



OPEN Growth and yield responses of sorghum (*Sorghum bicolor* [L.] Moench) varieties to sowing time in a rainforest zone of Nigeria

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Sorghum is an important staple and commodity crop for West Africa, however, its production rarely meet demand. Due to its importance, efforts should focus on extension of sorghum production frontiers beyond the current ecological boundaries (the savannas of West Africa). Field experiments were conducted to evaluate the influence of sowing date on the performance of sorghum varieties in a rainforest zone of Nigeria. Sowing dates were: 15th July, 2nd and 20th August and 5th September, 2017 and 18th July, 5th and 17th August and 7th September, 2018 while sorghum varieties were *Improved Deko*, *CSR-01*, *SK5912*, *121 CKSV-180* and *SAMSORG 17*. Sowing dates were coded: SD1 (Mid July), SD2 (early August), and SD3 (mid August) and SD4 (early September) for each year experiment (2017 and 2018). Sowing dates differed in growing season lengths and weather conditions. Early maturing varieties (121 CKSV-180, CSR-01 and SAMSORG 17) gave highest yield gain for mid August and early September sowing dates while the late maturing varieties (SK 5912 and Improved Deko) gave highest grain yields for mid July, early and mid August sowing dates. SAMSORG 17 and Improved Deko produced heaviest grain yields and CSR-01, SK5912 the lowest. Early and mid August (SD2 and SD3) dates are the best sowing dates and SAMSORG 17 and Improved Deko are the best varieties in the rainforest zone of Nigeria. The study highlighted the relevance of sowing date and cultivar choice as location-specific management strategy for sustainable sorghum production in the rainforest zone of southern Nigeria.

Keywords Sorghum, Cultivars, Sowing windows, Performance, Climate stress, Adaptation, Rainforest

Sorghum (*Sorghum bicolor* [L.] Moench) is a staple food as well as a commodity crop (raw material resources for the food, pharmaceuticals, brewery and confectionary industries). In the Sub-Saharan Africa (SSA), sorghum production rarely meets the demand of the growing population. This calls for the expansion of its cultivation into agroecosystems (rainforest, humid and dry savanna) of SSA for food security, industrial and economic development. Nigeria is the largest producer of sorghum in West Africa, accounting for about 65–70% of the total sorghum production in the region¹. Sorghum production in Nigeria in 2018 was 6.9 million tonnes, accounting for 50% of the total cereal production and occupying about 45% of the total land area devoted to cereal crop production in Nigeria². The world is facing a growing challenge of feeding over 9.5 billion people by 2050 in the face of the looming threat of climate change^{3,4}. Thus, increasing the productivity of cereals is one of several strategies for improving global food security^{5,6}. Bearing in mind, the importance of sorghum to national economy, increased efforts is focusing on the *expansion of sorghum production into agroecologies beyond its traditional savanna domain*. The crop therefore needs to adapt to new regimes of climate/weather and areas that were hitherto (previously) not suitable for their production.

Climate variability and change including extremity of weather has set new environmental boundaries) occasioned by drought, dry spells, elevated temperatures, variabilities of rainfall (amount, spread, intensities), increased pest pressures and the southward shift of the Sahel (Sahara desert)^{1,3,7}. Changes in environmental conditions is expected to affect the area suitable for agriculture, the length of the growing season and yield potentials of crops. Reports of climate projection and crop simulation studies have confirmed changes in crop responses to changing environment conditions in particular, sorghum^{8–10}, maize and pearl millet^{11,12} and short season grain legumes¹³.

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In the Sub-Saharan Africa (SSA), sorghum grain yields are very low (about 0.28 t.ha⁻¹) which is far below the genetic potential of the crop compared with countries like the USA (4.3 t.ha⁻¹), Argentina (4.9 t.ha⁻¹) and China (3.2 t.ha⁻¹)². Such low yields have been attributed to abiotic and biotic stresses and poor adaptation of improve and farmer's varieties¹⁴. Large genetic diversity exists in sorghum¹² with diverse maturity groups and potentials for adaptation (in terms of capture and use of resources) to agroecosystems and seasons and sowing dates. Such genetic diversity has relevance for taking advantage of opportunities offered by the various agroecosystems and resilience building. Globally, research has focused on the development of high yielding photoperiod-insensitive varieties crop varieties for adoption in various agroecosystems has become a priority of cereals breeding programs^{1,14}. Sorghum photoperiod sensitivity has been reduced by breeders in order to develop early maturing varieties with a broader geographic adaptation and drought and heat stress tolerance during the crop life cycle^{15,16,28}.

Sorghum yield gains across agroecosystems and climate have been credited to advances in from breeding and improvement and agronomic management research¹⁷. Potgieter et al.¹⁸ reported that regional increases in sorghum yields has occurred due to better agronomic practices such as appropriate choice of sowing dates and varieties, plant arrangement and soil fertility management, plant breeding efforts (e.g. drought tolerance via Stay Green). Research efforts had also focused on the development of high yielding sorghum varieties for various agroecosystems of West Africa^{19,20}. In particular, high yielding sorghum varieties were developed for the humid and dry savanna agroecosystems of West Africa. These varieties have strong potentials for adaptation to other agroecosystems, weather and soil^{6,19}.

The yielding ability of any crops is determined by genotype, time of sowing, environmental factors and management practices where it is used to grow^{16,21}. Weather conditions of growing season affect crop performance. For example, high temperatures during growing season and resultant high growing degree days (GDD) accelerate crop development and floral initiation processes²². Poor grain filling and grain yield loss for short season grain legumes over semi-arid Eastern Kenya²² and sorghum in West Africa^{23,24} had been reported. Sorghum landraces (African sorghum varieties) have been selected by farmers over generations^{16,25}. These varieties are characterized by low yield but with good grain qualities and tolerance to biotic and abiotic stresses especially in the savanna agroecosystems^{17,18,25}. Efforts to maintain or increase annual sorghum production in Nigeria may also include evaluation of varietal suitability especially, some newly released sorghum varieties for locations which were hitherto not suitable for its production²³. It is important to evaluate the performance and adaptation of high yielding and long and short maturing sorghum varieties in Nigerian agroecosystems to meet the growing population food requirements. In particular, information is inadequate on optimal sowing windows for sorghum in the rainforest zone of Nigeria.

We hypothesized that appropriate choice of sowing date and sorghum variety is a location-specific management strategy for improving sorghum productivity and climate resilience. Experiments were conducted to evaluate the effects of sowing date on the growth, development and yield of sorghum varieties including farmers' varieties in the rainforest zone of south-west Nigeria. The goal was to identify best sowing date and sorghum varieties (local and improved varieties) for production in the rainforest zone of Nigeria.

Materials and methods

Study area and weather conditions

Experiments were conducted to evaluate the performance of five varieties of sorghum (improved and farmers varieties) under four sowing dates in a rainforest zone of Nigeria. The trials were conducted in the Experiment Station of the Department of Crop, Soil and Pest Management, the Federal University of Technology, Akure, Nigeria. The site of study, Akure, is located in the rainforest zone of south west Nigeria. The site of experiment is characterized by heavy annual rainfall of over 1500 mm distributed in a bimodal pattern within seven to eight months duration and three to four months of dry season while each rainfall mode and seasons offer rainfed or irrigation cropping opportunities. The bimodal distribution of rainfall offers two rainfed cropping opportunities (the early and late rainy seasons). The rainy season which spans April to November ends up in a dry season from December to March (end of the rains to the beginning of another) characterized by terminal drought situation. The dry season is characterized by high atmospheric dryness, temperatures over 32 °C and abundant sunshine from the clear sky. Within the rainy season, farmers sow annual crops (staples) at varying sowing dates (Early March to September).

Field experiment

A split plot experiment with sowing date as the main-plot and sorghum varieties as subplot treatment was designed. Sorghum varieties evaluated are: landraces and improved varieties: SK 5912, CSR-01, Improved Deko, 121 CKSV-180 and SAMSORG 17. The seeds of sorghum varieties were obtained from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Kano, Nigeria. Sowing dates evaluated were: 15th July, 2nd and 17th August, and 5th September, 2017 while in 2018, sowing dates were 10th July, 5th and 18th August, and 5th September. The treatments were each replicate 3 times while the varieties were randomly assigned. Sorghum seeds were sown at 75 by 30 cm spacing to give population of 50 plants/m² (44, 444.44 plants.ha⁻¹) using experimental plots of 3 by 4 m. Seeds were sown at 5 cm depth to achieve 3–4 seedlings per hole which were later thinned to 2 plants per hill at 2 weeks after planting (WAP). Information of maturity groups (sowing to harvest in days) of the sorghum varieties evaluated is presented in Table 1.

Data collection and measurement

Observations were made using destructive (stover, panicle, spikes and grain yield per plant while the weight of 1000 seeds was taken) and non-destructive measurements (days to first and 50% flowering, plant height, number of hills per plot at harvest, number of stands per plot at harvest). The days to flowering were counted

S/N	Varieties	Crop maturation	Maturity group
1.	Improved Deko	Medium (95–100 days)	Early
2.	CSR-01	Medium (120–130 days)	Medium late
3.	SK 5912	Late (140–160 days)	Late
4.	12I CKSV-180	Early (80 days)	Early variety
5.	SAMSORG 17	Medium (95–100 days)	Medium early

Table 1. Maturity (sowing to harvest) of sorghum varieties evaluated.

from the date of sowing to when the first and 50% of flowers appeared in each plot. Height of sorghum plants were measured using a metre rule from 9 plants tagged per treatment plot. Stem height was measured from the base of each plant to the leaf bud. Panicle and grain yield and those of 1000 seeds were taken using an electronic balance. After harvesting three central rows in each subplot were sampled for fresh plant weights including the biological yields expressed in kg.ha^{-1} . The harvested plants were dried (at 80 °C for 48 h), threshed and weighed.

Weather data were obtained from the Department of Meteorology & Climate Science, Federal University of Technology, Akure, Nigeria on rainfall, humidity, vapour pressure deficit (vpd), solar radiation and mean temperature at the experimental site during the periods of study (2017 and 2018).

Growing degree-days over each sowing season were also calculated. The daily growing degree-day (GDD) [$^{\circ}\text{C}\cdot\text{days}$] was calculated using equation of McMaster and Wilhelm²⁷.

$$GDD = (T_{\text{max}} + T_{\text{min}}) - T_{\text{base}} \quad (1)$$

where T_{max} is the daily maximum temperature ($^{\circ}\text{C}$), T_{min} is the daily minimum temperature ($^{\circ}\text{C}$) and T_{base} ($^{\circ}\text{C}$) is the base temperature (temperature below which no significant crop development is expected).

Thermal time (TT) was expressed in degree days ($^{\circ}\text{Cd}$) and the accumulated thermal time (GDD) was calculated using the methods of McMaster and Wilhelm²⁷ and Trudgill et al.²⁶. Cardinal temperatures were 11 °C for base temperature, 34 °C for optimum temperature and 44 °C for maximum temperature²⁸. The resulting thermal time per day was used to calculate the progress of developmental processes and key phenological events (leaf appearance rates, flowering onset, 50% flowering dates). The calculated degree days summed over duration of the experiment of each sowing date gave the thermal time accumulated during growth. Thus, the growing degree days (GDD) (accumulated thermal time: $^{\circ}\text{Cd}$) attained during growth (period of experiment) was calculated from the daily maximum (T_{max}) and minimum (T_{min}) temperatures measured at the Meteorological Station located 500 m in from the experimental site.

Phyllochron and canopy extinction coefficient

Cardinal temperatures were 11 °C for base temperature, 34 °C for optimum temperature and 44 °C for maximum temperature²⁸. The resulting thermal time per day was used to calculate the progress of developmental processes and key phenological events (leaf appearance rates, flowering onset, 50% flowering dates, and TT to panicle initiation and 50% panicle emergence). The rate of leaf appearance (phyllochron) was calculated as the inverse slope of the regression that determined leaf appearance rate (phyllochron in $^{\circ}\text{Cd}/\text{leaf}$). Thus, phyllochron ($^{\circ}\text{C}$ days/leaf) was estimated by the inverse of the angular coefficient of the linear regression ($1/\text{LAR}$). Number of leaves per plant (TPLN) was linearly regressed against TT and the inverse of the angular coefficient of the linear regression was deployed to estimate phyllochron ($^{\circ}\text{C}$ day/leaf). Phyllochron (leaf appearance rate) was determined for each planting date and variety by the linear regression between the number of leaves produced and the thermal time in each sampled period. Thermal time ($^{\circ}\text{C}$) necessary for the appearance of a leaf is equal to $1/b$, where b is the slope coefficient of the regression.

The light extinction coefficient (k), according to the Beer–Lambert Law as modified by Sheehy and Cooper³⁰:

$$k = [\log_e (I / I_0)] / \text{LAI} \quad (2)$$

$$k = -\ln (I - I_0) / \text{LAI} \quad (3)$$

$$k = -\ln (1 - F) / \text{LAI} \quad (F \text{ is intercepted PAR}) \quad (4)$$

where I and I_0 are the irradiance values upon and under the canopy, respectively, leaf area index of leaves (LAI) causing the light attenuation, and k is the extinction coefficient or slope of the curve when the natural log ($\ln$) I/I_0 is plotted against LAI.

Light extinction coefficient (k), is calculated according to Dingkun et al.²⁹ by inverting Beer–Lambert's law as:

$$K_{df} = -\ln (0.94 \text{PAR}_{\text{transmitted}}) * \text{LA} I^{-1} \quad (5)$$

Representative values of k for sorghum cultivars at different development stages were derived by regressing of $\ln (\text{PAR}_{\text{transmitted}})$ vs. LAI²⁹.

The intercepted PAR (iPAR) was estimated with the formula:

$$\text{iPAR} = \text{PAR} * \text{IE} \quad (6)$$

where IE is the interception efficiency for the canopy crop, calculated with Beer's law as:

$$IE = 1 - e^{(-k \cdot LAI \cdot Cf)} \tag{7}$$

where k is the light extinction coefficient,

Plant leaf area

Sorghum leaf area index (LAI) and canopy light integrals (incident, transmitted and absorbed radiation, the ratio of radiation measurements below and above the canopy and PAR) were measured using LAI2000 (Plant Canopy Analyzer Model, Delta T, UK) equipment.

Data analysis

The data obtained on growth and yield variables of sorghum were subjected to statistical analysis using Analysis of Variance (ANOVA) test. Treatment means were compared using the Least Significance Difference (LSD) test to separate means when the analyses' results indicated significant differences ($P < 0.05$).

Results

Weather conditions and sowing dates

On the average, the early sowing dates (mid July and early August: SD1 and SD2) had higher cumulative seasonal rainfall (> 900 mm), lower vapour pressure deficits (c.3.6 kPa) and moderate temperatures (+ 30 °C) in contrast to conditions during the late sowing dates (mid August to early September: SD3 and SD4) which were characterized by high climatic demand (vapour pressure deficit and temperatures) and low cumulative seasonal rainfall (Table 2). Also, the mid July and early August sowing dates (SD1 and SD2) had longer growing season lengths (LGS; c. 122 days) and higher GDD (993 °C. day⁻¹) compared with SD3 and SD4 dates. Decreasing trends of cumulative seasonal rainfall received were obtained as sowing dates delayed from July to September (decreasing trends were SD1 > SD2 > SD3 > SD4) and concomitant increases in temperatures and VPD. These conditions have implications for biomass accumulation and grain yield formation in sorghum. Under the late sowing dates (SD3 and SD4), sorghum grew under increasing temperatures and VPDs especially during grain filling period. The length of growing season (LGS) reduced with delay in sowing dates: SD1 and SD2 had longer growing season and experienced a longer period from anthesis to physiological maturity (larger number of days to first and 50% flowering) and grain filling period compared to SD4 and SD5. The sowing dates were characterized by differences in weather conditions and sorghum exhibited differences in leaf area index (LAI) and extinction coefficient (k) (Table 2). There were increases in the intensities of soil moisture deficit, soil and air temperatures and VPD as sowing was delayed from mid July to early September. These conditions can explain the yield declines and earliness to flowering among varieties during late sowing dates. Contrary to situations during mid August and early September sowing dates, longer growing season (LGS), highest cumulative seasonal rainfall, lowest GDD, canopy extinction (k), VPD and temperatures were observed for the early sowing dates (SD1 and SD2).

Performance of sorghum varieties for each sowing date and year (2017 and 2018 trials)

The data obtained on performance for 2017 and 2018 trials showed the significance of the differences among sorghum varieties for some growth and yield variables of sorghum (Tables 3 and 4). In 2017, the weight of 1000 seeds was heaviest for SAMSORG 17 but close values were obtained for CSR-01 and SK 5912 (Table 3). For 2017 trial, LAI at 50% flowering and shoot and panicle weights were best for SD1 and SD2 and poorer for SD4. The days to 50% flowering were shorter for SD3 and SD4 and longest for SD1. The grain and 1000 seed weights and HI were best for SD3 and SD4. The results also showed that sorghum varieties performed differently in 2018 experiment (Table 4). Shoot weight and LAI were not significantly different among sorghum varieties. The longest days to attain first and 50% flowering was observed for SAMSORG 17 and CSR-01. The weights of panicle, grain and 1000 seeds and HI differed significantly among the varieties. Vegetative growth characters; plant height, number of leaves, LAI and shoot biomass yields were best for SK 5912 and Improved Deko and lowest for SAMSORG 17. The former varieties also had the longest days to first and 50% flowering. However, the weights of grain and 1000 seeds and harvest index were best for 121 CKSV-180, Improved Deko and SAMSORG 17. Results showed that during year 2018 trial, mid July sowing (SD1) was outstanding for shoot biomass and LAI, early August sowing (SD2) was earliest for attainment of first and 50% flowering, and best for panicle, grain and 1000 seed weights. During early September sowing (SD4), the performance of sorghum was close to those of SD3 (Table 4).

Planting dates	LGS (days)	Cum rainfall (mm)	GDD (°C day)	IPAR	Ext. coef (k)	Phyllo-chron	Mean temp (°C)	VPD (kPa)
Mid July	122	908	893.31	0.73	0.040	0.146	30.1	3.62
Early Aug.	118	884	847.15	0.79	0.042	0.153	29.3	3.78
Late Aug.	121	827	784.61	0.81	0.038	0.160	30.7	4.1
Early Sept.	114	771	817.82	0.83	0.033	0.167	31.3	4.3

Table 2. Some weather and sorghum growth variables of the sowing windows. LGS (Length of growing season); GDD (Growing degree days); Ext. Coefficient (Extinction coefficient); Mean temp (mean temperature); VDP (Vapour pressure deficit).

Planting dates	Varieties	Plant height (cm)	No. leaves	Shoot weight (kg/ plot)	LAI @50% flowering	Days to first flowering	Days to 50% flowering	Panicle weight (kg/ plot)	Grain yield (kg/ plot)	1000 seed weight (g)	Harvest index	Ext. coef (k)
Mid July	CSR-01	122.75	15.5	6.51	2.32	96.3	102.5	3.51	2.31	30.72	0.43	0.032
	SK 5912	132.25	16.0	6.23	2.45	100.3	104.8	3.83	2.42	31.67	0.45	0.043
	121 CKSV-180	108.82	14.5	5.36	2.51	84.9	92.4	4.02	2.54	31.82	0.48	0.055
	Improved Deko	142.31	16.5	6.85	2.09	94.5	100.3	4.31	3.15	32.45	0.45	0.011
	SAMSORG 17	118.28	15.3	6.03	1.54	82.7	90.4	4.24	2.73	31.44	0.44	0.011
	LSD (0.05)	15.21	1.23	1.04	0.42	5.28	4.3	0.41	0.32	1.21	0.03	0.003
Early August	CSR-01	117.65	11.5	5.72	1.73	90.5	97.3	3.84	2.67	31.57	0.46	0.032
	SK 5912	113.68	12.8	5.67	2.11	93.7	100.1	4.13	2.49	32.32	0.49	0.043
	121 CKSV-180	121.35	11.3	5.48	2.07	80.7	88.6	4.27	2.73	32.51	0.53	0.055
	Improved Deko	133.46	12.7	6.41	1.78	91.2	98.5	4.61	3.28	32.86	0.51	0.011
	SAMSORG 17	103.24	10.8	5.27	1.47	78.8	83.6	4.12	3.09	32.05	0.48	0.011
	LSD (0.05)	10.42	0.14	0.65	0.51	4.4	3.74	0.55	0.27	0.35	0.04	0.003
Mid August	CSR-01	111.75	11.4	5.28	1.53	83.6	92.5	3.73	2.52	31.82	0.48	0.032
	SK 5912	107.25	10.1	5.15	1.72	86.7	96.7	4.23	2.34	32.51	0.51	0.043
	121 CKSV-180	110.53	9.7	4.73	1.39	73.8	84.5	4.67	2.68	31.82	0.58	0.055
	Improved Deko	123.61	11.6	6.07	1.82	75.6	83.8	4.81	3.15	32.45	0.52	0.011
	SAMSORG 17	93.45	9.2	5.02	1.33	67.8	79.4	4.55	2.83	33.27	0.51	0.011
	LSD (0.05)	11.21	1.23	1.04	0.42	3.8	4.3	0.41	0.32	1.21	0.03	0.003
Early Sept	CSR-01	86.31	8.8	5.08	1.33	76.4	85.3	3.54	2.25	30.44	0.45	0.032
	SK 5912	77.33	8.5	4.57	1.28	74.6	81.4	3.91	2.16	31.22	0.43	0.043
	121 CKSV-180	71.33	8.8	4.35	1.88	77.5	85.8	4.13	2.36	31.62	0.48	0.055
	Improved Deko	103.62	9.3	5.42	1.11	75.2	84.3	4.29	2.78	31.73	0.51	0.011
	SAMSORG 17	74.57	8.2	4.63	1.07	67.3	80.4	4.34	2.44	31.17	0.47	0.011
	LSD (0.05)	9.42	1.23	1.04	0.42	3.5	4.3	0.41	0.32	1.21	0.03	0.003

Table 3. Effect of sowing date on the performance of sorghum varieties (2017 trial).

Sowing date effects on sorghum performance

The effects of sowing date on sorghum performance for 2017 and 2018 trials are presented in Table 5. Results showed that in 2017, the tallest sorghum plants, highest number of leaves and heaviest shoot weights were recorded for mid July (SD1) and early August (SD2) sowing dates while the lowest values of these variables were found for early September sowing date. About 27 and 21% decreases in the number of days to first and 50% flowering were obtained for SD1 and SD2 over SD4. Relative to early sowing dates (SD1 and SD2), panicle weights declined by about 23% for early September (SD4) sowing date. The heaviest weights of grain and 1000 seeds were produced by sorghum sown in mid August (SD3) date, values were close for SD1 and SD2 and lowest for SD4 date. Best values of panicle, grain and 1000 seed weights were recorded for sorghum at SD3.

In 2018, sorghum performance at the various sowing dates were similar to observations of 2017 experiment. The tallest sorghum plants and highest number of leaves were recorded for SD1 and SD2 and the lowest values of these variables were found for early September sowing date. Shoot weights declined by about 20% while panicle weights declined by about 12% for SD4 over SD1 and SD2 dates. While best values for panicle, grain and 1000 seed weights were recorded for SD3 lowest values were found for SD4 date.

Averagely, about 20, 35, 14, 15, 14 and 5% declines in values of plant height, LAI, weights of shoot, panicle and grain were obtained for SD4 over SD1 and SD2 dates while and 1000 seed weight improved for SD3 and SD4 dates (Table 6). Longest days to first and 50% flowering, shoot biomass panicle and grain yield were observed for early sowing dates (mid July and early August), mid August sowing date (SD3) had heaviest grain and 1000 seed weights and the lowest values were recorded for early September sowing (SD4). Both SD 3 and SD4 did best with respect to harvest index. Compared with mid July and early August sowing dates, the weights of panicle, grain and 1000 seeds were heaviest for mid August sowing date. Compared with earlier sowing dates (SD1, SD2 and SD3), early September sowing had shorter LGS, lower cumulative seasonal rainfall amount, higher temperatures, canopy extinction and VPD. Thus, mid August and early September sowing were better dates for 1000 seeds and HI.

Variety effects on sorghum performance

The summary of effects of variety on sorghum performance for 2017 and 2018 experiments is presented in Table 6. Variety had significant effects on the growth and yield of sorghum. During 2017 experiment, for the mid July sowing date (SD1), leaf area index (LAI) measured at 50% flowering were largest for SK 5912 and 121 CKSV-180 while the longest days to 50% flowering were observed for SK 5912 and Improved Deko. Panicle, grain and 1000 seed weights were heaviest for Improved Deko and lowest for CSR-01 and 121 CKSV-180 while harvest index (HI) were highest for CSR-01 and improved Deko. For the early August sowing date (SD2), panicle and grain yields were heaviest for Improved Deko and lowest for CSR-01 while HI were best for 121 CKSV-180 and Improved Deko. During the mid August sowing (SD3), shoot weights were heaviest for Improved Deko and SK 5912, LAI @ 50% flowering was best for SK 5912, 121 CKSV-180-180 and Improved Deko. Panicle and grain yields were best for Improved Deko and poorest for CSR-01. Harvest index was best for 121 CKSV-180, CSR 01 and Improved Deko which had close HI values. Similarly at early September sowing (SD4), shoot weights were heaviest for Improved Deko and SK 5912, LAI at 50% flowering were best for CSR-01 and SK 5912 while days to 50% flowering was longest for Improved Deko and shorter for 121 CKSV-180 and SAMSORG 17 (the early maturing varieties). Panicle and grain yields was heaviest for Improved Deko and lowest for CSR-01 and 121 CKSV-180.

Similar to 2017 experiment, the effects of sowing date was significant on sorghum performance for 2018 experiment. At the mid July sowing (SD1), the values of LAI @ 50% flowering were highest for SK 5912 and 121 CKSV-180 and lowest for CSR-01 and SAMSORG 17. Shoot weight were heaviest for SAMSORG 17 and Improved Deko, SAMSORG 17 had outstanding panicle and grain yields while harvest index (HI) were best for 121 CKSV-180 and SAMSORG 17. During early August sowing (SD2), shoot weights were heaviest for Improved Deko and SAMSORG 17. Days to 50% flowering was earliest for 121 CKSV-180, CSR-01 and SAMSORG 17 and longest for Improved Deko. Panicle, grain and 1000 seed weights were heaviest for SAMSORG 17 and lowest for CSR-01. Harvest index was highest for 121 CKSV-180 and lowest for CSR-01 and Improved Deko. For mid August sowing (SD3), tallest sorghum plants were produced by 121 CKSV-180 and Improved Deko, these varieties also produced highest number of leaves per plant. Heaviest shoot weights were produced by Improved Deko followed by SAMSORG 17, CSR-01 and SK 5912 while the lowest weight was recorded for 121 CKSV-180. Increasing order of LAI values were SK 5912 > 121 CKSV-180 > Improved Deko. Longer days to first and 50% flowering were found for Improve Deko and SK 5912 and shortest for SAMSORG 17. Heaviest weights of panicle were produced by Improved Deko and SK 5912 while SAMSORG 17 and improve Deko produced heaviest weights of grain which were lowest for 121 CKSV-180 and SK 5912. However, the weights of 1000 seeds was heaviest for SAMSORG 17, lowest for CSR-01 while close values were found for 121 CKSV-180 and SK 5912. Harvest index was significantly higher for SAMSORG 17 and 121 CKSV-180 compare to other varieties. During the early September sowing (SD4), shoot weight was heaviest for SAMSORG 17 and Improved Deko, the days to 50% flowering were longest for SK 5912 and SAMSORG 17. The heaviest panicle, grain and 1000 seed weights were recorded for SAMSORG 17 compared with other varieties evaluated.

Interaction effects

Significant interactions were found especially for variety and sowing date for most of the measured growth and yield characters of sorghum (Tables 7 and 8). The result of the interaction of sowing date and variety on the growth and yield variables of sorghum showed that the heaviest shoot biomass was observed for CSR-01 × Mid July (SD1) which was followed by CSR-01 × Mid August (SD3), Improved Deko × Early August (SD2) and 121 CKSV-180 × SD1 interactions ranked as the second, third and forth (Table 7). The lowest biomass yield was obtained from the interaction of SAMSORG 17 × SD2. The decreasing trends in values of LAI were in the order

Planting dates	Varieties	Plant height (cm)	No. leaves	Shoot weight (kg/ plot)	LAI @50% flowering	Days to first flowering	Days to 50% flowering	Panicle weight (kg/ plot)	Grain yield (kg/ plot)	1000 seed weight (g)	Harvest index	Ext. coef (k)
Mid July	CSR-01	157.57	13.5	5.78	1.95	79.1	83.5	3.59	2.48	30.81	0.45	0.034
	SK 5912	166.34	18.6	5.36	2.73	83.3	91.6	3.87	2.68	31.73	0.47	0.041
	121 CKSV-180	159.38	17.8	5.29	2.82	72.7	81.7	4.15	2.63	31.89	0.48	0.048
	Improved Deko	172.14	19.2	5.83	2.09	82.4	90.4	4.28	3.11	31.48	0.41	0.037
	SAMSORG 17	168.36	14.3	6.06	2.42	72.7	80.1	4.47	3.21	32.27	0.48	0.033
	LSD (0.05)	17.21	1.23	1.04	0.42	4.6	4.3	0.41	0.32	1.21	0.03	0.003
Early August	CSR-01	145.67	13.4	5.53	1.83	77.3	85.3	4.21	2.41	30.87	0.51	0.032
	SK 5912	153.62	15.7	5.14	2.10	80.4	89.3	4.57	2.74	31.55	0.54	0.043
	121 CKSV-180	127.32	12.9	5.07	2.03	77.8	85.3	4.16	3.15	32.22	0.55	0.055
	Improved Deko	148.26	16.2	7.03	1.94	81.4	91.8	4.63	3.28	31.74	0.53	0.031
	SAMSORG 17	131.41	13.1	6.31	1.82	75.7	83.6	4.44	3.30	32.56	0.56	0.022
	LSD (0.05)	12.43	1.23	1.04	0.42	3.4	4.3	0.41	0.32	1.21	0.03	0.003
Mid August	CSR-01	131.09	10.8	5.24	1.65	72.5	79.2	3.81	2.67	30.73	0.53	0.030
	SK 5912	137.25	10.5	5.17	1.83	77.4	81.6	4.25	2.48	32.24	0.57	0.041
	121 CKSV-180	141.48	13.4	4.83	2.05	74.5	86.9	4.04	2.39	32.83	0.60	0.048
	Improved Deko	142.12	13.8	6.12	1.72	78.3	88.5	4.46	3.18	32.67	0.58	0.027
	SAMSORG 17	119.53	11.2	5.26	1.57	71.6	80.7	4.15	3.34	33.08	0.60	0.021
	LSD (0.05)	7.21	1.23	1.14	0.42	2.7	4.3	0.41	0.32	1.21	0.03	0.003
Early Sept	CSR-01	100.42	9.1	5.12	1.35	68.6	73.7	3.65	2.24	30.31	0.49	0.028
	SK 5912	98.71	8.7	5.33	1.30	71.8	78.1	4.07	2.21	31.67	0.51	0.037
	121 CKSV-180	94.53	9.0	4.74	1.51	72.7	76.4	3.78	2.28	32.04	0.54	0.041
	Improved Deko	121.16	9.4	6.18	1.72	74.8	81.5	4.15	2.48	32.19	0.52	0.024
	SAMSORG 17	91.91	8.5	4.88	1.27	70.3	74.2	3.87	2.44	32.64	0.57	0.018
	LSD (0.05)	7.21	1.23	1.04	0.42	2.6	4.3	0.41	0.32	1.21	0.03	0.003

Table 4. Effect of sowing date on the performance of sorghum varieties (2018 trial).

CSR-01 × SD1, SK 5912 × PD1 × SD2 and SAMSORG 17 × SD3. The longest days to 50% flowering decreased in the order SK 5912 × SD1, 121 CKSV-180 × SD1 and Improved Deko × SD2 sowing.

The heaviest panicle weights were recorded for the interaction of CSR-01 × SD2 while Improved Deko × SD2 and 121 CKSV-180 × PD1 produced the second and third heaviest yields respectively. The heaviest grain yield (2.88 t ha^{-1}) was obtained from the interaction of SAMSORG 17 × SD2, the second from Improved Deko × SD2 (2.757 t ha^{-1}), third from SAMSORG 17 × SD2 (2.691), fourth by CSR-01 × SD2 (2.685 t ha^{-1}), fifth by 121 CKSV-180 × SD1 (2.65 t ha^{-1}) while CSR-01 × SD2 produced lowest grain yield (2.685 t ha^{-1}). The highest grain yield found for the interaction of SAMSORG 17 × SD2 would have benefited from the yield components especially, weight of 1000 seeds (31.17 g). The second highest grain yield of 2.76 t ha^{-1} was found from the interaction of Improved Deko × SD2 sowing. The weight of 1000 seeds were heaviest for SAMSORG 17 × SD2 (31.17 g) and SK 5912 × SD2 (31.14 g) while values were similar for CSR-01 × SD3 (30.48 g) and 121 CKSV-180 × SD2 (30.48 g) were higher compared with Improved Deko × SD2 (30.13 g). The highest harvest index (53%) was obtained from the interaction of 121 CKSV-180 × Mid July sowing and similar values were obtained for CSR-01 × SD2 and SK 5912 × early August sowing. The sorghum varieties differed, in performance, the best yield contributing characters were found for CSR-01 × SD and CSR-01 × SD3, the highest grain yields were obtained for these interactions.

Across sowing dates and years of experiment, best vegetative growth characters of sorghum (plant height, number and area of leaves and shoot biomass yield) were obtained for CSR-01, SK 5912 and Improved Deko and lowest for 121 CKSV-180 and SAMSORG 17. Sorghum varieties, CSR-01, SK 5912 and Improved Deko, had longer days to first and 50% flowering (Table 6). Averagely, days to first and 50% flowering were delayed by about 10 days for CSR-01, SK 5912 and Improved Deko over 121 CKSV-180 and SAMSORG 17. The shortest days to first and 50% flowering were observed for SAMSORG, and the attainment of flowering was delayed for almost 10 days for SK 5912 and 15 days for CSR-01 compare with other varieties. Harvest index and weights of grain and 1000 seeds were not significantly different among 121 CKSV-180, Improved Deko and SAMSORG 17. Grain yields differed significantly among the varieties, 1000 seed weights was heaviest for SAMSORG 17 and lighter for CSR-01 and SK 5912 while HI was lowest for CSR-01. For both 2017 and 2018 trials, vegetative characters of sorghum such as plant height, number and area of leaves and shoot biomass yield were best for SK and Improved Deko and lowest for SAMSORG 17. The weights of grain and 1000 seeds and HI were best for 121 CKSV-180, Improved Deko and SAMSORG 17. Sorghum during year 2017 had shorter days to first and 50% flowering and was best in terms of shoot weight while 2018 trial was better for LAI, panicle and grain yields and HI. Although sorghum plants were shorter, LAI, weights of shoot, panicle, grain and 1000 seeds were better for both 2017 over 2018 trials. In both years of experiment, sorghum sown in the early sowing dates (mid July and early August) had enhanced biomass, panicle and grain yields while late sowing dates (mid August and early September) promoted earliness to flowering (days to first and 50% flowering), 1000 seed weight and HI.

Discussion

Variety effects on sorghum performance

The growth and yield performance of sorghum varieties differed under four sowing windows evaluated. The varieties differed performance in terms of LAI, plant height, anthesis date, and shoot biomass, panicle and grain yields including HI. The late maturing varieties (SK 5912 and Improved Deko) was better during the early sowing dates (SD1 to SD3) while the early maturing varieties (CSR-01, 121 CKSV-180 and SAMSORG 17) out-yielded late maturing varieties during SD3 and SD4 windows.

The varieties were different in phenological attributes exemplified by days to 50% flowering which were longer for late maturity varieties and shorter for early maturing varieties. Across sowing dates, the early maturing cultivars produced heavier grain yields while heaviest biomass yields were found for the late maturing cultivars. The differences in the growth and yield variables of sorghum varieties can be attributed to genotypic differences^{21,30}. Varietal traits and yield potentials are heritable though may interact with growing environment conditions especially, the timing and intensity of abiotic stresses during the crop life cycle²¹. Genetic diversity among the sorghum varieties appeared to be expressed via differences in potentials to capture and use growth resources (weather and soil resources) of the sowing windows. The late maturing varieties had longer time to acquire growth resources (light, water and nutrients), which may explain the heavier shoot biomass produced. Sorghum varieties evaluated exhibited variety-specific agronomic traits which may influence expression of yield potentials under variable sowing windows. These observations are valuable to growers, agronomists and breeders, and may find applications for targeting crop designs to specific growing environments.

Singh et al.³², Agele⁸ and Ana et al.³³ reported that drought and heat stress will be on the increase due to expected warming, this implies that adoption of long season crop varieties for cultivation in environments (agroecosystems and seasons) characterized by severe soil moisture deficits and high temperature stresses will not be a good option. Early maturing varieties showed the most stable yields across sowing dates, the observations of phenology and leaf area suggests this stability may be due to reduced thermal time to floral initiation and/or a conservative canopy^{30,32,35}. Long season varieties characterized by large biomass production are known to be better adapted to more favourable environments in particular, adequate soil water availability. Assimilate production and partitioning are known to be sensitive to environment stresses especially, if such stress occur during the reproductive phase of crops^{34,35,37}. The long gestation varieties (varieties with long growth phases) (SK 5912 and improved Deko) took longer days to attain first and 50% flowering in addition to largest leaf areas (LAI @ 50% flowering) while the early maturing varieties (CSR-01, 121 CKSV-180 and SAMSORG 17) had heavier 1000 seed weights and harvest indices. The longer vegetative growth and higher LAI of the long maturity group offer opportunity for resource capture (moisture, nutrient and light), photosynthesis and dry matter production. The early maturing varieties (CSR-01 and SAMSORG 17) produced heavy 1000 seeds and harvest index could have stemmed from higher dry matter production and partitioning. The early maturing

Year	Planting dates	Plant height (cm)	No. leaves	Shoot weight (k/plotg)	LAI @50% flowering	Days to first flowering	Days to 50% ^t flowering	Panicle weight (kg/plot)	Grain yield (kg/ plot)	1000 seed weight (g)	Harvest index	Ext. coef (k)
2017	Mid July	174.17	15.4	7.13	2.15	88.3	97.4	5.67	2.74	31.67	0.43	0.032
	Early Aug	163.81	14.3	6.84	1.72	82.5	90.5	5.64	2.83	31.84	0.46	0.043
	Mid Aug	148.63	12.4	6.33	1.21	77.4	86.7	5.81	3.08	32.25	0.49	0.055
	Early Sept	122.38	11.3	6.15	0.98	62.7	73.4	4.34	2.81	31.33	0.46	0.011
	LSD (0.05)	18.81	2.3	0.44	0.53	8.2	7.5	0.53	0.36	0.61	0.03	0.0021
2018	Mid July	179.21	16.1	7.10	2.11	88.6	98.7	5.63	2.74	31.67	0.41	0.032
	Early Aug	167.72	15.6	6.83	1.79	78.5	87.2	5.71	3.05	32.72	0.45	0.043
	Mid Aug	151.24	13.4	6.48	1.28	70.7	82.3	5.34	3.18	31.31	0.48	0.055
	Early Sept	132.83	12.3	5.63	1.04	58.3	70.6	5.06	2.88	30.25	0.44	0.011
	LSD (0.05)	10.2	3.02	0.38	0.47	11.3	9.4	0.61	0.44	0.58	0.03	ns

Table 5. Sowing date effects on sorghum performance.

varieties (CSR-01, 121 CKSV-180, SAMSORG 17) had short vegetative growth and are suitable for late sowing due to drought escape traits^{37–40}.

Sowing date effects on sorghum performance

Sorghum sowing in the late sowing windows (mid August and early September: SD3 and SD4) had lower values for shoot biomass, panicle and grains yields but heavier 1000 seed weights. The late sowing dates (SD3 and SD4) were characterized by higher intensities of stresses (soil moisture, temperature and atmospheric dryness). Such unfavourable weather conditions especially during grain formation and filling stages are known to affect grain yields^{6,39,40}. The prevailing weather conditions of the late sowing dates can explain the poor yield production by sorghum varieties.

The sowing dates (July to September: SD1 to SD4), were characterized by different growing season duration and weather conditions (seasonal rainfall, mean temperatures, relative humidity, GDD). The weather conditions of the sowing windows appear to have affected ability of sorghum varieties to express their performance potentials. The early sowing dates (mid July and early August) enhanced leaf and height development in sorghum in addition to heavier weights of shoot, panicle and grain yields. Longer length of growing season offered abundant opportunity for resource capture for vegetative growth (longer days to flowering) in addition to favourable weather conditions (high seasonal cumulative rainfall, ambient temperatures, and humidity) which would have enhanced photosynthetic dry matter accumulation. In particular, sorghum produced heavier weights of panicle, grain yield and 1000 seed weight and HI for August sowing windows (early and mid) compare with mid July and early September sowing dates. For September sowing, lighter weights of shoot biomass, panicle and grain may be attributed to the increasing intensities of hydrothermal stresses of this sowing window. The increasing intensities of soil moisture deficit, high temperatures and VPD with delay sowing could explain the observed trends of the length of the growing season, duration of vegetative growth, earliness to flowering and declining yields and among varieties. Such unfavourable soil and weather conditions especially during grain formation and maturity can explain poor sorghum yield production^{38–41}.

Decreases in sorghum yields were obtained as sowing dates were delayed from mid July to early September. Shoot biomass, panicle and grain yields decreased with delay in sowing except for long gestation cultivars (SK5915 and improved Deko). The mid July and early August sowing dates (SD1 and SD2) had longer growing season length (> 120 days), higher cumulative seasonal rainfall (c. 900 mm) and favourable temperatures (c. 30 °C) compared with the late sowing dates (mid August and early September: SD3 and SD4) which had higher temperatures (c. 31 °C) and VPD (> 4.0 kPa) and lower cumulative rainfall (c. 700 mm). Under favourable growing environment conditions such as the early sowing dates, sorghum had longer vegetative phase and large canopy size for capture of growth resources (soil water and irradiance) and biomass and grain yield production. However, under unfavourable environment, shortened growth phases and limited plant size in addition to high rate of leaf senescence (earlier and faster) may lead to reduced biomass accumulation and grain yield production. Yield variations in cereals have been attributed to differences in source and sink sizes on sorghum in West Africa⁶.

The timing and intensity of soil moisture and temperature stresses appeared to have generated substantial differences in the performance of sorghum varieties evaluated. Weather extremes are known to enhance the progression towards the key phenological events (flowering, panicle initiation, duration of grain filling etc.)^{42,44,46}. The growing environment conditions prior to and during grain initiation and filling period may limit grain yield accumulation and number of grains per panicle for each sowing date. The weather conditions of sowing windows in addition to growing season lengths can modulate phenological phases (flowering and seed initiation, seed filling and maturity) in plants^{42,44}. Literature reports have confirmed that weather and soil conditions (water status) modulates flowering time in chickpea, wheat, sorghum^{20,28,46}. Such modulation of phenological phases may become a useful adaptation strategy for sorghum under climate change enhanced warming and drought. An understanding of these responses can be useful for designing management and adaptation strategies to weather adverse growing environment conditions by sorghum in the study area.

Sorghum during the late sowing dates (mid August and early September) grew under increasing intensities of moisture deficit and heat stresses exemplified by higher temperatures (accumulated GDD), lower seasonal cumulative rainfall amount, with concomitant reductions in duration of growing season (shorter growing season lengths) and high incident solar radiation (PAR). Climatic demand, vapour pressure deficit in particular, affects yield or influences other weather variables that affect yield^{6,8}. Vapour pressure deficit drives water loss via plant transpiration, thereby increasing water requirements and VPD affects diurnal temperature variation, cloud cover and precipitation. Heaviest shoot biomass, panicle and grain were produced by sorghum sown mid July and early August, which also serve as the most suitable planting dates for sorghum in the study area (the rainforest zone of south west Nigeria). These sowing dates accumulated highest rainfall amount and had longest growing season ranging between 102 and 120 days (averagely 120 days) while the later sowing dates (late August and early September) had shorter LGS (averagely 116 days) and lower cumulated seasonal rainfall.

Timing and intensity of soil moisture and temperature stresses can explain the differences in the responses of sorghum varieties evaluated (ranging from growth duration, rapid progression towards the attainment of key events (phenophases: flowering, panicle initiation, duration of grain filling etc.). An understanding of these responses can be useful for designing management and adaptation strategies to ameliorate the adverse growing environment conditions for sorghum in the study area. In rainfed sorghum, the soil and weather conditions the variable sowing dates present important challenge to its productivity, pest and disease pressure^{21,44}. Such challenge may affect ability to express genetic capabilities of across agroecosystems. Although, the increasing intensities of thermal and drought stress observed with delay in sowing, appears to have affected biomass accumulation and grain yield formation in sorghum. However, the weights of grains and 1000 seeds and HI were better for sorghum during late sowing dates. It is reported that in cereals including sorghum, grain filling and maturity

Year	Varieties	Plant height (cm)	No. leaves	Shoot weight (kg/ plot)	LAI @50% flowering	Days to first flowering	Days to 50% ^t flowering	Panicle weight (kg/plot)	Grain yield (kg/plot)	1000 seed weight (g)	Harvest index	Ext. coef (k)
2017	CSR-01	161.06	14.8	5.71	2.10	76.73	85.72	4.22	2.64	25.72	0.46	0.032
	SK 5912	177.53	13.6	5.66	2.07	79.27	92.48	4.33	2.73	26.44	0.44	0.043
	121 CKSV-180	161.33	13.1	5.61	2.10	72.48	85.13	4.49	2.78	28.76	0.47	0.055
	Improved Deko	188.42	14.7	5.77	2.12	83.62	91.08	4.26	2.83	30.18	0.50	0.011
	SAMSORG 17	135.61	12.6	5.67	2.06	70.52	82.52	4.20	2.77	31.63	0.53	0.011
	LSD (0.05)	27.63	1.13	0.04	0.03	4.35	4.12	0.13	0.06	3.14	0.03	
2018	CSR-01	161.53	15.3	5.87	2.17	79.35	88.25	4.47	2.75	27.82	0.45	0.032
	SK 5912	173.45	14.4	5.81	2.12	81.46	94.66	4.51	2.88	29.31	0.47	0.043
	121 CKSV-180	157.83	14.2	5.73	2.20	73.73	85.51	4.63	3.04	31.64	0.49	0.055
	Improved Deko	188.411	15.3	5.88	2.28	84.66	96.82	4.50	3.24	31.83	0.52	0.011
	SAMSORG 17	141.52	13.5	5.82	2.11	74.52	81.43	4.36	3.08	32.34	0.54	0.011
	LSD (0.05)	15.42	1.06	0.03	0.05	4.61	5.23	0.09	0.08	2.53	0.02	

Table 6. Effects of variety on growth and yield variables of sorghum.

Treatment combinations	Shoot weight (kg/plot)	LAI @ 50% flowering date	Days to 50% flowering	Panicle weight (kg/plot)	grain yield (kg/plot)	1000 seed weight (g)	Harvest index (HI)
CSR-01×SD1	5.61a	1.73b	95.45a	4.072a	2.382a	27.91a	0.47a
CSR-01×SD2	5.31a	1.82a	81.95c	4.327a	2.625a	28.47a	0.51a
CSR-01×SD3	4.82b	1.61a	81.41a	4.131a	2.832a	30.48a	0.45a
CSR-01×SD4	3.92c	1.33c	77.37b	3.305b	2.255a	28.51a	0.37b
SK 5912 ×SD1	5.18a	1.91b	92.65a	4.047a	2.382b	29.46a	0.47a
SK 5912 ×SD2	5.14a	1.72b	87.32	4.252a	2.631a	31.14a	0.51a
SK 5912×SD3	4.19b	1.14d	68.92	3.305b	2.255a	28.05a	0.43b
SK 5912×SD4	3.84c	1.03d	63.27	3.182b	1.985b	27.74a	0.36b
121CKSV-180×SD1	5.14a	1.72b	87.32	4.327a	2.625a	28.73a	0.53a
121CKSV-180×SD2	4.19b	1.15d	81.92	3.352b	2.255b	30.48a	0.44b
121CKSV-180×SD3	3.84c	1.03d	69.27	3.179b	1.985b	28.53a	0.38b
121CKSV-180×SD4	3.24bc	1.16d	51.35	2.495c	1.367c	26.78b	0.31b
Improved Deko×SD1	4.24b	1.25d	74.17	3.342b	2.165b	28.55a	0.39b
Improved Deko×SD2	5.16a	1.44b	69.31	4.213a	2.757a	30.43a	0.48a
Improved Deko×SD3	4.18b	1.07e	61.17	3.237b	2.224b	28.15a	0.43b
Improved Deko×SD4	2.65c	0.94e	55.32	2.841b	1.672c	25.84b	0.36b
Samsorg 17×SD1	3.25bc	1.10d	68.07	2.263c	2.691a	28.04a	0.38b
Samsorg 17×SD2	4.17b	1.42e	62.15	3.075b	2.877a	31.17a	0.45a
Samsorg 17×SD3	3.87c	1.13d	56.42	2.951b	2.424b	30.04a	0.39b
Samsorg 17×SD4	2.32c	0.86e	49.47	2.442c	2.163b	26.82b	0.32b
Significance level	*	*	*	*	*	*	*

Table 7. Interaction of variety and sowing date on sorghum performance. In a column, figures carrying same letters are not significantly different at 5% level of probability. * (significant at 5% level of probability). SD1 (Mid July), SD2 (Early August, SD3 (Mid august and SD4 (Early September sowing).

needs to occur during dry weather conditions for successful grain filling, maturity and pest avoidance^{12,20,44}. In the study area (rainforest zone of south west Nigeria), sorghum should be sown early to mid August, early July and Late September sowing windows to obtain optimum growth and yield performance.

Interaction of Sowing date and variety on sorghum performance

Based on the significance of the interactions of variety and sowing date for most of the measured growth and yield characters of sorghum, the expression of sorghum varieties' attributes was dependent on sowing dates (and associated weather conditions) particularly for shoot biomass, phenological events and grain yields and its components. The significant interaction of variety by sowing date (Var × SD) for shoot, panicle and grain yields can be attributed to the modification of varietal performance traits by weather conditions of the sowing window. The sowing dates were characterized by variable weather conditions of growing degree days (thermal time requirements), cumulative seasonal rainfall, temperatures and atmospheric dryness (vapour pressure deficit), photosynthetic active radiation (PAR). Matching crop phenology to environment is essential to improve yield and reduce risk of yield losses due to climate stress (high temperatures and soil moisture deficit)⁴⁵. This assertion confirms the the relevance of choice of appropriate sowing dates for sorghum in the different agroecosystems (rainforest, forest-savanna transition, and the savannas of Nigeria).

Conclusions

The sowing dates differed in growing season length, seasonal rainfall, iPAR, GDD and vapour pressure deficits. Sorghum sown during mid July and early August produced taller plants, larger leaf area indices, and heavier shoot biomass, panicle and grain yields compared with late sowing dates (mid August and early September). Over early September sowing, increases were obtained for: shoot biomass (25, 16 and 13%), LAI (67, 51 and 33%) and panicle weight (22, 16 and 8%) from Mid July, early and mid August sowing dates. The increases in grain yields were 19, 32 and 22% between mid July, early and mid August compared with the early September sowing while 1000 seed weights were heaviest for early and mid August as well as early September sowing dates. Sorghum sown at mid August and early September flowered 7 days earlier (83 days) compared with mid July and early August (90 days) sowing. Although, the early sowing dates (SD1 and SD2) offer more favourable environments for sorghum and lower production risk and yield advantage of these periods. The high biomass produced was at the expense of grain yield (as indicated by the lower harvest indices).

Across sowing dates, longer days to 50% flowering, heavier shoot biomass, panicle and grain yields were produced by the late maturing varieties (SK 5912 and Improved Deko) while heaviest 1000 seed weight were produced by early maturing varieties (CSR-01, 121 CKSV-180 and SAMSORG 17). Generally, the late maturing varieties (SK 5912 and Improved Deko) sown in mid July, early and mid August (SD1, SD2 and SD3) produced heavier grain yields while the early maturing varieties (121 CKSV-180, CSR-01 and SAMSORG 17) gave heaviest

Sources	Varieties	Plant height (cm)	No. leaves	Shoot weight (kg/plot)	LAI @50% flowering	Days to first flowering	Days to 50% flowering	Panicle weight (kg/plot)	Grain weight (kg/plot)	1000 seed weight (g)	Harvest index	Ext. coef (k)
Variety	CSR-01	165.76	14.8	5.72	2.13	75.64	88.53	4.19	2.64	23.75	0.43	0.041
	SK 5912	173.52	14.1	5.67	2.07	80.19	90.25	4.25	2.72	24.84	0.45	0.043
	121 CKSV-180	151.34	14.2	5.69	2.11	71.27	83.37	4.49	2.80	26.08	0.48	0.040
	Improved .Deko	180.45	15.2	5.81	2.17	82.15	93.13	4.26	2.85	27.63	0.45	0.045
	SAMSORG 17	147.64	13.7	5.61	2.08	67.18	80.25	4.12	2.77	28.75	0.47	0.038
	LSD (0.05)	28.07	0.09	0.62	0.05	7.32	5.33	0.32	0.25	3.51	0.04	0.002
Planting date	Mid July	153.45	13.4	6.83	2.31	86.36	97.23	5.14	2.76	28.82	0.46	0.040
	Early August	138.37	12.2	6.35	2.08	80.07	92.17	4.87	3.07	30.07	0.49	0.042
	Mid August	122.63	10.1	6.18	1.84	76.63	86.64	4.52	2.85	32.42	0.47	0.038
	Early September	108.76	8.3	5.47	1.38	70.26	80.52	4.21	2.33	30.13	0.45	0.033
	LSD (0.05)	18.38	2.41	0.73	0.07	6.43	7.22	0.21	0.46	4.24	0.03	0.003
Year	2017	167.37	12.5	6.71	2.13	82.34	93.21	4.17	2.67	27.38	0.47	0.042
	2018	162.44	11.8	7.13	2.21	78.82	86.73	4.23	2.82	30.14	0.49	0.040
	LSD (0.05)	ns	ns	ns	ns	*	*	ns	*	*	ns	ns
	Var × SD	*	ns	**	*	**	**	*	*	*	*	ns
	Var × Yr	ns	ns	ns	ns	*	*	ns	Ns	*	*	ns
	Var × SD × Yr	ns	ns	*	ns	*	ns	ns	ns	*	ns	ns

Table 8. Sorghum growth and yield performance as affected by variety, sowing date, and year (mean of 2017 and 2018 experiments). ns (non significant) * (significant) * (significant at 0.05 level of probability).

grain yields for early and mid August and early September (SD4) sowing. The late maturing varieties had longer days to 50% flowering, heavier shoot biomass, panicle and grain yields while significantly heavier 1000 seed weight were produced by early maturing varieties.

High climate stress (soil moisture deficit, atmospheric dryness (VPD) and high temperatures) was observed for late sowing dates (mid August and early September) while early sowing dates (mid July and early August) implies less production risk which may explain the yield advantage of sorghum during these periods. Although, the early sowing dates (SD1 and SD2) offered favourable environments for sorghum based on the relatively high yields for these sowing dates, however, high biomass was produced at the expense of grain yield (as indicated by the lower harvest indices). The interactions of variety and sowing date was significant for most of the measured growth and yield variables of sorghum, this indicated that environment conditions of the sowing windows were yield enhancement factors for sorghum genotypes. Sorghum varieties differed in their ability to cope with climate stresses of soil and air moisture deficits and high temperatures of the late sowing windows (mid August and early September dates). SAMSORG 17 and Improved Deko produced heaviest grain yields and the lowest were recorded for CSR-01 and SK 5912. The early and mid August (SD2 and SD3) were identified as best sowing dates and SAMSORG 17 and Improved Deko, best varieties for the study area (a rainforest zone of southern Nigeria). The study highlighted the relevance of sowing date and cultivar choice as location-specific management strategy for sustainable sorghum production in the rainforest agroecology of southern Nigeria. Informed choice of planting date and cultivar will contribute to optimization of seasonal resources for improving growth, yield and climate adaptation of sorghum.

Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

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Author contributions

Taiwo Grace conducted most activities relating to the field experiments and was responsible for most of manuscript preparation. This publication is extracted from a doctorate research. Agele Samuel is the lead author and major supervisor, he helped in providing major insight into the experimental outputs. He helped in manuscript preparation and provided major input into soil and weather information. Akinseye Matthew is member of the supervisory team. He gave major inputs into understanding the outcomes of experimental output. He helped in field management, data analysis, and graphics, and in running the tools responsible for generation of weather data used in the research. He also helped in manuscript preparation.

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Declarations

Competing interests

The authors declare no competing interests.

Additional information

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