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Performance of Bambara Nuts (*Vigna subterranean* L. Verdc) as Influenced by Genotypes and Weed Control Treatments in the Sudan Savanna Ecology, Nigeria

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Abstract

Global food security is threatened by population growth, climate change, and limited arable land. Bambara groundnut, an underutilized crop, faces challenges like low yields governed by weed competition and climate change stress. Given this, field trials were conducted to assess the performance of the Bambara nut as influenced by genotypes and weed control methods. The experiment comprised three genotypes of Bambara nut, “Yar Gombe”, “Duna Baki” and “Cream”, and eleven (11) weed control treatments, i.e. unweeded plots, hoe weeding at 3 and 6 weeks after sowing; application of imazethapyr at 2.0 kg a.i.ha^{-1}; imazethapyr at 1.5 + bentazone at 1.5 kg a.i.ha^{-1}; metolachlor at 2.0 kg a.i.ha^{-1}; metolachlor at 1.5 + bentazone at 1.5 kg a.i.ha^{-1}; pendimethalin at 2.0 kg a.i.ha^{-1}; pendimethalin at 1.5 kg a.i.ha^{-1} + bentazone at 1.5 kg a.i.ha^{-1}; pendimethalin at 1.5 kg a.i.ha^{-1} + supplementary hoe weeding; metolachlor at 1.5 kg a.i.ha^{-1}+ supplementary hoe weeding; imazethapyr at 1.5 kg a.i.ha^{-1} + supplementary hoe weeding). The study was laid out in a split-plot design and replicated three times, with genotypes and weed control occupying the main and subplots. Findings revealed that plant height did not significantly differ due to genotypes, but “Duna Baki” had the widest canopy. Application of metolachlor at 1.5 kg a.i. ha^{-1} + hoe weeding conducted at 6 weeks after sowing, resulting in noticeably taller plants. The application of metolachlor and + imazethapyr each at 1.5 kg a.i. ha^{-1} + hoe weeding at 6 weeks after sowing produced the widest canopy cover. “Duna Baki” had the highest seed yield, whereas the “Yar Gombe” and “Duna Baki” had the heaviest seed. The phytosociological analysis identified *Amaranthus spinosus, Eleusine indica, Cynodon dactylon,* and *Leucas martinicensis* as the four most common weeds based on their importance value index (IVI). Consequently, farmers in the study area should be advised to use metolachlor and pendimethalin each at 1.5 kg a.i to increase yield and efficiently manage weeds.

Keywords: Bambara nut, genotype, herbicide, weed control efficiency

Introduction

Bambara groundnut (*Vigna subterranean* L.) is a neglected African plant of the family Fabaceae. Bambara nut cultivation spans from the semi-arid region of Sub-Saharan Africa (SSA) (Hillocks et al., 2012; Tukahashir et al., 2016). The known distributions of Bambara groundnut extend from West to Southern Africa via Central Africa (FAO, 2019). The origin of Bambara groundnut concluded that the crop originated from the African continent. However, its exact area of origin in Africa has been subjected to debate. No spontaneous or wild form of the crop has been found in Mali; it is recognized for its high nutritional value, its tolerance to poor soil conditions, drought, salinity, and its ability to produce food in conditions where peanut completely fails (Tan et al., 2020). However, it remains, unfortunately, less cultivated and poorly known in tropical Africa. The seeds contain, on average, 64% of carbohydrates, 23% of protein and 6.5% of fats, 5.5% fiber, and are also considered rich in minerals, enabling them to become a complete food. The main producing countries are Nigeria, Chad, Niger, Togo, and Benin with a total production annual production capacity estimated at 330,000 tons per hectare (FAO, 2018). Presently the demand for Bambara nut exceeds its regional supply (FAO, 2019). Nigeria remains the largest producer in West Africa with a mean production of 0.1 million tons, ahead of Burkina Faso and Niger with 44,712 and 30,000 tons, respectively (Hillocks et al., 2012). Bambara nut is a leguminous crop of African origin and is mostly grown with limited inputs by farmers in the semi-arid tropics (Basu et al., 2007; FAO, 2019).

There is a great concern over the state of food and nutritional security worldwide due to over-reliance on

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major crop species as the main source of food and nutrition (Fanzo et al., 2021). The global population is projected to reach 10 billion by 2050, and the harvested yield from the major food crops may not be sufficient to meet the food demand of the projected population (Khan et al., 2017; van Dijk et al., 2021). There is a threat to global food security arising from climate change attributes such as fluctuating temperature regimes, prolonged drought, soil degradation, salinity, flooding, and biotic constraints (pest and disease). Among the biological constraints, weed plays a critical role in riding the quality of crops, particularly pulse crops with relatively initial slow growth habits that cannot withstand the amputation of growth recession, such as bambara nuts (Singh et al., 2022). Hence, controlling the growth of weeds in Bambara nuts becomes imperative. Farmers rely on landraces for their cultivation as presently, there is no registered cultivar in the market. However, this is responsible for low yield derived from farmers' fields (Ho et al., 2017; Fenzi and Couix, 2021). Therefore, the need to evaluate some landraces of bambara nut also becomes critical to ascertain the landraces that are suitable to specific ecologies, bearing in mind the change in climate as influenced by rainfall pattern and distribution. With this concept, the study was designed to evaluate the performance of bambara nuts as influenced by genotype and weed control treatments in the Sudan savanna ecology of Nigeria.

Materials and Methods

The trial was conducted during the rainy season of 2021 at the Research and Training Farm of the Centre for Dry Land Agriculture, Bayero University Kano (12°43' N Latitude; 8°31'0.9'' E Longitude; altitude of 481 m above sea level), situated at the Sudan Savanna agro-ecological zone of Nigeria. The experiment comprised three genotypes of Bambara nut: "Yar Gombe", "Duna Baki", and "Cream", and eleven (11) weed control treatments, i.e. unweeded (control), hoe weeding at 3 and 6 weeks after sowing (WAS); application of imazethapyr at 2.0 kg a.i.ha^{-1}; imazethapyr at 1.5 + bentazone at 1.5 kg a.i.ha^{-1}; metolachlor at 2.0 kg a.i. ha^{-1}; metolachlor at 1.5 + Bentazone at 1.5 kg a.i.ha^{-1}; pendimethalin at 2.0 kg a.i.ha^{-1}; pendimethalin at 1.5 kg a.i.ha^{-1} + bentazone at 1.5 kg a.i.ha^{-1}; pendimethalin at 1.5 kg a.i. ha^{-1} + supplementary hoe weeding (SHW) at 6 WAS; metolachlor at 1.5 kg a.i.ha^{-1} + SHW at 6 WAS; imazethapyr at 1.5 kg a.i.ha^{-1} + SHW at 6 WAS. All treatments were laid down in a split-plot design and replicated three times; genotypes and weed control occupying the main and subplots, respectively.

The field was cleared and harrowed to a fine tilth and ridge before individual plots were marked out of 3 m x 4 m (12 m^2), and the net plot size was 1.5 m x 4 m (5.6 m^2). A distance of 0.5, 1.0, and 1.5 m was allowed to separate plots, main plots, and replications. Two seeds of each genotype were sown and later thinned to 1 plant per stand at 2 WAS. The pre-emergence herbicides were applied a day after sowing using a knapsack sprayer fitted with a green deflector poly jet nozzle and set at a pressure of 2.1 kg.m^{-1} to give a spray volume of 250 L.ha^{-1}. The spraying was done in the morning when the weather was calm to avoid wind drift. The herbicides were applied on a treatment basis. The recommended fertilizer rate of 300kg. ha^{-1} each of N, P_2O_5, and K_2O in NPK 20-10-10 was applied at 2 WAS. Hoe weeding was carried out at 3 and 6 WAS for the hoe weeding and at 6 WAS for the treatment with the supplementary hoe weeding. The unweeded plots were left throughout the trial to serve as a negative check. Data were collected on the growth and yield characteristics of the crop by adopting standard agronomic procedures. Weed characters were also collected.

Weed Phytosociological Attributes

Weed species harvested from the 1 m^2 quadrant placed randomly in each plot were harvested and identified using a notebook and other standard procedures described by Akobundu et al. (2016) and Rana and Rana (2019), respectively. Those that could not be positively identified were packaged and transported to the herbarium section of the Department of Plant Science at Bayero University in Kano, Nigeria.

The phytosociological attributes of the weeds, namely weed density, weed relative density, weed frequency, weed relative frequency, weed abundance, and weed relative abundance, Weed density is summed up by the composition of weed species samples found within the total number of quadrants used. Weed frequency is the number of times any certain weed species occurs in the field. Important value index (IVI) is a measure to assess the overall significance of a species considering several properties of the species in the vegetation. The IVI was calculated as described by Curtis and McIntosh (1950). The parameters assessed for the purpose were density, frequency, and abundance. Each attribute is calculated using the below formula.

$$\text{Weed density} = \frac{\text{Total number of weed species in all quadrants}}{\text{Total number of quadrants studied}}$$

$$\text{Weed relative density} = \frac{\text{Density of weed species}}{\text{Total density of all weed specie studied}} \times 100$$

$$\text{Weed frequency} = \frac{\text{Number of quadrants to which weed specie occured}}{\text{Total number of quadrants used in the study}}$$

$$\text{Weed relative frequency} = \frac{\text{Frequency value of a weed species}}{\text{Total frequency of all weed specie studied}} \times 100$$

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Weed abundance = $\frac{\text{Total number of weed species in all quadrants}}{\text{Sum of quadrants in which specie occured}} \times 100$

Weed relative abundance = $\frac{\text{Abundance of a weed species in all quadrants}}{\text{Total abundance of all specie studied}} \times 100$

Importance value index (IVI) = Relative frequency (RF) + Relative density (RD) + Relative abundance (RA).

The data generated from the field were subjected to analysis of variance (ANOVA) using GENSTAT (17th edition). Significant means were separated using the Student Newman-Keuls Test (SNK) at the 5% probability level.

Results and Discussion

Effect of Genotypes and Weed Control Treatments on Plant Height of Bambara Nut

Plant height did not differ significantly (*P* >0.05) due to genotypes and interactions at 6, 8, 10, and 12 WAS. However, it differs significantly due to the unweeded control. Plant height at 6 WAS shows that all weed control treatments were significantly taller (P < 0.01) and produced taller plants than the unweeded, which produced the shortest plant.

At 8 WAS, the application of pendimethalin and metolachlor each at 1.5 kg a.i.ha^{-1} + SHW at 6 WAS significantly (*P*< 0.001) produced the tallest plants, though at par with other treatments compared to the unweeded plots. At 10 and 12 WAS, the application of imazethapyr at 2.0 kg a.i.ha^{-1} significantly resulted in the tallest plant, although comparable with the rest of the treatment except the unweeded plots. Compared to the unweeded control, applying metolachlor at 1.5 kg a.i.ha^{-1} + SHW at 6 WAS led to substantially taller plants. This improvement in plant height might be attributable to the treatment's ability to manage weeds throughout the growing season. This study's results were consistent with those of Olorukooba et al. (2022),

Table 1. Effect of genotypes and weed control treatment on plant height of Bambara nuts at 6, 8, 10, and 12 weeks after sowing (WAS) at Bayero University Kano, Nigeria, during the 2021 wet season

Treatment	Plant height (cm) at			
	6 WAS	8 WAS	10 WAS	12 WAS
Genotypes (G)				
"Duna Baki"	14.27	16.43	19.05	17.55
"Cream"	14.36	16.65	19.23	17.68
"Yar Gombe"	14.48	16.67	19.02	17.59
P values	0.453	0.817	0.833	0.951
SE	0.109	0.292	0.262	0.294
Weed control treatment (WC)				
Weedy check	10.82^{b}	12.41^{c}	13.41^{c}	12.52^{e}
Hoe weeding at 3 and 6 WAS	14.20^{a}	16.42^{ab}	19.04^{b}	17.43^{bcd}
Imazethapyr at 2.0 kg a.i. ha^{-1}	14.60^{a}	17.67^{ab}	18.30^{b}	19.37^{ab}
Metolachlor at 2.0 kg a.i. ha^{-1}	14.94^{a}	16.80^{ab}	19.02^{b}	17.70^{bcd}
Pendimethalin at 2.0 kg a.i. ha^{-1}	15.02^{a}	17.34^{ab}	18.47^{b}	17.26^{bcd}
Imazethapyr at 1.5 + bentazone at 1.5 kg a.i. ha^{-1}	15.42^{a}	17.11^{ab}	20.23^{ab}	18.11^{abc}
Metolachlor at 1.5 + bentazone 1.5 kg a.i. ha^{-1}	14.73^{a}	16.59^{ab}	18.78^{b}	17.42^{bcd}
Pendimethalin 1.5 + bentazone 1.5 kg a.i. ha^{-1}	14.16^{a}	15.77^{b}	18.38^{b}	17.46^{bcd}
Pendimethalin 1.5 kg a.i. ha^{-1} + SHW at 6 WAS	13.73^{a}	18.43^{a}	18.30^{b}	17.14^{cd}
Metolachlor 1.5 kg a.i. ha^{-1} + SHW at 6 WAS	14.96^{a}	18.43^{a}	22.01^{a}	19.91^{a}
Imazethapyr 1.5 kg a.i. ha^{-1} + SHW at 6 WAS	15.49^{a}	17.97^{ab}	20.76^{ab}	19.33^{abc}
p-value	<.001	<.001	<.001	<.001
SE	0.582	0.553	0.596	0.489
Interaction				
G x WC	0.051	0.611	0.526	0.059

Notes: Means followed by the same letter (s) in a column are not significantly different at a 5% level of probability, according to the SNK test. WAS= weeks after sowing, SE= standard error, SHW = supplementary hoe weeding.

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who found that pre-emergence herbicide application significantly boosted turmeric plant height compared to an unweeded control. According to Deshmukh et al. (2018), plant height was considerably impacted by applying integrated weed management control strategies. Furthermore, competition between weeds and crops from emergence to harvest negatively affects growth and yield (Damalas and Koutroubas, 2022).

Effect of Genotypes and Weed Control on Canopy Cover of Bambara Nut

Results indicated that the effects of genotypes and weed control treatments were highly significant (*P*<0.001) at 6, 8, 10, and 12 WAS, while the interaction was significant at 6 and 8 WAS only (Table 2). The “Duna Baki” genotype significantly produced a higher canopy than the other genotypes. The application of metolachlor and imazethapyr each at 1.5 kg a.i. ha^{-1} + SHW at 6 WAS significantly produced a wider canopy cover, although statistically comparable with other treatments except for the unweeded control, which resulted in the narrow canopy at 6, 8, 10, and 12 WAS.

The interaction between genotype and weed control treatments on canopy cover at 6 and 8 WAS showed that, while the other interaction effects were comparable (Table 3). The treatment of metolachlor at 1.5 kg a.i.ha^{-1} + SHW at 6 WAS in the “Duna Baki” considerably created a larger canopy cover. At 8 WAS, a similar tendency was also noted. The present study’s results align with those of Vishwakarma et al. (2023), who observed that the sequential use of herbicides enhanced the growth properties of soybeans by suppressing weed development. The genetic makeup of the genotype, which results in stronger growth features like more branches and leaves and a wider canopy, maybe the reason for “Duna Baki”’s capacity to outperform other genotypes. Additionally, this supported the conclusions of

Table 2. Effect of genotypes and weed control treatment on canopy cover (cm) of Bambara nut at 6, 8, 10, and 12 weeks after sowing (WAS) at Bayero University Kano, Nigeria, during the 2021 wet season

Treatment	Canopy cover (cm) at			
	6 WAS	8 WAS	10 WAS	12 WAS
Genotypes (G)				
“Duna Baki”	23.40^{a}	26.00^{a}	29.89^{a}	27.18^{a}
“Cream”	19.88^{c}	22.74^{b}	24.81^{c}	23.11^{c}
“Yar Gombe”	20.79^{b}	22.61^{b}	24.81^{b}	24.30^{b}
P value	<.001	0.015	<.001	0.001
SE	0.217	1.752	0.288	0.288
Weed control treatment (WC)				
Weedy check	19.49^{d}	19.94^{d}	21.67^{d}	19.92^{e}
Hoe weeding at 3 and 6 WAS	23.46^{a}	24.62^{a-c}	29.49^{a}	27.46^{ab}
Imazethapyr at 2.0 kg a.i.ha^{-1}	20.73^{abc}	24.12^{a-d}	25.22^{c}	22.10^{cd}
Metolachlor at 2.0 kg a.i. ha^{-1}	23.91^{a}	25.67^{a-d}	28.56^{ab}	27.61^{ab}
Pendimethalin at 2.0 kg a.i. ha^{-1}	20.60^{a-c}	22.57^{b-d}	25.47^{c}	23.97^{c}
Imazethapyr at 1.5 + bentazone at 1.5 kg a.i. ha^{-1}	20.96^{a-}	23.28^{b-d}	25.69^{bc}	23.97^{c}
Metolachlor at 1.5 + bentazone 1.5 kg a.i. ha^{-1}	22.24^{d}	20.26^{d}	24.08^{cd}	22.77^{cd}
Pendimethalin 1.5 + bentazone 1.5 kg a.i. ha^{-1}	19.11^{bc}	21.58^{cd}	24.51^{cd}	25.27^{bc}
Pendimethalin 1.5 kg a.i. ha^{-1} + SHW at 6 WAS	22.44^{ab}	25.22^{a-d}	28.73^{ab}	27.61^{ab}
Metolachlor 1.5 kg a.i. ha^{-1} + SHW at 6 WAS	23.58^{a}	28.12^{a}	31.17^{a}	29.44^{a}
Imazethapyr 1.5 kg a.i. ha^{-1} + SHW at 6 WAS	24.64^{a}	27.24^{a}	30.50^{a}	29.04^{a}
P value	<.001	<.001	<.001	<.001
SE	0.929	1.016	0.957	1.606
Interaction				
G x WC	0.004	0.021	0.063	0.008

Notes: Means followed by the same letter (s) in a column are not significantly different at a 5% probability level according to the SNK test. WAS= weeks after sowing, SHW = supplementary hoe weeding.

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Rahmadina et al. (2023) and Tavares et al. (2023) in soybean and Arabidopsis, respectively.

Effect of Weed Control and Genotypes on 100-seed Weight, Grain yield, Weed density, Weed Dry Weight, and Weed Control Efficiency

Significantly heavier seeds were produced by the “Duna Baki” and “Yar Gombe” genotypes than by the “Cream” color genotype (Table 4). While still comparable to other treatments, the application of metolachlor and imazethapyr each at 1.5 kg a.i. ha^{-1} + SHW at 6 resulted in much heavier seeds, except for the unweeded treatment with the lowest seed weight. Similarly, the result further showed that grain yield was highly (P<0.001) significant due to genotype, weed control, and interaction, whereas 100-seed weight was significant (P<0.05) due to genotype and highly significant (P<0.001) due to weed control treatments and interaction. The “Duna Baki” genotype produced noticeably higher grain yields than other genotypes (Table 4).

Hoe weeding at 3 and 6 WAS, pendimethalin, metolachlor, and imazethapyr each at 1.5 kg a.i.ha^{-1} + SHW at 6 WAS significantly resulted in a higher yield than the unweeded crops that yielded the lowest with about 48.3% yield reduction. The cultivation of the “Duna Baki” genotype using imazethapyr at 1.5 kg a.i.ha^{-1} + SHW at 6 WAS, though at par, significantly produced heavier seeds than other interaction effects. Conversely, compared to the remaining interaction effects, the cultivation of “Duna Baki” utilizing two hoe weedings at 3 and 6 WAS and pendimethalin at 1.5 kg a.i.ha^{-1} + SHW at 6 WAS considerably yielded a greater yield (Table 5). The genetic makeup of the genotype, which results in more substantial growth features like more branches and leaves and a wider canopy, may be the reason for “Duna Baki”’s capacity to outperform other genotypes. Additionally, this supported the earlier findings of Rahmadina et al. (2023). Additionally, the preemergence herbicide’s efficacy weed control and the additional hoe weeding at 6 WAS smoothed out the late-emerging weeds, allowing assimilates to be partitioned towards pegging and pod formation. These factors may also account for the potential of other weed treatments to increase yield compared to the unweeded plots. According to Mishra et al. (2022), unweeded plots lead to a 50-60% output reduction in wheat, whereas Korav et al. (2024) reported that pod yield and haulm yield of groundnut was significantly decreased by 6.5-32% and 6.4-34% during the wet and winter seasons, respectively, due to the prolonged duration of weed interference.

Therefore, good weed management techniques decrease weed competition and density, improving crop growth and photosynthetic activity. Improved weed control that forces the plant to use only the resources at its disposal (nutrients, solar radiation, and space) may also be responsible for the higher yield and heavier seed weight. This result supports Parthipan’s (2020) research, which found that effectively controlled weeds improve crop performance.

Weed density, weed dry weight, and weed control efficiency were not affected by genotypes and interaction, but it was highly significantly (P<0.001) affected by weed control treatment. Weedy check significantly produced higher weed density and dry weight than the rest of the treatments. On the other hand, weed control efficiency was higher in all herbicidal treated plots compared to unweeded treatment, which gave the lowest weed control efficiency. Low weed density and lesser weed competition may be the cause of the larger plant, broadest canopy, over vigorous plant, higher grain production, and 100-seed weight. Increased uptake of nutrients and water sped up photosynthesis and raised the amount of carbohydrates in the cell, which in turn caused cell elongation, division, and multiplication, increasing growth and yield. This result was consistent with the work of Shittu and Bassey (2023) and Shittu et al. (2023), who reported that higher weed dry weight was found in unweeded plots than those plots treated with herbicides in groundnut and roselle. Similar results of higher weed control efficiency in cowpea and soybean as a result of herbicide application and additional hoe weeding were reported by Omisore et al. (2016) and Damalas and Koutroubas (2022), respectively.

Effect of Weed Control and Genotypes on Weed Growth

Weed species composition

Sixteen weed biotypes were identified with their species composition of grasses, broadleaf weeds, and sedges. The grasses and broadleaf weeds comprise seven and six weed species each (Table 6). The distribution of the weeds into lifecycle reveals that the majority (11) are annuals (73.33%) while four (4) are perennials (26.66%). Weeds of the Poecea family are 7, Cyperaceae had 3, Amaranthacea had 2, Asteraceae, Acanthaceae, Chenopodiaceae, Euphorbiaceae, and Lamiaceae each had 1. The experimental sites were predominantly dominated by *Cynodon dactylon*, *Amaranthus* spp, *and Leucas martinicensis* compared with the rest, which was less. The predominance of *Cynodon dactylon, Amaranthus* spp, and *Leucas martinicensis* compared with the

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Table 3. Genotype and weed control interaction in affecting Bambara nut canopy cover at 6 and 8 weeks after sowing at Bayero University Kano, Nigeria, during the 2021 wet season

Genotype	Canopy cover (cm)										
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
						6-weeks after sowing					
"Duna Baki"	19.13^{g-l}	24.37^{a-f}	20.07^{f-l}	25.27^{a-e}	23.47^{a-g}	24.93^{a-e}	19.40^{g-l}	20.93^{e-k}	27.40^{ab}	24.87^{a-e}	27.60^{a}
"Cream"	16.57^{k-m}	19.73^{g-l}	19.67^{g-l}	19.47^{g-l}	19.00^{h-l}	19.93^{g-l}	18.40^{i-m}	22.20^{d-i}	18.93^{h-l}	21.53^{e-i}	23.27^{a-h}
"Yar Gombe"	16.77^{j-m}	26.27^{a-d}	22.47^{c-i}	27.00^{a-c}	19.33^{g-l}	18.00^{i-m}	16.27^{lm}	14.20^{m}	21.00^{e-j}	24.33a^{-f}	23.07^{b-h}
						8-weeks after sowing					
"Duna Baki"	21.43^{g-l}	26.77^{a-f}	22.03^{f-l}	27.63^{a-e}	24.87^{g-h}	27.43^{a-e}	22.37^{f-j}	23.67^{e-j}	29.27^{a-c}	30.03^{ab}	30.53^{a}
"Cream"	18.87^{j-l}	21.90^{f-l}	26.70^{a-f}	27.63^{a-e}	21.53^{g-l}	22.00^{f-l}	20.50^{h-l}	23.87^{d-j}	21.00^{g-l}	28.63^{a-c}	24.10^{d-j}
"Yar Gombe"	19.53^{j-l}	25.20^{b-h}	23.63^{e-j}	28.30^{a-e}	21.30^{g-l}	20.40^{h-l}	17.90^{kl}	17.20^{l}	24.13^{d-j}	25.70^{a-g}	25.37^{b-h}

Notes: T1: unweeded; T2: hoe weeding at 3 and 6 WAS; T3: imazethapyr at 2.0kg a.i.ha^{-1}; T4: imazethapyr at 1.5 + bentazone at 1.5 kg a.i.ha^{-1}; T5: metolachlor at 2.0 kg a.i.ha^{-1}; T6: metolachlor at 1.5 + bentazone at 1.5 kg a.i.ha^{-1}; T7: pendimethalin at 2.0 kg a.i.ha^{-1}; T8: pendimethalin at 1.5 kg a.i.ha^{-1} + bentazone at 1.5 kg a.i.ha^{-1}; T9: pendimethalin at 1.5 kg a.i.ha^{-1} + supplementary hoe weeding; T10: metolachlor at 1.5 kg a.i.ha^{-1}+ supplementary hoe weeding; T11: imazethapyr at 1.5 kg a.i.ha^{-1} + supplementary hoe weeding.

Table 4. Effect of genotype and weed control treatment on 100 seed weight, grain yield weed density, weed dry weight, and weed control efficiency of Bambara nut at Bayero University Kano, Nigeria, during the 2021 wet season

Treatment	100-seed weight (g)	Grain yield (kg.ha^{-1})	Weed density (n.m^{2})	Weed dry weight (kg.ha^{-1})	Weed control efficiency (%)
Genotype (G)					
"Duna Baki"	89.70^{a}	472.3^{a}	5.670	29.85	70.40
"Cream"	84.63^{b}	437.4^{b}	6.000	28.51	71.56
"Yar Gombe"	89.70^{a}	434.5^{b}	5.150	26.03	71.48
p-value	0.022	<.001	0.599	0.577	0.358
SE	0.801	2.073	0.560	2.440	0.560
Weed control treatment (WC)					
Unweeded plots	73.04^{f}	264.6^{f}	14.78^{a}	89.09^{a}	9.51^{d}
Hoe weeding at 3 and 6 WAS	92.83^{b-d}	510.7^{a}	3.56^{c-e}	15.92^{bc}	77.54^{b}
Imazethapyr at 2.0 kg a.i. ha^{-1}	83.60^{e}	398.8^{e}	6.89^{b}	35.93^{b}	67.40^{c}
Metolachlor at 2.0 kg a.i. ha^{-1}	90.68^{d}	469.7^{c}	5.33^{b-d}	18.46^{bc}	78.60^{b}
Pendimethalin at 2.0 kg a.i. ha^{-1}	82.44^{e}	411.7^{d}	6.33^{bc}	32.48^{bc}	70.77^{b}
Imazethapyr at 1.5 + bentazone at 1.5 kg a.i. ha^{-1}	92.03^{cd}	473.0^{c}	4.44^{b-e}	19.97^{bc}	77.97^{b}
Metolachlor at 1.5 + bentazone 1.5 kg a.i. ha^{-1}	99.28^{ab}	414.0^{d}	6.11^{bc}	30.19^{bc}	70.17^{b}
Pendimethalin 1.5 + bentazone 1.5 kg a.i. ha^{-1}	98.36^{a-c}	475.0^{c}	4.22^{b-e}	18.46^{bc}	74.11^{b}
Pendimethalin 1.5 a.i. ha^{-1} + SHW at 6 WAS	96.48^{a-d}	510.9^{a}	2.89^{de}	13.76^{c}	84.41^{a}
Metolachlor 1.5 kg a.i. ha^{-1} + SHW at 6 WAS	99.60^{a}	505.8^{a}	1.89^{e}	14.06^{c}	86.04^{a}
Imazethapyr 1.5 kg a.i. ha^{-1} + SHW at 6 WAS	99.94^{a}	495.1^{b}	5.22^{b-d}	24.44^{bc}	86.11^{a}
p-value	<.001	<.001	<.001	<.001	<.001
SE	2.213	2.794	0.659	4.73	0.191
Interaction					
G x WC	<.001	<.001	0.054	0.539	0.191

Notes: Means followed by the same letter(s) in a column are not significantly different at 5% according to the SNK significant difference test. WAS= weeks after sowing, SE= standard error, SHW = supplementary hoe weeding.

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Table 5. Interaction effect between genotype and weed control treatment on 100 seed weight and Grain yield of Bambara nut at Bayero University Kano, Nigeria, during 2021 wet season

Genotype	Weed control										
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
						100-seed weight (g)					
"Duna Baki"	58.77^{h}	87.77^{eg}	89.90^{eg}	87.23^{eg}	89.37^{d-g}	97.50^{a-e}	99.43^{a-d}	104.77^{ab}	103.50 $^{a-e}$	39.47i	105.80^{a}
"Cream"	81.00^{fg}	87.27^{efg}	81.40^{fg}	89.23^{dg}	79.00^{g}	90.17^{de}	97.27^{a-e}	96.83^{a-e}	93.73^{cde}	38.13^{i}	97.23^{a-e}
"Yar Gombe"	79.37^{g}	87.27^{efg}	80.40^{f}	87.23^{efg}	78.97^{g}	88.33^{efg}	94.77^{b-e}	94.27^{b-e}	92.20^{de}	55.00^{h}	103.17^{abc}
						Grain yield (kg.ha^{-1})					
"Duna Baki"	288.7^{m}	532.7^{a}	436.7^{i}	484.3^{f}	445.7^{hi}	488.0^{f}	403.3^{j}	506.7^{cd}	533.0^{a}	522.7^{ab}	517.7^{b}
"Cream"	254.7^{n}	510.0^{bc}	377.7^{l}	460.3^{g}	392.7^{jk}	463.3^{g}	398.0^{j}	458.0^{gh}	507.3^{c}	504.3^{cde}	485.3^{f}
"Yar Gombe"	250.3^{n}	489.3^{f}	382.0^{kl}	464.3^{g}	396.7^{j}	467.7^{g}	403.3^{j}	460.3^{g}	492.3^{df}	490.3^{ef}	483.3^{f}

Notes: T1: weedy check; T2: hoe weeding at 3 and 6 WAS; T3: mazethapyr at 2.0kg a.i.ha^{-1}; T4: imazethapyr at 1.5 + bentazone at 1.5 kg a.i.ha^{-1}; T5: metolachlor at 2.0 kg a.i.ha^{-1}; T6: metolachlor at 1.5 + bentazone at 1.5 kg a.i.ha^{-1}; T7: pendimethalin at 2.0 kg a.i.ha^{-1}; T8: pendimethalin at 1.5 kg a.i.ha^{-1} + bentazone at 1.5 kg a.i.ha^{-1}; T9: pendimethalin at 1.5 kg a.i.ha^{-1} + supplementary hoe weeding; T10: metolachlor at 1.5 kg a.i.ha^{-1}+ supplementary hoe weeding; T11: imazethapyr at 1.5 kg a.i.ha^{-1} + supplementary hoe weeding.

Table 6. Weed species composition of Bambara nut as affected by weed control treatments and genotypes during the 2021 wet season at Bayero University Kano, Nigeria

Weed biotypes	Common names	Family	Life cycle	Level of occurrence
Grasses				
Axonopus compresus (Sw.) P.Beauv.	Broadleaf carpet grass	Poaceae	Annual/biennial	*
Cynodon doctylon Pers	Bermuda grass	Poaceae	Perennial	***
Digitaria ciliaris Retz.) Koeler	Crab grass	Poaceae	Annual	*
Echinochloa colona (L.) Link	Jungle rice	Poaceae	Annual	*
Eragrostic cilianensis ex Janchen	Gray love grass	Poaceae	Annual/biennial	**
Eragrosti cunioloides ex Janchen	Chinese love grass	Poaceae	Annual	**
Polypogon monspeliensis (L.) Desf	Rabbit foot grass	Poaceae	Annual	*
Broadleaf				
Amaranthus spinosus (L.)	Spiny pigweed	Amaranthaceae	Annual	***
Chenopodium murals (L.)	Nettle_leaves goosefoot	Chenopodiaceae	Annual	*
Leucas martinicensis R. Br.	White wort	Lamiaceae	Annual	***
Phyllanthus virgatus G.Forst	Narrow piss weed	Euphorbiaceae	Annual	*
Pseudognaphalium luteoalbum (L.) Hilliard & B.L.Burtt	Cotton weed	Asteraceae	Annual	*
Pupalia lappacea (L.) Juss	Creepingcock's comb	Amaranthaceae	Annual	
Sedges				
Cyperus rotundus	Purple nutsedge	Cyperaceae	Perennial	*
Cyperus esculentus	Yellow nutsedge	Cyperaceae	Perennial	*
Fimbristylis miliacea (L)	Grass-like fimbry	Cyperaceae	Perennial	*

Notes: * = Low infestation 1–29%; ** = Moderate infestation 30–59%; *** = High infestation 60–90%.

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rest of the weed biotypes in cucumber plots could be attributed to the noxiousness of these weeds, as earlier reported by Daramola (2021) and Zubair et al. (2024) to be associated with cucumber and carrot in all ecologies of the world. Heap (2019) also affirms that *Amaranthus* spp is resistant to certain herbicides, hence its noxiousness.

Phytosociological Characteristics of the Weed Biotypes Associated with Bambara Nut

Table 7 presents the weed phytosociological characteristics and their important value index (IVI) of various weed species. The index determines the relative importance of each weed species in a given ecosystem based on their abundance, frequency, and density. The higher the index value, the more important the weed species is. According to Travlos et al. (2018), the weed important value index helps quantify the impact of different management strategies on weed populations and crop yields. *Cynodon dactylon* and *Amaranthus spinosus* had the highest important value index (53.5 and 52.8), indicating that they are the most important weed species in the ecosystem under consideration. This could be due to its high abundance, frequency, and coverage in the area. With just 1-2 plants of *Amaranthus spp.* per square yard growing with cucumber throughout the crop life cycle can reduce yield by 15%, while 5-7 plants of the same species per square yard can reduce cucumber yield by 52%, as reported by Shittu et al. (2024). The *Eleusine indica* (46.6) and *Leucas martinicensis* (42.9) are also important weed species in the ecosystem and also have the highest relative frequency were found to be similar to the findings of Ali et al. (2019) and Muhammad et al. (2021). The findings are also similar to the research of Mahmood et al. (2015), where *E. indica* had reduced the yield of the watermelon field to about 55%, which implies it requires much attention and employing integrated weed management would manage it better. *Pupalia lappacea* (27.2) and *Cyperus rotundus* (22.5) have moderately important value index values, indicating that they are relatively important weed species in the ecosystem; findings from Meleta et al. (2024) recommend the use of non-chemical methods such as hand and hoe weeding in controlling them. *Axonopus compresus* (11.6), *Fimbristylis littoralis* (12.6), *Eragrostis minor* (16.3), and *Echinochloa colona* (17.5) have lower index values, *Polypogon*

Table 7. Phytosociological characteristics of weed biotypes of Bambara nut during 2021 dry wet season at Bayero University Kano, Nigeria

Weed biotypes	M/L	TNI	WD	WF	WA	RF%	RD%	RA%	IVI
Amaranthus spinosus (L.)	BA	63	2.6	33.3	9.0	13.3	8.2	5.72	52.8
Axonopus compresus (Sw.) P. Beauv.	GP	13	0.5	4.2	13.0	1.7	1.6	8.3	11.6
Chenopodium murals (L.)	BA	8	0.2	4.1	7.0	1.5	0.7	4.9	7.6
Cynodon dactylon (L.) Pers	GP	131	5.5	46	12.0	18.4	17.5	7.6	53.5
Cyperus esculentus (L.)	SP	8	0.3	4.2	8.0	1.7	0.9	5.1	7.7
Cyperus rotundus (L.)	SP	51	2.1	29.2	6.4	11.7	6.7	4.1	22.5
Digitaria ciliaris (Retz.) Koeler	GP	35	1.5	8.0	18.0	3.2	4.8	11.5	19.5
Echinochloa colona (L.) Link	GA	37	1.5	17	9.3	6.8	4.8	5.9	17.5
Eleusine indica (L.) Gaertn.	GP	153	6.4	41.7	15.3	16.6	20.3	9.7	46.6
Eragrostis cilianensis ex Janchen	GP	16	0.7	8.0	8.0	3.2	2.2	5.1	10.5
Eragrostis minor ex Janchen	GA	32	1.3	13.0	11.0	5.2	4.1	7.0	16.3
Fimbristylis littoralis (L.) Vahi	SP	14	0.6	4.2	14.0	1.7	1.9	9.0	12.6
Leucas martinicensis R. Br	BA	58	4.4	32.1	8.8	13.1	8.1	5.06	42.9
Polypogon monspeliensis (L.) Desf	GA	2	0.1	4.2	2.0	1.7	0.3	1.3	3.3
Pseudognaphalium luteoalbum (L.) Hilliard & B.L.Burtt	BB	2	0.1	4.2	2.0	1.7	0.3	1.3	3.3
Phyllanthus virgatus G.Forst	BA	2	0.1	4.2	2.0	1.7	0.3	1.3	3.3
Pupalia lappacea (L.) Juss.	BA	209	8.7	37.5	23.2	15.0	27.6	14.8	27.2

Notes: M: morphology; (B: broadleaf, G: grasses, S: sedge) L: lifecycle; (A: annual, B: bennial, P: perennial), TNI: total number of individual; WD: weed density; WF: weed frequency; WA: weed abundance; RF: relative frequency; RD: relative density; RA: relative abundance; IVI: important value index.

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viridis (3.3) and *Eragrostis cilianensis* (10.5) have the lowest important value index values, indicating that they are the least important weed species in the ecosystem under consideration. The major feature of these weed species is their widespread existence and difficulty in management, rapid spread, production of many seeds, high efficiency in water use, and net photosynthesis (McGowen et al., 2018).

The effectiveness of herbicides on different weed species is influenced by factors such as herbicide type, dosage, weed growth stage, and environmental conditions. Predicting a specific weed's response to a herbicide can be challenging due to these variables. Generally, herbicides designed for broadleaf weeds may be less effective on grassy weeds and vice versa. Additionally, weed resistance to herbicides is a growing concern. Diverse weed populations can accelerate this resistance, reducing herbicide efficacy (Heap, 2021). Thus, combining chemical, cultural, and mechanical control methods is essential for successful weed management (Shittu et al., 2024; Shittu and Lamarana, 2024).

Conclusions

The selection of genotypes and weed management techniques considerably impacted Bambara nut performance. Plant height did not significantly differ between genotypes, and "Duna Baki" had the widest canopy. Metolachlor 1.5 kg a.i. ha^{-1} + supplementary hoe weeding applied 6 weeks after sowing, resulting in significantly taller Bambara nuts, whereas the application of metolachlor and + imazethapyr each at 1.5 kg a.i. ha^{-1} + hoe weeding at 6 weeks after sowing considerably produced the widest canopy cover. Dan Baki had the best seed yield, whereas the "Yar Gombe" and "Duna Baki" had the heaviest seed weight. Conversely, a higher 100-seed weight was significantly achieved in Bambara nuts treated with metolachlor and imazethapyr at 1.5 kg a.i. ha^{-1} + supplementary hoe weeding 6 weeks after sowing and a higher seed yield was obtained by crops treated with metolachlor and pendimethalin at 1.5 kg a.i. ha^{-1} + hoe weeding at 6 weeks after sowing and hoe weeding at 3 and 6 weeks after sowing. Farmers in the study area are advised to use the "Duna Baki" genotype applied with metolachlor and pendimethalin, each at 1.5 kg a.i per ha, to efficiently manage weeds and increase yield and + hoe weeding at 6 weeks after sowing.

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