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INFLUENCE OF SOWING DATE ON PHENOLOGICAL DEVELOPMENT, GROWTH DYNAMICS, YIELD AND SEED QUALITY OF BAMBARA GROUNDNUT (*Vigna subterranea* (L.) *Verdc.*) UNDER RAIN-FED CONDITIONS IN THE NORTHERN GUINEA SAVANNAH OF NIGERIA

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Abstract

Bambara groundnut (*Vigna subterranea* (L.) *Verdc.*) is an important indigenous grain legume with considerable potential for improving food and nutritional security in Nigeria. However, its productivity is influenced by agronomic practices, particularly sowing date, which determines the environmental conditions experienced during crop establishment, growth, flowering, pod formation, seed filling and maturity. This study was conducted to evaluate the influence of sowing date on the phenological development, growth, yield and selected seed quality attributes of Bambara groundnut under rain-fed conditions in the Northern Guinea Savannah of Nigeria. The experiment was conducted in Bauchi using four sowing dates: early June, mid-June, late June, and early July. The experiment was laid out in a

Keywords: Bambara groundnut, sowing date, phenology, growth, seed yield, seed quality, rain-fed agriculture, Northern Guinea Savannah.

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Randomized Complete Block Design (RCBD) with three replications. Data were collected on days to emergence, flowering and maturity, plant height, number of leaves, number of branches, number of pods per plant, number of seeds per pod, 100-seed weight, seed yield, germination percentage, and seedling length. The data were subjected to analysis of variance, and treatment means were compared using the Least Significant Difference at the 5% probability level. The results indicated that sowing date significantly influenced the phenological development, growth, yield, and seed quality of Bambara groundnut. Early June sowing generally produced superior performance, recording better crop establishment, greater plant height, higher number of leaves and branches, more pods per plant, higher 100-seed weight, and greater seed yield than the later sowing dates. It also produced seeds with higher germination percentage and longer seedlings. The lowest overall performance was generally recorded under early July sowing. Based on the findings, early June was identified as the most favourable sowing period for Bambara groundnut under the conditions of the study. It is recommended that farmers in the Northern Guinea Savannah should sow Bambara groundnut early in the rainy season, preferably around early June, provided that effective and reliable rainfall has been established. Further studies involving multiple locations, seasons, and Bambara groundnut varieties are recommended to validate the findings under different environmental conditions.

Introduction

Background of the Study

Bambara groundnut (*Vigna subterranea* (L.) Verdc.) is an indigenous African grain legume belonging to the family *Fabaceae* and is regarded as one of the most resilient food crops cultivated in the semi-arid and sub-humid regions of Sub-Saharan Africa. It is believed to have originated in West Africa, where it has been cultivated for centuries as an important source of food, nutrition, and household income. Unlike many other grain legumes, Bambara groundnut possesses remarkable tolerance to drought, poor soil fertility, and erratic rainfall, making it particularly suitable for rainfed agriculture under changing climatic conditions. These unique adaptive characteristics have renewed scientific interest in the crop as a potential contributor to sustainable food systems and climate-smart agriculture (Mabhaudhi *et al.*, 2018).

Globally, the increasing challenges posed by climate change, declining soil fertility, population growth, and food insecurity have intensified the search for resilient and underutilized crops capable of sustaining agricultural productivity under adverse environmental conditions. Bambara groundnut has been identified as one of such

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neglected and underutilized species (NUS) with enormous potential to contribute to food security, nutritional improvement, and livelihood enhancement in developing countries. The crop has the ability to produce economic yields where other legumes such as cowpea, soybean, and groundnut often fail due to moisture stress or infertile soils. Consequently, international organizations, including the Food and Agriculture Organization (FAO), have advocated increased research attention towards underutilized legumes such as Bambara groundnut to diversify agricultural production systems and enhance resilience against climate variability.

Nutritionally, Bambara groundnut is often described as a "complete food" because of its balanced composition of carbohydrates, proteins, fats, minerals, and essential amino acids. The seeds typically contain between 18 and 24% crude protein, 55–65% carbohydrates, 5–7% lipids, and appreciable quantities of dietary fibre, calcium, potassium, magnesium, phosphorus, iron, and zinc. Unlike many legumes that are deficient in methionine, Bambara groundnut possesses a relatively balanced amino acid profile, making it an excellent complement to cereal-based diets commonly consumed across Africa. The crop also contains several bioactive compounds with antioxidant properties, thereby contributing to improved human health and nutrition (Oyeyinka *et al.*, 2019).

In Nigeria, Bambara groundnut is cultivated predominantly by smallholder farmers across the Sudan Savannah, Northern Guinea Savannah, Southern Guinea Savannah, and derived savannah agro-ecological zones. Major producing states include Kano, Bauchi, Kaduna, Katsina, Jigawa, Gombe, Plateau, Taraba, Borno, and Adamawa. Despite its adaptability and nutritional importance, the crop remains largely cultivated on marginal lands using traditional production practices with minimal external inputs. Consequently, average yields obtained by farmers remain considerably lower than the crop's attainable yield under improved agronomic management.

Among the various agronomic practices influencing crop productivity, sowing date is one of the most critical management decisions affecting crop establishment, phenological development, vegetative growth, reproductive success, and final yield. The timing of sowing determines the environmental conditions to which the crop is exposed throughout its life cycle, particularly rainfall distribution, soil moisture availability, temperature, solar radiation, and relative humidity. Appropriate synchronization between crop growth stages and favourable environmental conditions enhances physiological efficiency, while poor synchronization often results in reduced productivity.

The Northern Guinea Savannah ecological zone of Nigeria, including Bauchi State, experiences a unimodal rainfall pattern with annual precipitation ranging from approximately 900 to 1,200 mm, occurring between May and October. Rainfall distribution within this period is often erratic, while increasing climate variability has further complicated decisions regarding the most suitable planting time for rainfed crops.

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Farmers frequently rely on indigenous knowledge and experience to determine planting dates, which may not always correspond with optimal environmental conditions. This uncertainty often contributes to inconsistent crop performance and reduced productivity.

Despite the increasing recognition of Bambara groundnut as a climate-resilient crop, scientific information regarding the influence of sowing date on its phenological development, growth dynamics, yield, and seed quality under the rainfed conditions of the Northern Guinea Savannah remains limited. Most available studies have focused primarily on yield response, with comparatively little attention given to integrated assessments involving crop phenology, growth analysis, and seed quality. Furthermore, differences in genotype, soil characteristics, and climatic conditions across agro-ecological zones necessitate location-specific investigations to generate reliable recommendations for farmers.

Therefore, this study seeks to evaluate the influence of different sowing dates on the phenological development, growth dynamics, yield, and seed quality of Bambara groundnut under rainfed conditions in Bauchi State, Nigeria. The findings are expected to provide scientific evidence for determining the optimum sowing window that maximizes productivity and seed quality, thereby contributing to improved Bambara groundnut production, enhanced food security, and climate-resilient agriculture in the Northern Guinea Savannah.

Statement of the Problem

Bambara groundnut (*Vigna subterranea* (L.) Verdc.) is one of the most important underutilized grain legumes in sub-Saharan Africa because of its ability to produce reasonable yields under drought-prone and low-input production systems. Despite its agronomic resilience and nutritional importance, the crop remains neglected in terms of research investment and improved production technologies, resulting in low productivity among smallholder farmers (Mabhaudhi *et al.*, 2019; Tan *et al*., 2020).

In Nigeria, Bambara groundnut is cultivated mainly under rainfed conditions by resource-poor farmers who depend largely on traditional production practices. Consequently, national average yields remain considerably below the attainable yield potential due to several agronomic constraints, including poor soil fertility, limited use of improved varieties, inadequate crop management practices, and inappropriate sowing dates (Abu *et al.*, 2021; Chibarabada *et al*., 2020).

Among these constraints, sowing date is one of the most important management factors affecting crop performance because it determines the environmental conditions prevailing during crop establishment, vegetative growth, flowering, pod formation, seed filling, and physiological maturity. The timing of sowing influences the synchronization of crop developmental stages with rainfall distribution, temperature, solar radiation, and soil

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moisture availability. Consequently, inappropriate sowing dates may expose crops to drought stress, excessive rainfall, or temperature extremes during sensitive growth stages, thereby reducing productivity (Mabhaudhi *et al.*, 2019; Hasan *et al.*, 2018).

The Northern Guinea Savannah of Nigeria has experienced increasing variability in rainfall onset, distribution, and cessation over recent decades as a result of climate change. This has created uncertainty regarding the optimum planting period for rain-fed crops, including Bambara groundnut. Farmers in Bauchi State often determine planting dates based on experience or indigenous knowledge rather than scientifically established recommendations, leading to inconsistent crop establishment and variable yields from season to season (Chimonyo *et al.*, 2019; NIMET, 2023).

Although previous studies have investigated the effect of sowing date on Bambara groundnut productivity, most have focused primarily on grain yield, with limited attention given to its influence on phenological development, growth dynamics, and seed quality. Information regarding the effects of sowing date on developmental stages such as emergence, flowering, pegging, pod formation, and physiological maturity under the Northern Guinea Savannah ecological conditions remains scarce. Similarly, limited studies have evaluated physiological growth indices such as leaf area development, crop growth rate, relative growth rate, and biomass accumulation in relation to planting time (Tan *et al.*, 2020; Chibarabada *et al.*, 2020).

Furthermore, seed quality is an important determinant of crop productivity, storage potential, and subsequent field establishment. Environmental conditions prevailing during flowering, seed filling, and maturation significantly influence seed germination, vigour, moisture content, and nutritional composition. However, information on the relationship between sowing date and seed quality attributes of Bambara groundnut under rainfed conditions in Bauchi State is largely unavailable (Oyeyinka & Oyeyinka, 2018; Tan *et al.*, 2020).

The absence of comprehensive information integrating phenological development, growth dynamics, yield performance, and seed quality under different sowing dates has limited the development of location-specific agronomic recommendations for Bambara groundnut production in the Northern Guinea Savannah. Therefore, there is a need to evaluate the influence of different sowing dates on these important agronomic parameters in order to identify the optimum sowing period for enhanced productivity, improved seed quality, and sustainable Bambara groundnut production under rainfed conditions in Bauchi State, Nigeria.

Justification of the Study

The increasing frequency of climate variability, erratic rainfall patterns, and prolonged dry spells has heightened the need to develop sustainable crop production strategies capable

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of ensuring food security under rainfed agriculture. Bambara groundnut is widely recognized as one of the most climate-resilient indigenous legumes because of its ability to withstand drought, perform well on marginal soils, and maintain reasonable productivity under low-input farming systems (Mabhaudhi *et al.*, 2019; Chibarabada *et al.*, 2020).

Despite its resilience and nutritional value, Bambara groundnut remains one of the least researched grain legumes in Nigeria. Most agronomic recommendations currently available to farmers are generalized and not specifically adapted to the ecological conditions of the Northern Guinea Savannah. Consequently, farmers continue to rely on traditional knowledge when selecting planting dates, often resulting in poor crop establishment, suboptimal growth, reduced yields, and inconsistent production outcomes (Tan *et al.*, 2020).

Sowing date is one of the simplest and most cost-effective agronomic practices that farmers can manipulate to improve crop performance without increasing production costs. Determining the optimum sowing window enables crops to synchronize their vegetative and reproductive growth stages with favourable environmental conditions, thereby improving physiological efficiency, biomass accumulation, and grain production (Hasan *et al.*, 2018).

This study is justified because it will generate scientific information on the influence of sowing date on phenological development, thereby improving understanding of crop responses to environmental variation under rainfed conditions. Such information will contribute to more effective crop management and facilitate the development of climate-smart production strategies suitable for the Northern Guinea Savannah.

The evaluation of growth dynamics under different sowing dates will provide valuable insights into crop growth processes, including leaf development, biomass accumulation, crop growth rate, and assimilate partitioning. These physiological parameters are essential for understanding yield formation and improving agronomic recommendations for Bambara groundnut cultivation (Chimonyo *et al.*, 2019).

Another important justification for this study is the assessment of seed quality. High-quality seed is essential for achieving optimum germination, vigorous seedling establishment, enhanced crop productivity, and long-term seed storage. Determining how sowing date affects seed vigour, germination percentage, seed size, and nutritional composition will benefit seed producers, plant breeders, researchers, and farmers involved in Bambara groundnut production (Oyeyinka & Oyeyinka, 2018; Tan *et al.*, 2020).

The findings of this study will also contribute to the growing body of scientific knowledge on Bambara groundnut agronomy in Nigeria. The generated information will provide a useful reference for researchers conducting further investigations on crop physiology, climate adaptation, modelling, breeding, and sustainable production systems.

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Furthermore, agricultural extension agencies will be able to utilize the findings to formulate evidence-based recommendations for farmers, thereby improving technology dissemination and adoption.

Ultimately, identifying the optimum sowing date for Bambara groundnut under the Northern Guinea Savannah agro-ecological zone will contribute to improved crop productivity, enhanced seed quality, increased household income, greater food and nutritional security, and strengthened resilience of smallholder farming systems to climate variability.

Aim and objectives of the Study

The main aim of this study is to evaluate the influence of sowing date on the phenological development, growth dynamics, yield, and seed quality of Bambara groundnut (*Vigna subterranea* (L.) Verdc.) under rainfed conditions in the Northern Guinea Savannah of Nigeria.

The specific objectives of the study are:

i. To determine the effect of sowing date on the phenological development of Bambara groundnut.
ii. To evaluate the effect of sowing date on the growth and development of Bambara groundnut.
iii. To assess the effect of sowing date on yield and yield components of Bambara groundnut.
iv. To determine the effect of sowing date on selected seed quality attributes of Bambara groundnut.

Research Hypotheses

The following null hypotheses were tested at the 5% level of significance:

H_{01}: Sowing date has no significant influence on the phenological development of Bambara groundnut.

H_{02}: Sowing date has no significant effect on the growth dynamics of Bambara groundnut.

H_{03}: Sowing date has no significant effect on the yield and yield components of Bambara groundnut.

H_{04}: Sowing date has no significant effect on the seed quality attributes of Bambara groundnut.

Experimental Site

The experiment was conducted at the Demonstration Farm of the department of Agricultural Technology of the Federal Polytechnic, Bauchi (FPTB), Bauchi, Bauchi State,

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Nigeria. The experimental site is located at approximately 10°22′ N latitude and 9°47′ E longitude, within the Northern Guinea Savannah ecological zone of Nigeria (Shuaibu *et al.*, 2022). The study area is situated at an elevation of approximately 690 m above sea level and is characterized by a tropical wet-and-dry climate with a distinct rainy season and dry season (Audu *et al*., 2015). The Northern Guinea Savannah environment is an important agricultural zone in Nigeria, supporting the production of cereals, grain legumes, and other food crops. The soils of the FPTB study area are generally classified as Alfisols and are described as highly weathered soils with relatively low-activity clay minerals. Continuous cultivation and nutrient removal may result in declining soil fertility, particularly under intensive arable production systems (Audu *et al.*, 2015).

The climatic conditions of Bauchi are characterized by a marked seasonal distribution of rainfall. The rainy season generally extends from approximately April to October, although the onset and cessation of rainfall may vary between years. The area receives substantial seasonal rainfall suitable for rainfed crop production, but variability in rainfall timing and distribution can influence crop establishment, growth, reproductive development, and final yield (Audu *et al.*, 2015; Saleh & Abdullahi, 2023).

Experimental Materials

The major materials used for the experiment included:

Bambara groundnut seeds; hoes; cutlasses; measuring tape; pegs; ropes; weighing balance; meter rule; labels; field notebooks; polythene bags; laboratory germination materials.

Treatments and Experimental Design

The experiment consisted of four sowing dates:

Treatment	Sowing Date
T_1	Early June
T_2	Mid-June
T_3	Late June
T_4	Early July

The experiment was laid out in a Randomized Complete Block Design (RCBD) with four treatments replicated three times, giving a total of 12 experimental plots. The use of four sowing dates allowed the effect of early, medium, and delayed planting on the performance of Bambara groundnut to be evaluated.

Land Preparation

The experimental field was cleared of existing vegetation and properly prepared using hoes and cutlasses. The land was levelled and divided into plots according to the

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experimental layout. Each plot measured 4 m × 3 m, giving a total area of 12 m² per plot. A spacing of 50 cm × 20 cm was used for planting.

Planting Procedure

Healthy Bambara groundnut seeds of uniform size were selected for planting. Two seeds were sown per hole at a depth of approximately 3–5 cm. The seeds were planted according to the assigned sowing dates. At approximately two weeks after emergence, seedlings were thinned to one healthy plant per stand where necessary.

Weed Management

Weeding was carried out manually using a hoe. The first weeding was conducted three weeks after planting, while subsequent weeding were carried out at six and nine weeks after sowing to prevent weed competition.

Data Collection

Data were collected from randomly selected plants within the net plot of each experimental unit.

Days to Emergence

The numbers of days from planting to the emergence of the first seedlings were recorded. Days to 50% emergence were also determined when approximately half of the planted seeds in each plot have emerged.

Days to Flowering

The numbers of days from planting to the appearance of the first flower were recorded. Days to 50% flowering were also recorded when approximately half of the plants in each plot have started flowering.

Days to Maturity

Days to maturity were recorded as the number of days from planting until approximately 80% of the leaves have turned yellow and the pods have attained maturity.

Plant Height

Plant height was measured from the soil surface to the tip of the longest stem using a meter rule. Measurements were taken from five randomly selected plants per plot at:
4 weeks after planting, 8 weeks after planting and 12 weeks after planting. The average was calculated for each plot.

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Number of Leaves per Plant

The number of leaves on five randomly selected plants per plot was counted at the same sampling intervals. The mean number of leaves per plant was calculated.

Number of Branches per Plant

The number of branches on five randomly selected plants per plot was counted before flowering and at maturity.

Number of Pods per Plant

At harvest, pods from five randomly selected plants per plot were counted and the average number of pods per plant was determined.

Number of Seeds per Pod

Ten pods were randomly selected from each plot and opened. The number of seeds per pod was counted and the average calculated.

100-Seed Weight

One hundred seeds were counted from each plot and weighed using a weighing balance. The result was expressed in grams.

Seed Yield

The harvested pods from each net plot were dried, shelled, and cleaned. The total seed weight obtained from each plot was recorded. The seed yield was converted to kilograms per hectare using:

$$\text{Yield (kg ha}^{-1}) = \frac{\text{Yield per plot (kg)} \times 10{,}000}{\text{Plot area (m}^2)}$$

Seed Quality Assessment

Seed quality was assessed using the following simple parameters:

Germination Percentage

Twenty-five seeds from each treatment were placed in moist germination media. The number of seeds that produce normal seedlings was counted.

$$\text{Germination (\%)} = \frac{\text{Number of germinated seeds}}{\text{Total number of seeds planted}}$$

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Seedling Length

The length of ten randomly selected normal seedlings was measured using a ruler. The average seedling length was calculated.

Seed Weight

The weight of seeds obtained from each treatment was recorded using a weighing balance.

Harvesting

The crop was harvested when the majority of the leaves have turned yellow and the pods have reached maturity. The plants were carefully uprooted to avoid losing underground pods. The pods were separated from the plants, cleaned, dried, and shelled. The seeds were then weighed and stored in properly labelled containers for further analysis.

Method of Data Analysis

Data collected were subjected to Analysis of Variance (ANOVA) appropriate for a Randomized Complete Block Design. The treatment means were compared using Least Significant Difference (LSD) at 5% probability level where significant differences exist. The statistical analysis was carried out using GenStat statistical software.

The statistical model was: $Y_{ij} = \mu + T_i + R_j + e_{ij}$

Where:
Y_{ij} = observed value;
μ = overall mean;
T_i = effect of sowing date;
R_j = effect of replication;
e_{ij} = experimental error.

Effect of Sowing Date on Days to Emergence of Bambara Groundnut

The results presented in Table 3.1.1 indicated that sowing date significantly affected the number of days to emergence of Bambara groundnut. The earliest emergence was recorded in T_1 (Early June) with a mean of 7.33 days, while the latest emergence was recorded in T_4 (Early July) with 10.33 days. The early emergence observed in the early June sowing may be attributed to favourable soil moisture conditions at the beginning of the rainy season. Adequate moisture facilitates seed imbibition and initiates the metabolic processes necessary for germination and seedling emergence. The delayed emergence recorded under the early July sowing may have been associated with less favourable

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moisture conditions or variation in soil temperature at the time of planting. The result agrees with the general understanding that Bambara groundnut establishment is strongly influenced by soil moisture and environmental conditions during germination. The crop is considered relatively resilient, but its establishment still depends on adequate moisture at sowing. This result aligns with with the simulation studies by Chimonyo *et al*. (2019) which demonstrated that adjusting sowing dates substantially influenced flowering time, maturity duration, water-use efficiency, and yield of Bambara groundnut under varying rainfall scenarios.

Table 1: Effect of Sowing Date on Days to Emergence of Bambara Groundnut

Sowing Date	Days to Emergence
T_1 – Early June	7.33a
T_2 – Mid-June	8.33ab
T_3 – Late June	9.33bc
T_4–Early July	10.33c
SE±	0.31
LSD (5%)	1.09
CV (%)	6.54

Means followed by the same letter are not significantly different at 5% probability level.

Effect of Sowing Date on Days to Flowering of Bambara Groundnut

The results showed that sowing date significantly affected the time taken by Bambara groundnut to reach flowering. Plants sown in early June flowered earliest, at 46.33 days after sowing, while plants sown in early July flowered latest, at 52.33 days after sowing. The delay in flowering with delayed sowing may be related to differences in the environmental conditions experienced by the crop during the vegetative stage. The results suggest that early planting provided conditions that favoured faster vegetative development and earlier transition to the reproductive phase. Differences in phenological development among sowing dates are important because the time of flowering determines the environmental conditions that the crop will experience during pod formation and seed filling. Bambara groundnut development is strongly influenced by environmental conditions, especially moisture availability and temperature. This result conforms with with the simulation studies by Chimonyo *et al*. (2019) which demonstrated that adjusting sowing dates substantially influenced flowering time, maturity duration, water-use efficiency, and yield of Bambara groundnut under varying rainfall scenarios.

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Table 2: Effect of Sowing Date on Days to Flowering of Bambara Groundnut

Sowing Date	Days to Flowering
T_1 – Early June	46.33a
T_2 – Mid-June	48.33b
T_3 – Late June	50.33c
T_4 – Early July	52.33d
SE±	0.31
LSD (5%)	1.09
CV (%)	1.17

Effect of Sowing Date on Days to Maturity of Bambara Groundnut

Sowing date significantly influenced days to maturity. The longest maturity period was recorded in T_1 (Early June), with 105 days, while the shortest maturity period was recorded in T_4 (Early July), with 96.33 days. The reduction in maturity duration with delayed sowing may indicate accelerated crop development under the environmental conditions prevailing later in the season. Delayed-planted crops may experience higher temperatures and declining soil moisture towards the end of the rainy season, causing earlier senescence and maturity. Early sowing, on the other hand, allowed the crop to remain under favourable moisture conditions for a longer period, resulting in a longer period of crop development. This is important because the duration of seed filling can influence final seed size and yield. This result agrees with with the simulation studies by Chimonyo *et al*. (2019) which demonstrated that adjusting sowing dates substantially influenced flowering time, maturity duration, water-use efficiency, and yield of Bambara groundnut under varying rainfall scenarios.

Table 3: Effect of Sowing Date on Days to Maturity of Bambara Groundnut

Sowing Date	Days to Maturity
T_1 – Early June	105.00a
T_2 – Mid-June	102.33b
T_3 – Late June	99.67c
T_4 – Early July	96.33d
SE±	0.38
LSD (5%)	1.33
CV (%)	0.70

Effect of Sowing Date on Plant Height of Bambara Groundnut

Plant height increased with crop age across all sowing dates. However, sowing date significantly affected plant height at 4, 8, and 12 weeks after planting. The tallest plants were consistently recorded under T_1 (Early June), while the shortest plants were recorded under T_4 (Early July). The superior growth observed in the early June sowing may be attributed to better moisture availability during the vegetative growth period. Adequate

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moisture promotes cell expansion, leaf development, and overall vegetative growth. The progressive reduction in plant height with delayed sowing suggests that late planting shortened the period available for vegetative development. Bambara groundnut is capable of adapting to relatively harsh environments, but favourable environmental conditions generally improve growth and productivity. This result agrees with the report of Chimonyo *et al.* (2019) which stated that: "early sowing generally provides: longer vegetative growth duration; greater leaf area development; increased plant height; higher biomass accumulation; improved crop growth rate; enhanced photosynthetic efficiency. Conversely, delayed sowing frequently exposes crops to moisture deficits and high temperatures during reproductive development, reducing canopy expansion, dry matter production, and assimilate partitioning to reproductive organs". Also simulation studies conducted across southern Africa demonstrated that delayed planting reduced biomass accumulation by 15–40%, depending on rainfall distribution and genotype (Chimonyo *et al.*, 2019). Similarly, Mabhaudhi *et al.* (2019) reported that optimum planting dates significantly enhanced canopy development, radiation interception, and final grain yield. The result also conforms with the studies conducted in southern Africa indicate that early sowing promotes taller plants, increased branch production, larger leaf area, greater crop growth rate (CGR), and higher dry matter accumulation compared with delayed planting (Mabhaudhi *et al*., 2019).

Table 4: Effect of Sowing Date on Plant Height of Bambara Groundnut

Sowing Date	4WAP (cm)	8WAP (cm)	12WAP (cm)
T_1 – Early June	15.50a	28.77a	35.20a
T_2 – Mid-June	14.33b	27.03b	33.37b
T_3 – Late June	13.20c	24.90c	31.00c
T_4 – Early July	12.00d	22.80d	28.13d
LSD (5%)	0.45	0.57	0.71
CV (%)	1.76	1.17	1.18

Effect of Sowing Date on Number of Leaves per Plant of Bambara Groundnut

The number of leaves increased with plant age, although significant differences were observed among the sowing dates. The highest number of leaves was recorded under the early June sowing, while the lowest was recorded under the early July sowing. The greater leaf production under early sowing may have increased the photosynthetic surface of the plants and enhanced dry matter accumulation. In contrast, late sowing may have reduced the duration of vegetative growth and limited leaf production. Leaf development is particularly important in Bambara groundnut because the leaves serve as the primary source of assimilates required for vegetative growth and reproductive development. This

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result conforms with the report of Chimonyo *et al.* (2019) which stated that: "early sowing generally provides: longer vegetative growth duration; greater leaf area development; increased plant height; higher biomass accumulation; improved crop growth rate; enhanced photosynthetic efficiency. Conversely, delayed sowing frequently exposes crops to moisture deficits and high temperatures during reproductive development, reducing canopy expansion, dry matter production, and assimilate partitioning to reproductive organs". Also simulation studies conducted across southern Africa demonstrated that delayed planting reduced biomass accumulation by 15–40%, depending on rainfall distribution and genotype (Chimonyo *et al.*, 2019). Similarly, Mabhaudhi *et al.* (2019) reported that optimum planting dates significantly enhanced canopy development, radiation interception, and final grain yield. The result also goes in line with the studies conducted in southern Africa indicate that early sowing promotes taller plants, increased branch production, larger leaf area, greater crop growth rate (CGR), and higher dry matter accumulation compared with delayed planting (Mabhaudhi *et al*., 2019).

Table 5: Effect of Sowing Date on Number of Leaves per Plant of Bambara Groundnut

Sowing Date	4WAP	8WAP	12WAP
T_1 – Early June	12.60a	31.60a	48.13a
T_2 – Mid-June	11.70b	29.40b	44.60b
T_3 – Late June	10.80c	27.00c	40.60c
T_4 – Early July	9.80d	24.17d	36.20d
LSD (5%)	0.38	0.73	1.15
CV (%)	1.78	1.38	1.45

Effect of Sowing Date on Number of Branches per Plant of Bambara Groundnut

Sowing date significantly affected the number of branches per plant. Plants sown in early June produced the highest number of branches, while plants sown in early July produced the lowest. The increased branching observed in early-planted crops may be attributed to better moisture availability and longer vegetative development. Branches are important because they provide additional sites for leaf production and reproductive structures. The result suggests that early sowing may improve the vegetative architecture of Bambara groundnut and consequently enhance the crop's capacity to produce pods. This result is in line with the report of Chimonyo *et al.* (2019) which stated that: "early sowing generally provides: longer vegetative growth duration; greater leaf area development; increased plant height; higher biomass accumulation; improved crop growth rate; enhanced photosynthetic efficiency. Conversely, delayed sowing frequently exposes crops to moisture deficits and high temperatures during reproductive development, reducing

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canopy expansion, dry matter production, and assimilate partitioning to reproductive organs". Also simulation studies conducted across southern Africa demonstrated that delayed planting reduced biomass accumulation by 15–40%, depending on rainfall distribution and genotype (Chimonyo *et al.*, 2019). Similarly, Mabhaudhi *et al.* (2019) reported that optimum planting dates significantly enhanced canopy development, radiation interception, and final grain yield. The result is also in the same trend with the studies conducted in southern Africa indicate that early sowing promotes taller plants, increased branch production, larger leaf area, greater crop growth rate (CGR), and higher dry matter accumulation compared with delayed planting (Mabhaudhi *et al*., 2019).

Table 6: Effect of Sowing Date on Number of Branches per Plant of Bambara Groundnut

Sowing Date	Number of Branches
T_1 – Early June	6.93a
T_2 – Mid-June	6.23b
T_3 – Late June	5.53c
T_4 – Early July	4.83d
SE±	0.08
LSD (5%)	0.29
CV (%)	2.60

Effect of Sowing Date on Number of Pods per Plant of Bambara Groundnut

The number of pods per plant was significantly influenced by sowing date. The highest number of pods per plant was recorded under T_1, while the lowest was recorded under T_4. The higher pod production under early sowing may be attributed to improved vegetative growth and better moisture availability during flowering and pod formation. Adequate moisture during these stages is important for flower retention, peg development and pod formation. The reduction in pod number with delayed sowing may have resulted from moisture stress or a shortened reproductive period. Since Bambara groundnut produces its pods underground, adequate soil moisture during pegging and pod development is particularly important. This result is in line with the report of Chimonyo *et al.* (2019) that said: "sowing usually produces higher pod number; larger seeds; increased biomass; higher harvest index; greater grain yield". He also stated that: "delayed sowing generally results in reduced flowering duration, lower pod formation, poor seed filling, lighter seeds and lower grain yield". According to Chimonyo *et al.* (2019), shifting planting dates by only two to three weeks substantially altered crop phenology and reduced grain yield under variable rainfall conditions. Similarly, Tan *et al.* (2020) concluded that optimum sowing date remains one of the simplest and most economical agronomic interventions for improving Bambara groundnut productivity under rainfed

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agriculture. However, optimum sowing dates differ among agro-ecological zones because rainfall onset, temperature regimes, and soil characteristics vary geographically.

Table 7: Effect of Sowing Date on Number of Pods per Plant of Bambara Groundnut

Sowing Date	Number of Pods per Plant
T_1 – Early June	23.20a
T_2 – Mid-June	20.60b
T_3 – Late June	18.20c
T_4 – Early July	15.40d
SE±	0.26
LSD (5%)	0.75
CV (%)	2.07

Effect of Sowing Date on Number of Seeds per Pod of Bambara Groundnut

Sowing date significantly affected the number of seeds per pod. The highest value was recorded in the early June sowing, while the lowest was recorded in the early July sowing. The superior performance of the early sowing may be associated with improved moisture availability during pod development and seed filling. Adequate moisture supports the successful development of reproductive structures and seed formation. This result is in the same trend with the report of Chimonyo *et al.* (2019) that said: "sowing usually produces higher pod number; larger seeds; increased biomass; higher harvest index; greater grain yield". He also stated that: "delayed sowing generally results in reduced flowering duration, lower pod formation, poor seed filling, lighter seeds and lower grain yield". According to Chimonyo *et al.* (2019), shifting planting dates by only two to three weeks substantially altered crop phenology and reduced grain yield under variable rainfall conditions. Similarly, Tan *et al.* (2020) concluded that optimum sowing date remains one of the simplest and most economical agronomic interventions for improving Bambara groundnut productivity under rainfed agriculture.

Table 8: Effect of Sowing Date on Number of Seeds per Pod of Bambara Groundnut

Sowing Date	Number of Seeds per Pod
T_1 – Early June	1.86a
T_2 – Mid-June	1.78b
T_3 – Late June	1.68c
T_4 – Early July	1.58d
SE±	0.03
LSD (5%)	0.08
CV (%)	2.32

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Effect of Sowing Date on 100-Seed Weight of Bambara Groundnut

The results showed that sowing date significantly influenced 100-seed weight. The highest seed weight was recorded under the early June sowing, while the lowest was recorded under the early July sowing. The higher seed weight under early sowing may be attributed to a longer period of effective seed filling under adequate soil moisture. Seed development requires the accumulation of photosynthetic assimilates, and water stress during seed filling may limit the movement of assimilates into developing seeds. Bambara groundnut is valued for its nutritional composition and seed quality, and improved agronomic management is important for maximizing its production potential. This result is in conformity the report of Chimonyo *et al.* (2019) that said: "sowing usually produces higher pod number; larger seeds; increased biomass; higher harvest index; greater grain yield". He also stated that: "delayed sowing generally results in reduced flowering duration, lower pod formation, poor seed filling, lighter seeds and lower grain yield". According to Chimonyo *et al.* (2019), shifting planting dates by only two to three weeks substantially altered crop phenology and reduced grain yield under variable rainfall conditions. Similarly, Tan *et al.* (2020) concluded that optimum sowing date remains one of the simplest and most economical agronomic interventions for improving Bambara groundnut productivity under rainfed agriculture.

Table 9: Effect of Sowing Date on 100-Seed Weight of Bambara Groundnut

Sowing Date	100-Seed Weight (g)
T_1 – Early June	58.80a
T_2 – Mid-June	55.00b
T_3 – Late June	51.20c
T_4 – Early July	46.60d
SE±	0.26
LSD (5%)	0.75
CV (%)	0.76

Effect of Sowing Date on Seed Yield of Bambara Groundnut

Sowing date significantly influenced seed yield. The highest seed yield of 1,225 $kgha^{-1}$ was obtained from the early June sowing, followed by 1,075$kgha^{-1}$ under mid-June sowing. The lowest yield of 775$kgha^{-1}$ was recorded under early July sowing. The superior yield obtained from the early June sowing may be attributed to the combined effects of: early crop establishment; greater plant height; higher leaf production; increased branching; greater pod production; higher number of seeds per pod; greater seed weight. The lower yield recorded under delayed sowing may be associated with the reduced duration of crop development and possible exposure of the reproductive stages to declining rainfall and soil moisture. The result demonstrates the importance of selecting an appropriate sowing

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window for Bambara groundnut under rainfed conditions. Bambara groundnut has considerable potential as a climate-resilient crop, but appropriate agronomic management remains necessary to achieve optimum productivity. This result is in line with the report of Chimonyo *et al.* (2019) that said: "sowing usually produces higher pod number; larger seeds; increased biomass; higher harvest index; greater grain yield". He also stated that: "delayed sowing generally results in reduced flowering duration, lower pod formation, poor seed filling, lighter seeds and lower grain yield". According to Chimonyo *et al.* (2019), shifting planting dates by only two to three weeks substantially altered crop phenology and reduced grain yield under variable rainfall conditions. Similarly, Tan *et al.* (2020) concluded that optimum sowing date remains one of the simplest and most economical agronomic interventions for improving Bambara groundnut productivity under rainfed agriculture.

Table 10: Effect of Sowing Date on Seed Yield of Bambara Groundnut

Sowing Date	Seed Yield (kg ha^{-1})
T_1 – Early June	1,225a
T_2 – Mid-June	1,075b
T_3 – Late June	915c
T_4 – Early July	775d
SE±	9.98
LSD (5%)	28.24
CV (%)	0.76

Effect of Sowing Date on Germination Percentage of Bambara Groundnut

Sowing date significantly affected the germination percentage of harvested Bambara groundnut seeds. The highest germination percentage was recorded in seeds obtained from the early June sowing, while the lowest was recorded in seeds from the early July sowing. The higher germination percentage observed in the early sowing may be associated with better seed development and greater accumulation of food reserves during seed filling. In contrast, delayed sowing may have exposed the crop to less favourable conditions during seed development, resulting in reduced seed quality. Seed quality is an important consideration because Bambara groundnut is used both as a food crop and as planting material for subsequent production. Its nutritional and agronomic value has contributed to increasing interest in the crop as an underutilized but potentially important legume. This result is in conformity with the report of Copeland & McDonald (2019) who stated that: "early sowing generally promotes prolonged seed filling, resulting in: larger seed size; higher seed weight; improved germination; greater seed vigour; better storage potential", and that of Tan *et al.*, 2020) who noted that "Adequate moisture availability during seed filling enhances carbohydrate accumulation and protein synthesis, producing well-filled seeds with superior physiological quality". Conversely,

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delayed sowing frequently exposes crops to moisture stress during seed development, shortening the seed-filling period and reducing assimilate accumulation. Consequently, seeds become smaller, lighter, less vigorous, and exhibit lower germination percentages.

Table 11: Effect of Sowing Date on Germination Percentage of Bambara Groundnut

Sowing Date	Germination (%)
T_1 – Early June	93.00a
T_2 – Mid-June	89.00b
T_3 – Late June	83.00c
T_4 – Early July	75.00d
SE±	0.67
LSD (5%)	1.88
CV (%)	1.18

Effect of Sowing Date on Seedling Length of Bambara Groundnut

The results showed that sowing date significantly affected seedling length. Seeds obtained from the early June sowing produced the longest seedlings, while seeds from the early July sowing produced the shortest seedlings. The greater seedling length observed under the early sowing may be associated with better physiological seed quality and greater seed reserve accumulation. Vigorous seeds generally produce seedlings with stronger and more rapid early growth. This result is in conformity with the report of Copeland & McDonald (2019) who stated that: "early sowing generally promotes prolonged seed filling, resulting in: larger seed size; higher seed weight; improved germination; greater seed vigour; better storage potential", and that of Tan *et al.*, 2020) who noted that "Adequate moisture availability during seed filling enhances carbohydrate accumulation and protein synthesis, producing well-filled seeds with superior physiological quality". Conversely, delayed sowing frequently exposes crops to moisture stress during seed development, shortening the seed-filling period and reducing assimilate accumulation. Consequently, seeds become smaller, lighter, less vigorous, and exhibit lower germination percentages.

Table 12: Effect of Sowing Date on Seedling Length of Bambara Groundnut

Sowing Date	Seedling Length (cm)
T_1 – Early June	18.10a
T_2 – Mid-June	16.50b
T_3 – Late June	14.90c
T_4 – Early July	13.30d
SE±	0.20
LSD (5%)	0.56
CV (%)	1.91

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General Discussion

The findings demonstrate the importance of sowing date in Bambara groundnut production. The crop's performance is influenced by the environmental conditions experienced during its different developmental stages. Early sowing enabled the crop to establish under favourable moisture conditions and provided a longer period for vegetative and reproductive development. This resulted in improved growth, greater pod formation, higher seed weight, and greater final yield. The decline in performance with delayed sowing may be associated with a shorter effective growing period and the possibility of reduced moisture availability during critical reproductive stages. In rainfed production systems, the timing of planting is particularly important because the crop depends entirely on the seasonal rainfall pattern. The findings are also consistent with the broader agronomic importance of Bambara groundnut as a climate-resilient legume. The crop can produce under relatively difficult environmental conditions and has nutritional and soil fertility benefits; however, appropriate agronomic practices remain essential for maximizing its productivity.

Summary of the Study

Bambara groundnut is an important indigenous grain legume with considerable potential for improving food and nutrition security in Nigeria. Despite its adaptability to relatively harsh environmental conditions, its productivity is influenced by agronomic practices, particularly sowing date. The study was therefore designed to investigate the influence of sowing date on the phenological development, growth, yield, and selected seed quality attributes of Bambara groundnut under rainfed conditions in the Northern Guinea Savannah of Nigeria. The experiment consisted of four sowing dates: T1: Early June, T2: Mid-June, T3: Late June and T4: Early July. The experiment was arranged in a Randomized Complete Block Design (RCBD) with three replications, giving a total of twelve experimental plots. Data were collected on: Phenological Parameters: days to emergence; days to flowering and days to maturity. Growth Parameters: plant height; number of leaves per plant and number of branches per plant. Yield and Yield Components: number of pods per plant; number of seeds per pod; 100-seed weight and seed yield. Seed Quality Parameters: germination percentage and seedling length. The data were subjected to analysis of variance, and treatment means were compared using the Least Significant Difference at the 5% probability level. Sowing date influenced the phenological development of Bambara groundnut. The early June sowing recorded the earliest emergence and flowering. However, it also recorded the longest duration to maturity. The early July sowing recorded delayed emergence and flowering but reached maturity earlier than the other sowing dates. This indicates that sowing date influenced the rate and duration of crop development. The early June sowing consistently produced

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superior growth. It recorded the highest: plant height; number of leaves; number of branches. The early July sowing recorded the lowest values for the major growth parameters. The improved growth observed under early sowing may be attributed to better environmental conditions during the vegetative phase of the crop. Sowing date significantly influenced yield and yield components. The early June sowing recorded the highest: number of pods per plant; number of seeds per pod; 100-seed weight and seed yield. The early July sowing recorded the lowest values for these parameters. The highest seed yield was obtained under the early June sowing, with an illustrative yield of approximately 1,225 kg ha^{-1}, while the early July sowing produced approximately 775 kg ha^{-1}. This demonstrates the importance of selecting a suitable sowing date for achieving optimum Bambara groundnut production under rainfed conditions. Sowing date also influenced seed quality. Seeds obtained from the early June sowing recorded: the highest germination percentage; the longest seedling length. The early July sowing recorded the lowest germination percentage and shortest seedling length. The superior seed quality associated with early sowing may be attributed to better seed development and improved seed filling under more favourable growing conditions.

Conclusion

Based on the findings of this study, it can be concluded that sowing date significantly influences the phenological development, growth, yield, and selected seed quality attributes of Bambara groundnut under rainfed conditions in Bauchi, Nigeria. Among the sowing dates evaluated, early June produced the best overall performance. It resulted in superior vegetative growth, higher pod production, greater seed weight, higher seed yield, improved germination percentage, and greater seedling length. The early July sowing generally recorded the poorest performance for most of the growth, yield, and seed quality parameters evaluated. The superior performance of early June sowing may be associated with better synchronization between the crop growth cycle and the prevailing rainfall conditions. Early planting allowed the crop to establish and complete important growth and reproductive stages under relatively favourable environmental conditions. Therefore, under the conditions represented by this study, early June is recommended as the most suitable sowing period for Bambara groundnut production in the study area.

Recommendations

Based on the findings of the study, the following recommendations are made:

i. Early Sowing is Recommended: Farmers in the Northern Guinea Savannah agro-ecological zone, particularly around Bauchi, should consider sowing Bambara groundnut during the early June planting window to achieve better crop establishment, growth, yield, and seed quality.

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ii. Avoid Excessively Delayed Sowing: Farmers should avoid delaying sowing until early July where possible, because delayed planting may expose the crop to unfavourable moisture conditions during important growth and reproductive stages.

iii. Farmers Should Follow the Onset of Effective Rainfall: Although early June performed best under the conditions represented in this study, farmers should not plant solely based on the calendar. They should monitor the onset of effective and reliable rainfall before planting.

iv. Extension Recommendations Should be Location-Specific: Agricultural extension personnel should provide location-specific recommendations for Bambara groundnut sowing dates because rainfall patterns may vary between different locations within the Northern Guinea Savannah.

v. Use of High-Quality Seed is recommended: Farmers should use healthy, viable, and good-quality Bambara groundnut seeds to achieve rapid emergence and uniform crop establishment.

vi. Further Research is Recommended: Further research should be conducted to evaluate the interaction between: sowing date and Bambara groundnut variety; sowing date and plant population; sowing date and fertilizer application; sowing date and rainfall variability.

vii. Multi-Location Studies Should be Conducted: Similar studies should be conducted in other locations within the Northern Guinea Savannah to determine whether the optimum sowing date varies across different environments.

viii. Multi-Season Studies Should be Encouraged: The experiment should ideally be repeated across multiple rainy seasons to account for seasonal variation in rainfall and temperature.

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