp from other legume hosts reveals promiscuous nodulation. *South African Journal of Botany, 160*, 493–503.

Hlanga, N. C., Modi, A. T. & Mathew, I. (2021). Evaluating nutritional content among Bambara groundnut lines. *Journal of Food Composition and Analysis,* 102, 104053. https://dor.org/10.1016/j.jfca.2021.104053

Ibraheem, O., Falodun, A. E., Akinyelu, J., Ogundipe, O. M., Ibikunle, P. D., Ezema, M. D., Oyeniran, O. H., Nwagwe, O. R., Odoh, I. M., Olusola, A. O. & Ajayi, J. M. (2023). NaHco3 treatment potentiates the nutritional qualities and androgenic capabilities of Bambara (subterranean L. Verdc) groundnut seeds. *Food Chemistry Advances, 2*, 100279. https://doi.org/10.1016j.focha.2023.100279

Kumar, S., Dikshit, H. K., Mishra, G. P. & Singh, A. (Eds) (2022). Biofortification of staple crops. Singapore: *Springer*, 117–131. DOI: 10.1007/978-981–16-3280-8.

Mabitsela, M. M., Motsi, H., Hull, K. J., Labuschagne, D. P., Booysen, M. J., Mavengahama, S. & Phiri, E. E. (2023). First report of aeroponically grown Bambara groundnut, an African indigenous hypogea legume; Implication for climate adaptation. *Heliyon, 9*(3), e014675. https//doi.org/10.1016/j.heliyon.2023.e014675

Mandizvo, T. & Odindo, A. O. (2019a). Seed coat structural and imbibitional characteristics of dark and light coloured Bambara groundnut (*Vigna subterranean* L.) Landraces. *Heliyons, 5*(2)*,* e01249. https://doi:10.1016/j.heliyon.2019.e01249

Mandizvo, T. & Odindo, A. O. (2019b). Seed mineral reserves and vigor of Bambara groundnut (*Vigna subterranean* L.) Landraces differing in seed coat colour. *Heliyons, 5*(5), e01635. https://doi.org/10.1016/j.heliyon.2019.e01635

Muhammad, I., Rafii, M., Nazli, M. H., Ramlee, S. I., Harun, A. R. & Oladosu, Y. (2021). Determination of lethal (LD) and growth reduction (GR) doses on acute and chronic gamma–irradiated Bambara groundnut (*Vigna subterranean* (L) Verdc.) Varieties. *Journal of Radiation Research and Applied Sciences, 14*(1), 133–145.

Olayide, O. E., Donkob, S. A., Gershon, L., Ansah, K., Adzawla, W., Reilly, P. J. O. & Alabi, T. (2018). Assessing socioeconomic factors influencing production and commercialization of Bambara groundnut as an indigenous climate resilient crop in Nigeria. In: Leal filho W. (Eds). *Handbook of climate charge Resilience.* https://doi.org/10.10071978-3-319-71025-9-158-1

Onweremadu, E. U. & Peter, K. D. (2016). Pedogenesis of soils of two tropical microclimates in Owerri Area, southeastern Nigeria. *International Journal of Soil Science, 11*, 14–18.

Oyeyinka, S. A., Umaru, E., Olatunde, S. & Josep, J. K. (2019). Effect of shot microwave heating time on physicochemical and functional properties of Bambara groundnut starch. *Food Bioscience, 28*, 36–41.

Saboor, A., Ali, M.A., Hussain, S., El Enshasy, H. A., Hussain,

S., Ahmed N., Gafur, A., sayyed, R. Z., Fahad, S., Danish, S. & Datta, R. (2021). Zinc nutrition and arbuscular mycorrhizal symbiosis effects on maize (*Zea mays* L.*)* growth and productivity. *Saudi Journal of Biological Sciences, 28*(11), 6339–6351.

Shiyam, J- O., Nkor, N. N., Binang, W. B. & Effa, E. B. (2016). Yield response of bambara groundnut *(Vigna suterranea* (L) Verdc) varieties to organomineral fertilizer in the coastal forest of south eastern Nigeria. *SCIREA Journal of Agriculture, 1*(1), 91–106.

Sukkaew, W., Thanachit, S., Anusontpornpern, S. & Kheoruenromne (2022). Response of cassava (*Manihot esculanta* Grants) to calcium and potassium in a humid tropical upland loamy sand soil. *Annals of Agricultural Sciences, 67*(2), 204–210.

Talsma, E. F. & Pachon, H. (2017). Biofortification of crops with minerals and vitamins. World Health Organization, Rome. https://www.who/elena/titles/bbc/biofortification/en

Talsma, E. F. (2014). Yellow cassava efficacy of provitamin: A rich cassava on improvement of Vitamin A status in Kenyam school children, 148. Wageningen, Netherlands: Wageningen University and Research.

Talucder, M. S. A., Ruba, U. B. & Robi, Md A. S. (2024). Potentiality of neglected and Underutilized species (NUS) as a future resilient food; A systematic review. *Journal of Agriculture and Food Research, 16*, 101116. https/doi.org/10.1016/j.jafr.2021.101116

Tells de Moura, O. V., Berbara, R. L. L., Torchia, D. F., Da Silva, H. F. D., Tolde castro, T. A. V., Tavares, O. C. H., Rodrigues, N. F., Zinta, E., Santos, L. A. & Garlia, A. C. (2023). Humic foliar application as sustainable technology for improving the growth yield and abiotic stress protection of agricultural crops: A review. *Journal of the Saudi Society of Agricultural Sciences, 22*(8), 493–513.

Uko, A., Iren, I., Effa, E. & Isong, A. (2019). Comparative efficacy of organic manures for improved performance of waterleaf (*Talinum fructicosum* (L.) Juss) in the Humid Rainforest. *International Journal of Sciences, 8*(8), 1–10. http://www.ijsciences.com/pub/issue/2019-8/Doi:10.18483/ijsci.2126

Wanga, M. A., Ithete, R. N., Hukununa, R. K., Kangumba, A., Hangula, M. N., Hasheela, E. B. S., Sarbu, F. & Shimelis, H. (2024). Optimum gamma irradiation doses for mutagenesis in bambara groundnut (*Vigna subterranean* L.) Genotypes. *Reproduction and Breeding, 4*(2), 88–94.

WHO (2022). Guidelines on food fortification with micronutrients. World Health Organization (WHO), Geneva, Switzerland. Available at: https://wvvw.who. int/nutrition/publications/micronutrients.9241561734/en/ (Accessed October, 2023).

Received: **February, 11, 2025**; *Approved*: **May, 12, 2025**; *Published*: **October, 2026**