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RESEARCH ARTICLE OPEN ACCESS

Response of castor (*Ricinus communis* L.) to organic fertilizer application and sowing date in the humid tropics

M.A. Kasali[1], V.I.O. Olowe[2,*], O.S. Sakariyawo[1] and P.U. Odueme[2]

[1]Department of Plant Physiology and Crop Production, Federal University of Agriculture, Abeokuta (FUNAAB) P. M. B.2240, Abeokuta, Nigeria
[2] Institute of Food Security, Environmental Resources and Agricultural Research (IFSERAR), FUNAAB

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Abstract – There is limited information on the appropriate agronomic practices for castor in the humid tropics. This study evaluated the effects of organic fertilizer (OF) and sowing date (SD) on the agronomic performance of castor during late cropping season (June – Dec.) of 2021 and 2022 at the Institute of Food Security, Environmental Resources and Agricultural Research, Abeokuta, Nigeria. Two factors: OF – control and organic fertilizer (main plot) and SD – eight sowing dates (SD1-SD8 *i.e.*, from June 18 to August 5) at 7-day intervals (sub plot) were laid in a split-plot arrangement fitted into Randomized Complete Block Design in three replicates. Data were collected on agronomic traits of castor. Organic fertilizer significantly ($P < 0.05$) expedited days to flowering and increased height to primary raceme in 2021. SD had significant ($P < 0.05$) effect on days of flowering, seed yield, and yield attributes of castor. Castor sown at SD1 and SD2 in 2022 produced high seed yield of 773.7 and 799.1 kg/ha higher by 498.8% and 503.0% than SD8 yield of 129.2 kg/ha. It is concluded that for optimum castor seed production, sowing should be done from June 18 to latest July 2 with or without organic fertilizer in the humid tropics.

Keywords: Agronomic performance / growth / phenology / seed yield / traits

Résumé – Réponse du ricin (*Ricinus communis 1* L.) à l'application d'engrais organiques et à la date de semis en zones tropicales humides. Il existe peu d'informations sur les pratiques agronomiques adaptées au ricin en zones tropicales humides. Cette étude a évalué les effets de l'engrais organique (*organic fertilizer*, OF) et de la date de semis (*sowing date*, SD) sur la performance agronomique du ricin pendant la saison tardive de culture (juin – décembre) de 2021 et 2022 à l'*Institute of Food Security, Environmental Resources and Agricultural Research*, Abeokuta, Nigéria. Deux facteurs, OF – contrôle ou engrais organique (parcelle principale)- et SD – huit dates de semis (SD1-SD8, soit du 18 juin au 5 aoÛt) à 7 jours d'intervalle (sous-parcelle)- ont été étudiés dans un plan expérimental randomisé en *split-plot* (dispositif à parcelles subdivisées) avec trois répétitions. Des données ont été collectées sur les caractéristiques agronomiques du ricin. L'apport d'engrais organique a significativement ($P < 0,05$) accéléré les dates de floraison et augmenté la hauteur de l'inflorescence primaire en 2021. La date du semis a eu un effet significatif ($P < 0,05$) sur les dates de floraison, le rendement en graines et les composantes du rendement du ricin. Le ricin semé en SD1 et SD2 en 2022 a produit un rendement en graines élevé de 773,7 et 799,1 kg/ha, supérieur de 499% et 503% à celui obtenu en SD8 (129,2 kg/ha). Il est conclu que pour une production optimale de graines de ricin, le semis doit être effectué précocement soit du 18 juin au 2 juillet, avec ou sans engrais organique, dans les zones tropicales humides.

Mots-clés : Performance agronomique / croissance / phénologie / rendement en graines / caractères

*Corresponding author: olowevio@funaab.edu.ng

Highlights

- Response of castor to organic fertilizer (OF) application and sowing date (SD) was investigated in Nigeria. SD had more significant effect on most agronomic traits than OF. No significant OF×SD was recorded.
- For optimum production of castor, sowing can be done from SD1 (June 18) to latest SD3 (July 2) with or without organic fertilizer in the tropics.

1 Introduction

Castor (*Ricinus communis* L.) is an oilseed crop with seed that contains 40–60% oil, 1–5% ricin, 0.3–0.5% ricinin, 4.3% N, 1.8% P and 1.3% K (Perdomo *et al.,* 2013; Mondal and Das, 2019). The oil is one of the rare natural high-purity glycerides, because the fatty acid portion contains almost 90% ricinoleic acid (Akpan *et al.,* 2006). Castor oil is non-volatile, non-drying, light yellow, and widely used for industrial and medical purposes and others such as its leaves for feeding silkworms, oil traditionally used as purgative and in the preparation of various cosmetic products, plastic industry, lubricants and manufacturing of biofuel (Ogunniyi, 2006). Castor is usually grown during rainy season and is often affected by early/mid/terminal drought leading to partial loss or even complete crop failure in the tropics (Ramanjaneyulu *et al.,* 2013). Castor cake is a rich organic fertilizer as it contains about 5.5% Nitrogen, 1.8–1.9% Phosphorus, 1.1% Potassium, and other nutrients (Lima *et al.,* 2011; Shrirame *et al.,* 2011). Castor grows in a wide range of environments such as the warm-temperate and tropical regions, and flourishes under varieties of climate conditions (Severino *et al.,* 2012; Salihu *et al.,* 2014) As of 2022, this crop occupied 1.24 Mha in the world, with a production of 1.82 Mt and an average world yield of 1.5 t/ha (FAOSTAT, 2024).

In Africa, 106,796.94 kg of castor was produced in 2022 and it corresponded to only 5.8% of the world's production (1.82 Mt) with a low average yield of 0.4 t/ha from a total of 264.877 ha (FAOSTAT, 2024). This is against the backdrop of rising demand for castor oil globally. Recently, the major driving factors of castor production were reported to be expanding population, increasing utilization of the oil as a feedstock for biodiesel, rising inclination of consumer preference for organic and plant-based cosmetics, growing use in the pharmaceutical sector and use of the oil and its derivatives in a variety of end-use sectors (Global Castor Oil Market Report (GCOMR, 2023). Furthermore, the global castor oil market is expected to grow at a Compound Annual Growth Rate (CAGR) of 4.31% reaching US$1.61 billion in 2027 (GCOMR, 2023).

Despite the rising demand for castor in the world market, castor production faces many production constraints such as adaption of new castor varieties to mechanical harvesting (de Oliveira Neto *et al.,* 2019), appropriate sowing date of castor across different ecological locations (Kumar *et al.,* 2015; Kumar and Yamanura, 2019), pests, wind, hail and improper use of herbicides and defoliants that leads to reduced seed yield because of reduction in photosynthetic apparatus (Lakshmamma *et al.,* 2009; Lakshmi *et al.,* 2010; Severino *et al.,* 2010; Latterini *et al.,* 2022). The inherent traits of indeterminate growth and evergreen habit, leading to high production of fresh aerial biomass and uneven ripening of capsules hinder smooth mechanical make direct harvesting practicably impossible resulting in significant seed yield loss (Stefanoni *et al.,* 2022). However, recent development of warf varieties has almost resolved the challenge ((de Oliveira Neto *et al.,* 2019). Other constraints include predominantly degraded tropical soils and poor fertilizer regimes (Lal, 2011; Brusseau *et al.,* 2019), unstable castor oil prices in the market due to the rising bioplastics consumption and castor use in the food industry and as lubricants (GCOMR, 2023).

The use of chemical fertilizers poses a serious problem due to the numerous detrimental effects it has on crop production which include: increased production cost, decreased soil fertility, contamination of underground water, nutrient imbalance, and accumulation of heavy metals among others (Roidah, 2013; Chali Abate, 2023). Synthetic fertilizer is rapidly lost by evaporation or by leaching which causes serious environmental pollution (Aisha *et al.,* 2007). To reduce the problem of nutrient loss from the soil, nutrients added to the soil can be retained for a longer period through the use of organic fertilizers. Given the growing demand for organic agriculture produce, organic fertilizer use must be expanded to reduce greenhouse gas emissions polluting the environment and ensuring the long-term viability of soils as well as reducing the use of inorganic fertilizers (Khodaei-Joghan *et al.,* 2018). The addition of amendments like manure to the soil improves its structure which creates a more favorable environment for root growth and development (Biswas *et al.,* 2001). Yiridoe *et al.* (2005) found that crops fertilized with organic manure had greater health benefits than those treated with inorganic fertilizer. Biostimulants have been reported to boost crop yields through their interaction with plants and the plant's environment thereby increasing root growth and nutrient uptake (Vessey, 2003).

Sowing date affects growth, yield, and other contributing qualities of crops. Early sowing date improved the uptake of nutrients (nitrogen, phosphorous, potassium, and sulphur) over delayed sowing (Pamar *et al.,* 2009; Patel *et al.,* 2009). However, there is a paucity of similar information on the sowing date of castor in humid tropical Africa.

With the focus now gradually shifting to alternative natural resources such as organic soil amendments, it is now more expedient than ever to maintain consistent cultivation of the castor plant and subsequent sustainable production of its oil to meet the ever-increasing demand for the product in industrial applications. However, there is a dearth of information on the agronomic response of castor to some of these production strategies in the humid tropics of Africa. There is no single literature that combines the use of organic amendment and varying sowing date effects on castor production in the tropics. The hypothesis of the study hinged on the possibility of enhancing the agronomic performance of castor by applying organic fertilizer irrespective of the sowing date. Therefore, this study was aimed at ascertaining the effects of organic fertilizer and staggered sowing dates on the growth and productivity of castor in the humid tropics.

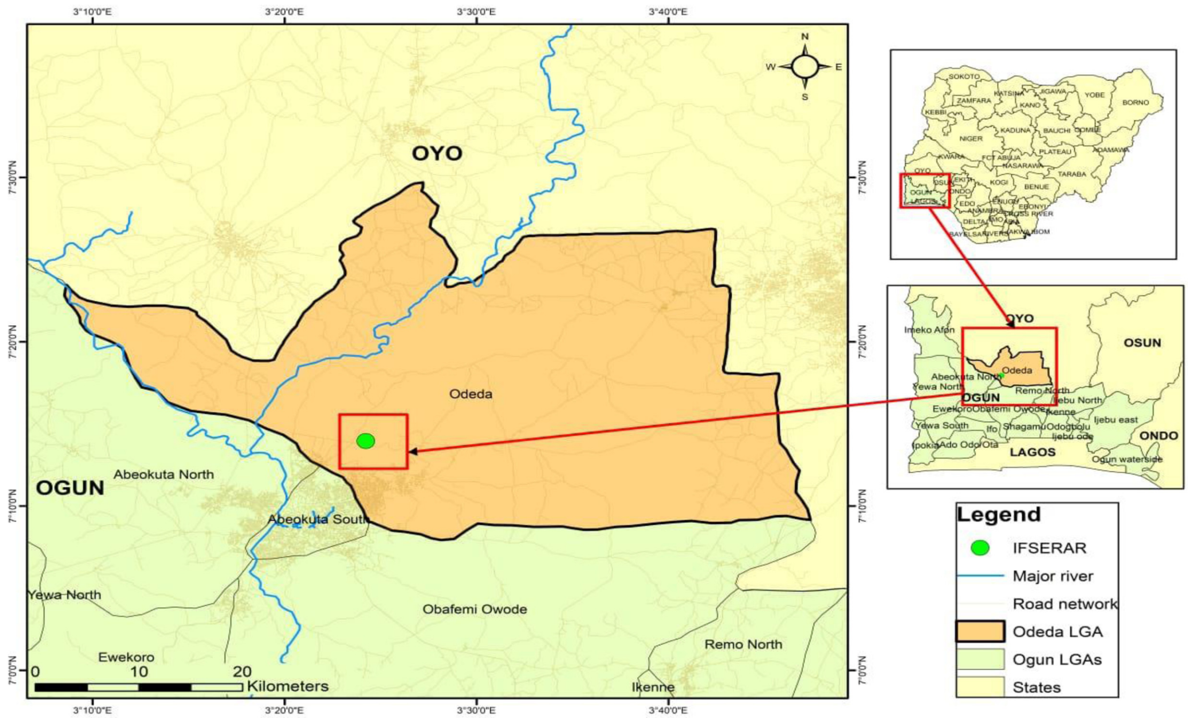

Fig. 1. Map of the experiment location.

2 Materials and methods

2.1 Location of the experiment

The two-year field experiment was conducted at the organic research plots of the Institute of Food Security, Environmental Resources and Agricultural Research (IFSERAR), Federal University of Agriculture, Abeokuta (FUNAAB), Nigeria situated between Latitudes 7°13'53.16"N and 7°13'51.17"N, Longitude 3° 23'49.12"E, and 3°23'51.86"E, on altitude 131.5 m above sea level during the late cropping seasons (June-December) of 2021 and 2022. The study area is located in the forest-savanna transition zone of the southwest region of Nigeria (Fig. 1).

2.2 Plant material and organic fertilizer

The variety used was 'Brazilian White' which is a medium maturing variety with grey seeds having brown markings (Olowe *et al.,* 2023). The organic fertilizer used was Aleshinloye Grade-B (an abattoir-based fertilizer) which was applied to specific plots four weeks after sowing for each sowing date at the rate equivalent to 45 kg N/ha. The nutrient composition of the organic fertilizer is shown in Table 1. The fertilizer contained 1.07% nitrogen in 2021 while in 2022, the composition was 0.69% nitrogen. These values were used to calculate the rate of application in 2021 and 2022 respectively. Based on the pH recorded, the organic fertilizer was slightly alkaline in both years.

2.3 Treatments and experimental design

Two experimental factors were studied: fertilizer application and sowing date. The experimental design used was a randomized complete block design (RCBD) with three (3) replications. The two factors were arranged in split plot with the organic fertilizer (organic fertilizer and no organic fertilizer) allocated to the main plot, while sowing date (SD) staggered at weekly intervals for eight weeks was allocated to the sub-plot (SD1 – June 18, SD2 – June 25, SD3- July 2, SD4 – July 9, SD5 – July 16, SD6 – July 22, SD7 – July 29, SD8 – August 5). Unfortunately, the castor sown at SD8 – on August 5. 2021 did not produce any raceme because of the dry conditions experienced during the tail end of the cropping season. The organic fertilizer was allocated to the main plot to minimize to the level of commingling within the experimental plots; while sowing date was allocated to the sub-plot being a factor we were more interested in studying.

Table 1. Nutrient composition of organic fertilizer (Aleshinloye Grade-B).

Parameters	2021	2022
pH	7.79	7.82
OC, %	1.23	1.52
TN, %	1.067	0.69
P, %	0.297	0.136
Na, %	0.010	0.012
K, %	0.354	0.030
Ca, %	0.104	0.091
Mg, %	0.049	0.072
Mn, %	0.004	0.534
Fe, %	0.001	0.181
Zn, %	0.001	0.099

Table 2. Pre-cropping physical and chemical properties of the soil in 2021 and 2022.

Soil Properties	2021	2022
Physical Properties		
Sand (%)	78.30	80.31
Silt (%)	18.84	17.85
Clay (%)	2.86	1.84
Textural Class	Loamy sand	Loamy sand
Chemical Properties		
pH	7.42	7.40
Organic Carbon (%)	2.33	2.00
Total Nitrogen (g/kg)	0.62	0.84
Available P (mg/kg)	32.38	31.03
Exchangeable		
Mg (cmol/kg)	2.05	3.41
Ca (cmol/kg)	3.04	2.93
K (cmol/kg)	1.18	0.43
Na (cmol/kg)	0.21	0.37
Extractable		
Mn (mg/kg)	8.07	4.85
Fe (mg/kg)	13.23	13.09
Zn (mg/kg)	5.94	4.21

2.4 Field operations

Each plot size was 2.7 m x 4 m with a plant spacing of 90 cm between rows and 40 cm within rows with an inter-rep spacing of 1 m. The total plant density was 44,000 plants per hectare. Seeds were sown at two to three seeds per hole then later thinned to one per stand. Sowing commenced in June through August at seven days interval in 2021 and 2022. Weeding was done for each sowing date at 4, 8 and 12 weeks after sowing (WAS). Harvesting was done manually when the racemes had reached physiological maturity and turned brown.

2.5 Soil measurements

Soil samples were randomly taken diagonally on a plot basis from the topsoil (0–20 cm) before sowing using a soil auger and bulked for laboratory analysis to determine the physical and chemical properties of the soil. The soil samples were air-dried before the analysis. Results of pre-cropping soil analysis are shown in Table 2. Analysis of soil samples was carried out by following the procedures complied by Aduayi and Haque (1992).

2.6 Plant measurements

At 4 WAS, five randomly selected plants from the net plot were tagged for data collection. Data were collected such as the number of phenological days to flowering (when 50% of the plants on a plot had flower bud with at least one open flower) and maturity of primary raceme (number of days from planting to maturity of fruit/capsule from the primary raceme), height at maturity (measured from plant base to the tip of the highest raceme in cm), height to the lowest primary raceme (height from the plant base to the point of insertion of the lowest raceme in cm), stem diameter (measured in cm using a digital vernier caliper), and grain yield (kg/ha) and yield traits (number of racemes per plant, number of nodes per plant, number of nodes before first raceme, number of capsules per plant, weight of seeds (g), weight of capsule (g), 100 seed weight (g) and shelling percent (%)) on plot basis.

2.7 Data analysis

All data collected during the two consecutive year studies were subjected to analysis of variance (ANOVA) using the MSTAT-C package version 1.42 (Freed *et al.,* 1989) to test the effects of sowing dates and organic fertilizer application and their interaction, and the means of significant treatments were separated using Duncan's Multiple Range Test (DMRT) at 5% level of probability.

3 Results

3.1 Growth conditions

Traditionally, this region (forest-savanna transition agro-ecological zone) normally experiences bimodal rainfall distribution, with two peaks in July and September with a dry spell in August (August break). However, this trend did not occur in 2021 and 2022. The two peaks were recorded in July and August of 2021, and June and September of 2022. Throughout the experiment, total rainfall of 794.2 mm and 504.6 mm was recorded in 2021 and 2022, and 824.6 mm for the 35 yr long-term period (1984–2020), respectively (Fig. 2). On average, the rainfall distribution during the late cropping season of 2021 and 2022 was 30.4 mm and 320.6 mm below the average, respectively. Overall, the late cropping seasons of 2021 and 2022 were 0.1° and 0.6 °C cooler than the average, respectively. Temperature was not limiting during the period of experimentation in both years and it ranged between 26.5 and 27.0 °C. This temperature range is within the 25–32 °C range suitable for castor germination (Cafaro *et al.*, 2023). The soil textural class was loamy sand with a soil pH that was slightly alkaline in both years. The soils were low in nitrogen, high in phosphorus, and medium in potassium (Tab. 2).

3.2 Number of days to 50% flowering and height to primary raceme as affected by organic fertilizer application in 2021 and 2022

Organic fertilizer application only significantly ($P < 0.05$) affected number of days to 50% flowering and height to primary raceme in 2021 (Tab. 3). When organic fertilizer was applied, days to flowering were hastened by six days relative to the control in 2021. Height to primary raceme was significantly ($P < 0.05$)enhanced by 19.3% following the application of organic fertilizer in 2021 compared with the control. Organic fertilizer application had no significant effect on the two parameters in 2022 even though the same trend observed in 2021 was recorded in 2022.

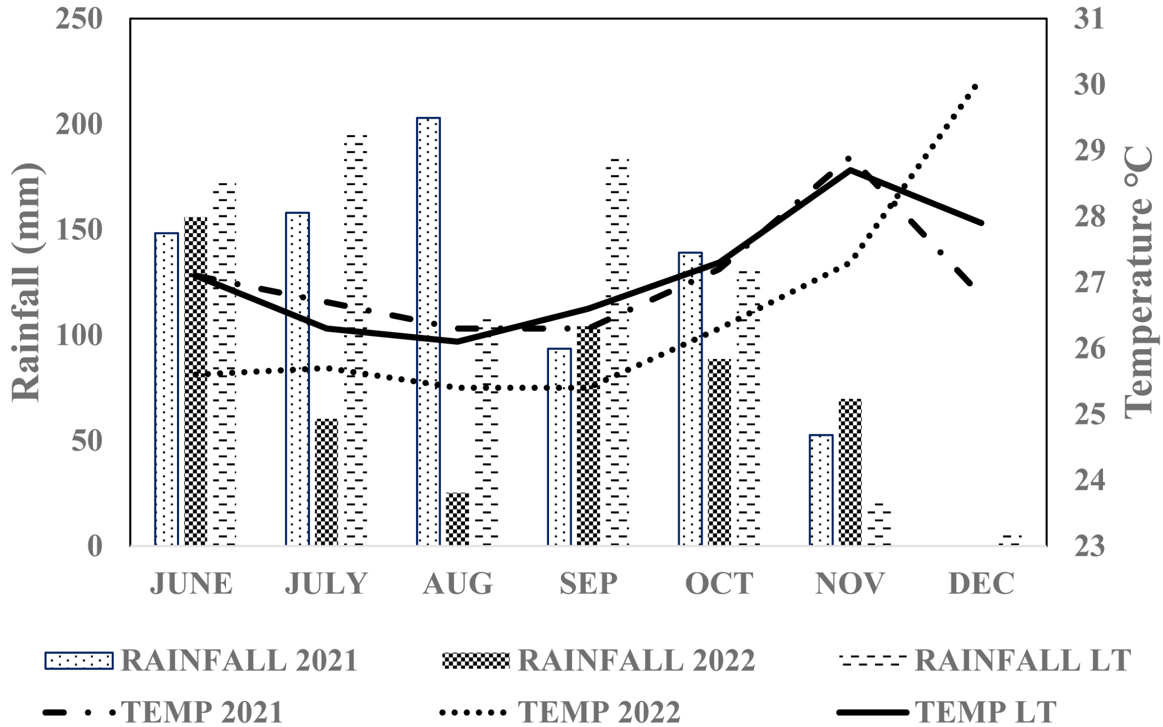

Fig. 2. Monthly rainfall and mean monthly temperature during the late cropping seasons (June-Dec.) of 2021, 2022 and Long-term (LT) period (1984–2020). *Source:* Department of Water Resources Management and Agro-Meteorology, Federal University of Agriculture, Abeokuta (FUNAAB).

Table 3. Effects of organic fertilizer application on number of days to 50% flowering and height to primary raceme in 2021 and 2022.

Treatment	Days to 50% flowering		Height to primary raceme	
	2021	2022	2021	2022
Fertilizer (F)				
NF	87^{a}	93^{a}	131.8^{b}	107.1^{a}
OF	81^{b}	91^{a}	157.3^{a}	117.6^{a}
SED ± (2 df)	0.5	2.8	5.31	6.92

NF: No Fertilizer, OF: Organic Fertilizer. SED – Standard Error of Difference. For the main effects, values within columns followed by the same letters are not significantly different according to Duncan's Multiple Range Test (DMRT) at 5% probability level

3.3 Number of days to 50% flowering, physiological maturity, height to first race, height at maturity and stem diameter of castor as affected by sowing date in 2021 and 2022

The sowing date effect was significant ($P < 0.05$) for all the traits in both years, except the number of days to physiological maturity in 2021 (Tab. 4). Flowering was significantly ($P < 0.05$) delayed by 10–17 days when sowing was done in late July (SD6 – July 22 and SD7 – July 29 in 2021 relative to other castor plants sown at SD1 and SD2. However, the earliest sown castor (SD1 – June 18) matured later than the latest sown castor (SD8 – August 5) in 2022 by 16 days (significant at $P < 0.05$). Height to primary raceme decreased significantly ($P < 0.05$) as sowing was delayed till the last sowing date in both years (SD7 and SD8) relative to the first five sowing dates from mid-June (SD1) till mid-July (SD5) in both years. A similar trend was recorded for height at physiological maturity in both years. The last sown castor plants were the shortest in both years. The earliest sown (SD1 – June 18) castor recorded the widest stem diameter in both years and was significantly ($P < 0.05$) wider than the stem diameter of other castor sown at other dates, except for SD2 and SD4 in 2021 (Tab. 4).

3.4 Number and weight of capsules per plant, number of raceme, branches, and nodes per plant of castor as affected by sowing date in 2021 and 2022

The number and weight of capsules per plant, number of raceme, branches, and nodes per plant were significantly ($P < 0.05$) affected by the sowing date (Tab. 5). The number of capsules per plant significantly ($P < 0.05$) reduced by 68.7% as sowing was delayed from SD4 (July 9) till SD7 (July 29) in 2021 and by 82.6% from SD4 (July 9) till SD8 (August 5) in 2022. The highest number and weight of capsules per plant were recorded when the castor was sown on SD3 (July 2) and

Table 4. Effects of sowing date on number of days to flowering, physiological maturity, height at primary raceme, and height at maturity and stem diameter of castor in 2021 and 2022.

Sowing Date (SD)	ND50FL	NDPM	HTPR (cm)	HTPM (cm)	STD (cm)
			2021		
Sowing date (SD)					
SD1	82^{b}	147^{a}	181.8^{a}	274.8^{a}	13.8^{a}
SD2	78^{b}	141^{a}	161.9^{ab}	235.1^{ab}	10.3^{ab}
SD3	79^{b}	145^{a}	143.2^{b}	197.5^{bc}	8.3^{b}
SD4	79^{b}	147^{a}	140.1^{b}	194.9^{bc}	10.7^{ab}
SD5	81^{b}	137^{a}	151.8^{ab}	188.6^{bc}	8.8^{b}
SD6	92^{a}	141^{a}	128.2^{bc}	156.3^{cd}	8.5^{b}
SD7	95^{a}	136^{a}	104.5^{c}	120.8^{d}	6.3^{b}
SED ± (24 df)	2.17	4.73	14.98	21.42	1.95
			2022		
Sowing Date (SD)					
SD1	93.5^{ab}	148.5^{a}	127.2^{ab}	205.9^{ab}	22.7^{a}
SD2	86.2^{bc}	142.7^{ab}	151.5^{a}	202.5^{ab}	19.0^{b}
SD3	96.8^{ab}	139.8^{ab}	124.7^{ab}	166.2^{bc}	17.2^{bc}
SD4	78.3^{c}	132.7^{b}	148.9^{a}	214.6^{a}	14.2^{cd}
SD5	86.5^{bc}	133.2^{b}	107.0^{bc}	145.0^{cd}	12.1^{de}
SD6	99.8^{a}	138.0^{b}	91.5^{cd}	119.5^{de}	10.7^{de}
SD7	95.2^{ab}	140.0^{ab}	76.7^{d}	101.1^{e}	9.3^{e}
SD8	100.0^{a}	132.3^{b}	71.2^{d}	87.7^{e}	9.5^{e}
SED ± (28 df)	5.40	4.44	14.00	19.27	1.72

SD1: June 18, SD 2: June 25, SD 3: July 2, SD 4: July 9, SD 5: July 16, SD 6: July 22, SD 7: July 29, SD 8: August 5, ND50FL: Number of days to 50% flowering, NDPM: Number of days to physiological flowering, HTPR: Height at primary raceme, HTPM: Height at physiological maturity, STD: Stem diameter, SED: Standard Error of Difference, For the main effects, values within the same column with similar alphabets are not significantly different according to DMRT at 5% probability.

SD4 (July 9) in 2021 and 2022, respectively. The earliest sown castor (SD1 – June 18) produced the highest number of raceme in 2021 and was significantly ($P < 0.05$) higher by 44.4–66.6% than the number produced by castor sown at other dates. In 2022, castor plants sown at SD1 to SD5 produced raceme that were on par. This same trend was recorded on number of branches per plant in both years. Castor sown on the last sowing date in both years produced the least number of branches per plant. In 2021, the number of nodes per plant was generally on par across the sowing dates with castor sown at SD4 (July 9) recording the lowest number of nodes per plant. Whereas, the lowest number of nodes was recorded when sowing was delayed till (SD8 –August 5), 2022 (Tab. 5).

3.5 Seed yield, weight of seeds, one hundred seed weight, and shelling percent as affected by sowing dates in 2021 and 2022

Statistical analysis revealed a significant ($P < 0.05$) effect of sowing date on the weight of seeds per plant, one hundred seed weight, shelling percent, and seed yield of castor in 2021 and 2022 (Tab. 6). The effects of sowing date was significant for these traits in both years, except shelling percent. The weight of seeds per plant declined significantly ($P < 0.05$) as sowing was delayed from SD4 (July 9) till SD7 (July 29) in 20221. The highest seed weight per plant was recorded in 2022 when the castor was sown on SD4 (July 9) and was on par with the seeds of castor sown on SD1 (June 18) and SD2 (July 9). Early sown castor plants produced significantly higher 100 seed weight compared to the late sown castor on July 29 (SD7) in 2021 and August 05 (SD8) in 2022. Results of the analysis of variance revealed that the sowing date had a significant ($P < 0.05$) effect on castor seed yield in both years (Tab. 6). In 2021, the earliest sown castor (SD1 – June 18) recorded the highest grain yield. Whereas, in 2022, castor sown at SD2 (July 2) produced the highest seed yield, and delaying sowing beyond SD4 reduced seed yield significantly ($P < 0.05$) compared with castor sown at SD1 and SD2.

4 Discussion

In general, the castor plant is a rustic and hardy species that grows across diverse tropical and subtropical regions of the world (Chakrabarty *et al.,* 2021), and sowing at an optimum period with other agronomic factors in place is crucial for its production (Cheema *et al.,* 2013). In this study, the 2 yr of experimentation recorded relatively favorable rainfall distribution during the critical growth periods of flowering to physiological maturity as described by Cheema *et al.* (2013). These periods occurred in September and October which recorded 80.9 mm lesser than the average in 2021 and 43.2 mm lesser than the average in 2022. Furthermore, Assefa *et al.* (2018) reported that seasonal water distribution is more critical than total water supply for successful crop production. Temperature was between 26.5–27.0 °C and was adequate for castor seed germination requirement of 25–32 °C (Cafaro

Table 5. Effects of sowing date on some yield attributes of castor in 2021 and 2022.

Sowing Date (SD)	NCAP	WTCAP (g)	NRAC	NBR	NNODES
		2021			
Sowing date (SD)					
SD1	43.0^{ab}	72.5^{ab}	1.8^{a}	2.3^{a}	21.7^{a}
SD2	39.2^{abc}	65.0^{abc}	1.2^{b}	1.8^{ab}	20.5^{ab}
SD3	55.3^{a}	104.3^{a}	1.3^{b}	1.8^{ab}	20.2^{ab}
SD4	20.8^{bc}	32.3^{bc}	1.2^{b}	1.5^{b}	18.7^{b}
SD5	31.0^{bc}	45.0^{bc}	1.2^{b}	1.5^{b}	20.2^{ab}
SD6	20.3^{bc}	31.5^{bc}	1.0^{b}	1.5^{b}	21.8^{a}
SD7	17.3^{c}	22.7^{c}	1.0^{b}	1.2^{b}	22.0^{a}
SED ± (24 df)	10.36	20.19	0.23	0.32	0.99
		2022			
Sowing Date (SD)					
SD1	35.2^{ab}	49.2^{bc}	2.3^{a}	2.3^{a}	21.2^{a}
SD2	33.8^{ab}	51.7^{abc}	2.2^{a}	2.3^{a}	20.2^{ab}
SD3	34.5^{ab}	68.3^{ab}	1.7^{ab}	2.0^{ab}	17.5^{b}
SD4	44.5^{a}	90.2^{a}	2.3^{a}	2.5^{a}	18.7^{ab}
SD5	25.2^{abc}	41.0^{bcd}	1.7^{ab}	2.0^{ab}	17.5^{b}
SD6	16.7^{bc}	22.7^{cd}	1.2^{b}	1.3^{bc}	13.3^{c}
SD7	6.3^{c}	5.2^{d}	1.0^{b}	1.3^{bc}	11.2^{c}
SD8	7.7^{c}	8.0^{d}	1.2^{b}	1.0^{c}	1.41
SED ± (28 df)	9.30	18.29	0.38	0.82	

SD1: June 18, SD 2: June 25, SD 3: July 2, SD 4: July 9, SD 5: July 16, SD 6: July 22, SD 7: July 29, SD 8: August 5, NCAP: number of capsules per plant, WCAP: weight of capsules per plant, NRAC: number of raceme per plant, NBR: number of branches per plant, NNODES: number of nodes per plant, SED: Standard Error of Difference, For the main effects, values within the same column with similar alphabets are not significantly different according to DMRT at 5% probability.

et al., 2023). The pH of the experimental soils was 7.4 in both years before sowing which corroborates the studies by Nweke *et al.* (2017) that the ideal pH range for good castor yield and healthy growth is between 6–7.3.

Organic fertilizer application did not significantly affect seed yield and most of the agronomic traits measured in this study. It reduced the days-to-50% flowering of the main castor raceme by 7 days in 2021 compared to the unfertilized castor. This is in line with the report of Yagoub *et al.* (2012) that nitrogen fertilizers hasten flowering in oil seed crops. Days to flowering and maturity of the main raceme of castor have been reported to be strongly related to castor seed yield (Movaliya *et al.,* 2018). Organic fertilizer application enhanced height to the insertion of primary raceme in the wetter year 2021. Similarly, Ugbaja (1996) reported that the application of different types of manure (poultry, swine, fresh and burnt rice husk dust) increased the top growth of castor in ferralitic soils of south eastern Nigeria due to the supply of the macro and microelements in the manures. In the last decade, efforts to produce organic castor have been reported using, castor bean cake (180 kg/ha) and irrigation at 80% in Brazil (Rodrigues da Paixao *et al.*, 2013), enriched farmyard manure in India (Kalaiselvi, 2017), treated sewage sludge using different methods (solarized, composted, vermicomposted and limed methods) in Brazil (Nascimento *et al.,* 2022) and castor shell compost on three weeks old transplants of castor in India (Patel *et al.*, 2022). More recently, integrated use of organic and synthetic fertilizers were used in castor production to boost seed yield. Application of the combination of green manure, 75% of the recommended dose of fertilizer (RDF), and foliar application of banana pseudostem sap 30, 60 and 90 days after sowing improved nutrient content and maintained soil fertility status under castor in India (Chaudhary *et al.,* 2023), mycorrhizae and combined application of amino acids either as foliar or soil in Iran (Esmaeilian *et al.,* 2023) and RDF at 75% and combination of biological NPK (Patel *et al.,* 2023). Some studies have demonstrated that the application of organic fertilizers to the soil provided micro-organisms a rich food source and considerably improved the composition and variety of microbial communities as compared to not adding anything (Chang *et al.,* 2007; Diacono and Montemurro, 2010). The use of some of these nutrient sources either alone or in combinations should form the core of future research studies in organic castor production in the humid tropics.

The results of this study also revealed that sowing date significantly affected the days to flowering and maturity of the main raceme in both years, except the days to maturity in 2022. This suggests that genetic heritability also plays a major role in defining the expression of these traits apart from environmental conditions and agronomic practices. Delayed flowering could be attributed to the fact that the plants had less days to grow, considering the late sowing. Sowing date however, had a significant effect on the height of primary raceme and plant height at maturity in both years with the earlier sown castor (SD1–June 18 and SD2–July 25) recording the highest values for these traits, except SD4–July 9 in 2022. This trend could be

Table 6. Effects of sowing date on seed yield and some yield attributes of castor in 2021 and 2022.

Sowing Date (SD)	WTS	100SWT (g)	SH%	SYD (kg/ha)
		2021		
Sowing date (SD)				
SD1	8.3[a]	33.4[a]	10.9[a]	229.9[a]
SD2	6.6[abc]	30.0[ab]	13.4[a]	182.1[abc]
SD3	7.7[ab]	31.2[ab]	8.5[a]	212.7[ab]
SD4	3.7[cd]	17.9[bc]	15.7[a]	103.3[cd]
SD5	4.1[bcd]	28.1[abc]	9.8[a]	114.5[bcd]
SD6	1.9[d]	19.4[bc]	4.9[a]	53.2[d]
SD7	2.8[cd]	8.6[c]	9.8[a]	78.5[cd]
SED ± (24 df)	1.73	7.62	5.47	47.95
		2022		
Sowing Date (SD)				
SD1	27.7[ab]	49.6[ab]	19.3[a]	773.7[ab]
SD2	28.8[ab]	55.2[a]	10.0[a]	799.1[a]
SD3	16.7[bc]	47.9[ab]	19.8[a]	462.9[abc]
SD4	32.9[a]	53.4[ab]	20.7[a]	441.1[bc]
SD5	12.1[cd]	36.6[bc]	11.5[a]	334.6[c]
SD6	13.8[cd]	25.8[cd]	6.8[a]	293.9[c]
SD7	3.5[d]	10.3[d]	9.0[a]	115.6[c]
SD8	8.7[d]	15.9[d]	8.4[a]	129.2[c]
SED ± (28 df)	5.45	7.78	5.66	156.61

SD1: June 18, SD 2: June 25, SD 3: July 2, SD 4: July 9, SD 5: July 16, SD 6: July 22, SD 7: July 29, SD 8: August 5, WTS: Weight of seeds per plant, 100SWT: 100 seed weight, SH%: shelling percent, SYD: Seed yield, SED: Standard Error of Difference, For the main effects, values within the same column with similar alphabets are not significantly different according to DMRT at 5% probability.

attributed to the longer access the earlier sown plants had to the growth resources compared to later sown castor plants. Similar studies have reported that earlier sown castor resulted in taller plants in comparison with the later sown (Reddy *et al.,* 2007; Sreedhar and Yakadri, 2007; Daniel *et al.,* 2017). The late sown castor plants (SD5–July 16 to SD8–Aug. 5) might have experienced moisture stress attributable to fewer rainy days and rainfall distribution, especially in the dryer year 2022. Oswalt *et al.* (2014) and Oliveira *et al.* (2017) had earlier stated that the height of castor is directly related to water availability during the growth cycle and competition for light and excessive growth is capable of limiting mechanical harvest. The height at maturity (120.8–274.8 cm in 2021 and 87.7–214.6 cm in 2022) in this study across the sowing dates compared well with values reported for ten accessions of castor evaluated separately at Ogbomosho, a derived savanna location in Nigeria (73.6–190.0 cm) by Omotoso *et al.* (2019) and 99.5–221.1 cm in the derived savannah agro-ecological zone of the tropics by Udoh and Abu (2016). High plant height, high main raceme insertion, and medium stem diameter have been identified as some of the morpho-agronomic characteristics of interest to the mechanized production of castor (de Oliveira Neto *et al.,* 2019). In our study, stem diameter reduced as sowing was delayed. Our test variety recorded a stem diameter (6.3–13.8 cm in 2021 and 9.3–22.7 cm in 2022) that was wider than the reported thin stem diameter (< 3.0 cm) by Oliveira *et al.* (2019) and recommended to be desirable for mechanized harvest (Lopes *et al.,* 2008; Ferreira *et al.,* 2009) because they are easier for harvesters to cut. Nevertheless, the recorded stem diameter at SD1 and SD2 in both years of our study compared well with the highest stem diameter (17.6 cm) reported in a study in Brazil (Brito *et al.,* 2014). The earliest sown castor SD1 (June 18) produced the highest number of nodes per plant and it resulted in the highest seed yield of castor. Number of nodes per plant was recently reported by Movaliya *et al.* (2018) as a trait directly related to castor seed yield.

The seed yield of castor depends largely on the yield attributes of the crop as it is influenced directly or indirectly by such attributes (Movaliya *et al.,* 2018). Furthermore, in castor breeding, number of branches and capsules per plant have been identified as crucial factors in castor seed yield (Lakshmamma *et al.,* 2005; Vanaja *et al.,* 2008). However, the sowing date significantly affected all the measured yield attributes of castor in both years, except shelling percent. On average, as sowing was delayed beyond SD4 (July 9) number and weight of capsules per plant reduced. Similar results have been reported by Sree *et al.* (2008) in India and Alemaw *et al.* (2013) in Ethiopia. The test variety Brazilian White produced fewer racemes and branches than the ten accessions earlier evaluated in Nigeria by Omotoso *et al.* (2019) in both years. These traits have been reported to depend largely on genetic heritability which cannot be seriously affected by environmental factors (Freire *et al.,* 2007; Soratto *et al.,* 2012). The 100-seed weight of castor reduced as sowing was delayed beyond SD5–July 16 in 2021 and SD4–July 9 in 2022. The values recorded in this study ranged between 8.6 and 37.2 g in 2021 and, 15.9 and 49.6 g in 2022 across the sowing dates and compared well with reported values by Omotoso *et al.* (2019) in Nigeria, Alemaw *et al.* (2013) in Ethiopia de Oliveira Neto *et al.* (2019) in Brazil, and Cafaro *et al.* (2023) in the South Mediterranian basin. Generally, some agronomic traits of castor such as the number of nodes and racemes per plant (Hooks *et al.,* 1971; Prasad and Rana, 1984) and length of main raceme, number of capsules per plant and seed weight (Giriraj *et al.,* 1974; Solanki and Joshi, 2000; Solanki *et al.,* 2003) are being controlled by genetic makeup of the varieties. Hence there is a limit to the manipulation of management practices that can affect these traits.

Regarding seed yield of castor in this study, sowing date significantly affected the trait. Seed yield declined with delay in sowing beyond SD5–July 16, 2021 and SD2–June 25, 2022. It has been reported in the literature that early sowing of castor often result in higher seed yield because of a higher yield of primary raceme and lower yield of secondary racemes and that early sown castor can benefit from more conducive rainfall distribution and temperature conditions (Sree and Reddy, 2004; Öztürk *et al.,* 2014). Yield depression recorded as sowing was delayed was recently attributed to a deficit in rainfall in India (Kalaichelvi, 2020). Castor plants were more vigorous in 2021 than in 2022 and this trend did not translate to superior seed yield. Similar findings have been reported for soybeans that oftentimes, accumulation of dry matter does not translate to high grain yield (Olowe and Adebimpe, 2009; Jesulana *et al.,* 2021). Castor plants produced heavier seeds in 2022 than in 2021 and this resulted in higher seed yield. Castor sown in mid-June (SD1–June 18) and late-June (SD2–June 22) in 2022 produced seed yield of 773.7 and 799.1 kg/ha and were hgher than the seed yield (129.2 kg/ha) of latest sown castor (SD8 – August 4) by 498.8% and 503.0%, respectively. These seed yield values were superior to the African average of 405.4 kg/ha but lower than the world average of 1,677.6 kg/ha reported in (FAOSTAT, 2024). This confirmed earlier reported suitability of castor for large-scale production in the forest-savanna transition zone of Nigeria which is outside its traditional growing region (Oso *et al.,* 2011; Dairo *et al.,* 2016).

5 Conclusion

The agronomic response of castor to organic fertilizer application and sowing date was investigated for the first time in a single study in the humid tropics. The results obtained from the 2 yr study demonstrated that castor is a low feeder of nutrients. Organic fertilizer application expedited days to flowering by 6 days during the wetter year 2021 relative to the control. On average, the early sown castor (SD1: June 18 and SD2: June 25) were more vigorous in height characteristics and stem diameter than the late sown castor (SD7 –July 29 and SD8 – August 5) in 2022. Castor sown at SD1 – June 18 and SD2 – June 25 produced seed yields of 773.7 and 779.1 kg/ha higher by 498.8% and 503.0% than SD8 yield of 129.2 kg/ha. It is, therefore, concluded that for optimum castor seed production, sowing should be done from mid-June (SD1) to latest early-July (SD3) with or without organic fertilizer application in the humid tropics. It is suggested that further in-depth studies can be carried out in other agroecological zones in the tropics to validate the optimum sowing date and appropriateness of organic fertilizer application, and the integrated use of organic soil amendments in order to extend the frontiers of knowledge in castor agronomy.

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The authors declare no conflict of interest.

Data availability statement

Data from which this manuscript was written are readily available at any reasonable request.

Author contribution statement

Mariam Kasali – Data curation, formal analysis, resources, investigation, writing and editing, Supervision, project administration

Victor Olowe – Conceptualization, data curation, formal analysis, methodology, resources, supervision, writing – review and editing, project administration

Sule Sakariyawo – Formal analysis, writing and editing, visualization

Patience Odueme – Methodology, supervision, writing and editing

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