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RESEARCH ARTICLE

Planting date and genotype effect on morpho-agronomic traits of Burkina Faso sweet grain sorghum

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Abstract

Sweet grain sorghum is an under-exploited crop mainly grown around dwelling houses. Its production faces harsh environmental conditions. This study aims to assess sowing date effect on morpho-agronomical traits of sweet grain sorghum. Thus, 30 genotypes of sweet grain sorghum were assessed under 2 planting dates (June 26 and July 20) 24 days apart in a Randomized Complete Block Designs with 3 replications using 10 traits. The results showed a significant effect of sowing date on most of the traits, except internode length. All genotypes were sensitive to photoperiod variation by reducing their sowing-flowering cycle from 08 to 20 days, size and yield at the second planting date. Delayed sowing also resulted in a decrease in plant height (66.4 cm), 100 grain weight (8.3%), panicle weight (16.84%) and grain yield per plant (18.93%). The genotypes expressed a differential sensitivity to photoperiod variation with a mean coefficient of 0.59. Finally, a clustered flowering of all genotypes between September 11 and 27 was observed for both sowing dates. These results could be exploited by sweet sorghum breeding programme in the definition of the cropping calendar.

Keywords

Burkina Faso, climate, genetic diversity, photoperiodism, sweet sorghum

Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is integral to the survival of the population and livestock in Burkina Faso (1-3). It is cultivated in almost the entire territory over more than 1907651 ha, for a production around 1849595 tons during the 2019-2020 agricultural season (4).

Several types of sorghum, with varied but little-known potential, are grown and maintained by farmers. The management of this diversity by farmers allows for an evolutionary adjustment to a heterogeneous environment, but also to meet population needs (5). Among the types of sorghum, sweet grain sorghum, is sparsely valued by the country's breeding programme (3). One of the main characteristics of sweet grain sorghum is its high amount of carbohydrates such as sucrose, glucose and fructose content in the grains (3, 6). Despite its cultivation in the 4 agro-climatic zones in the country, sweet grain sorghum remains a marginal crop. It is not much used by the population and its cultivation is still practiced in small farming land, especially in cage fields (7, 8). The grains of this sorghum are consumed directly in the doughy state and the marketing of panicles provides substantial income to farmers and traders (6, 7). Previous studies on this local food crop have focused mainly on farmers' knowledge of its cultivation (7, 8), its agro-morphological and genetic diversity (9-11), its response to mineral fertilization, the biochemical composition of its grains (6) and its genetic relationships with other types of sorghum (12-14). However, (7, 8) reported a gradual abandonment of sweet grain sorghum cultivation due to the intensification of economically profitable crops (cotton, maize), the development of formal seed programs supported by national policies (15, 16) and the contrasting Sahelian agro-climatic conditions such as erratic rainfall, gradual reduction of arable land and low fertilizer inputs (17-19).

The recurrence of early and late cycle droughts in West Africa has led to the improvement of very early varieties by agricultural extension programme as they seem to be better adapted to short wintering periods (20). However, most farmers remain attached to their traditional varieties with longer cycles than modern varieties (5, 21). Traditional varieties, despite their limited productivity, have high yield stability (18). Indeed, several previous studies have shown a very high sensitivity of most West African sorghums to photoperiod variation (22-24). This trait gives them an important evolutionary advantage due to the continental area, characterized by a high variation in rainfall (24-26). The photoperiod sensitivity of these cultivars ensures that flowering is synchronized with the end of the rainy season, irrespective of the sowing (25, 27, 28). Photosensitive species generally readjust their reproductive cycle to natural variations in photoperiod to ensure production before the end of the rainy season (29, 30).

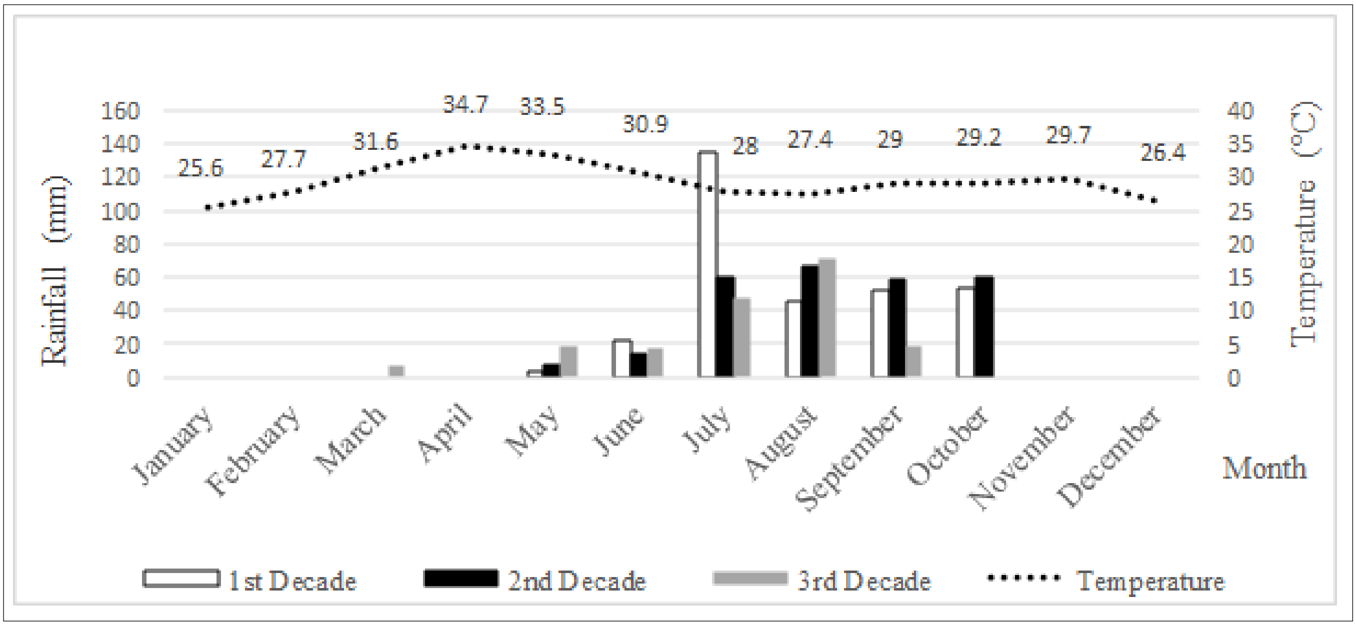

Fig. 1. Decadal precipitation diagram (33) and monthly average temperature curve of the experimental area (34).

In view of the wide variation in rainy season establishment periods affecting planting dates, it becomes important to better understand the response of sweet grain sorghum genotypes to photoperiod variation. Thus, the present study aims to evaluate the effect of delayed sowing on the expression of morpho-agronomical traits and to determine the level of the photoperiod sensitivity of sweet grain sorghum genotypes.

Materials and Methods

Experimental site

The experimental study was conducted in the experimental station of the Rural Development Institute (IDR) in “Gampèla” during the 2019-2020 cropping season. “Gampèla” is a locality located about 18 km east of Ouagadougou with geographical coordinates 12°25'N and 1°12'W (31). The experimental site is characterized by a unimodal rainy season from June to October with an annual rainfall of between 600 and 900 mm (32). In 2019, the first rains were recorded in March and the cumulative rainfall recorded at the experimental station was 762.3 mm on 47 rainy days. Rainfall peaked in July with 321.3 mm in 13 rainy days and then decreased from September onwards (138.5 mm) and stopped in mid-October (112.5 mm) (33). The average monthly temperature fell from March (34.7 °C) to August (27.4 °C) and then increased to a stable value of 29 ˚C from September onwards (Fig. 1) (34).

During the trial conducted between June and October, the average monthly insolation decreased from June onwards, with an average daily duration of 8.2 h/day, reaching a threshold of 5.7 h/day in August, before increasing by 08 h/day from September onwards. Atmospheric humidity increased from the beginning of the crop year to reach a peak in August (77%) and then decreased from September onwards to 72%. The 2 points of intersection of the combined curves of variations in monthly average insolation and atmospheric humidity (Fig. 2) marked the beginning and end of the crop year respectively. Thus, the first substantial rains of the 2019 crop year were recorded in the last 10 days of June and the last rains were recorded in the first 20 days of October (34).

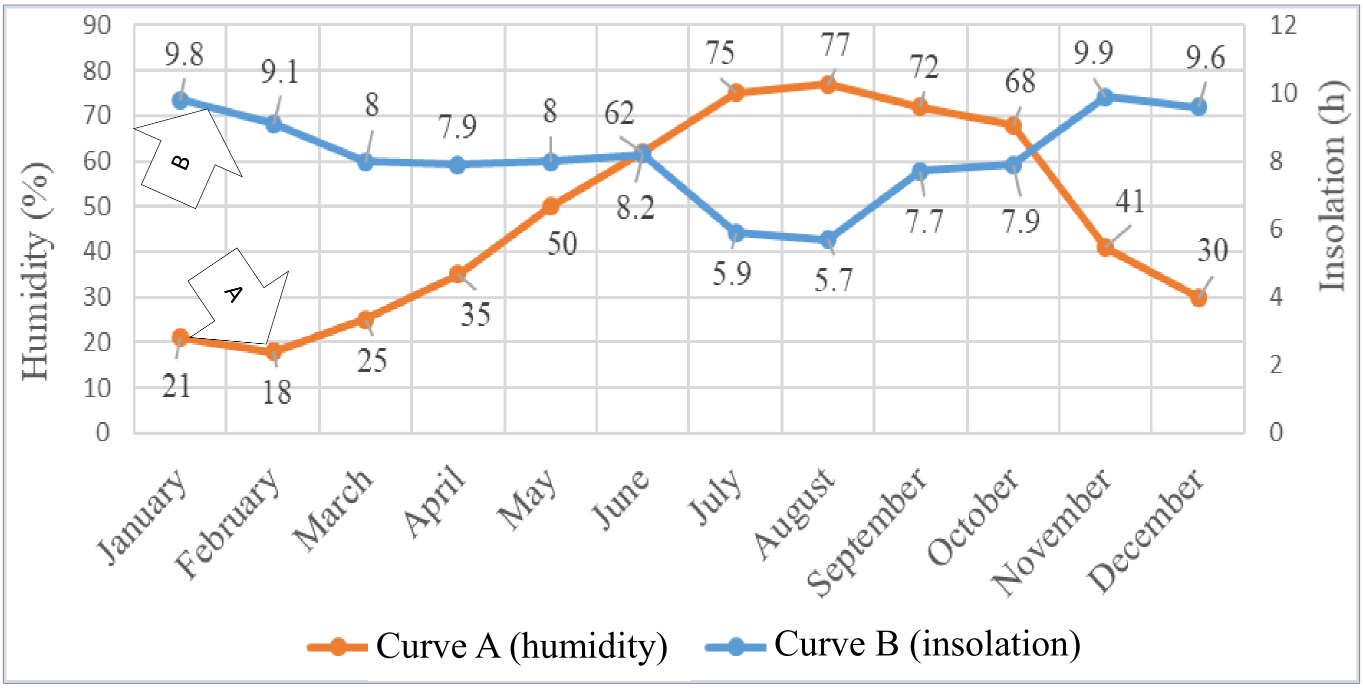

Fig. 2. Monthly average distribution of insolation and atmospheric humidity in 2019 (34).

Plant material

The plant material consists of 30 sweet grain sorghum genotypes from the gene bank of the "Laboratoire Biosciences" of the "Université Joseph KI-ZERBO" (Table 1). The collection was carried out between 2008 and 2014 as part of the preservation of the agro-biodiversity of sweet sorghum in Burkina Faso. The genotypes studied were selected by drawing lots and taking care to include genotypes from the different agro-climatic areas of collection. Previous work by (8) reported that sweet grain sorghum is mainly grown in the sub-Sahelian and northern Sudanian zones, hence their predominance in the study sample.

Experimental design

A randomized complete block design was used in this study and was replicated 2 different planting dates. The 2 trials separated from each other by 4 m. Each trial was set up with 3 replicates 2 m apart. Each replication included the 30 genotypes, each planted in a 5.2 m long row. The row spacing was 80 cm and the distance between the patches was 40 cm, i.e., 14 patches per row. The area of each trial was approximately 455 m^2 (23.2 m× 19.6 m). Two factors were evaluated through this setup. The genotype factor and the sowing date factor which has 2 levels, namely first and second staggered sowing dates (D1 and D2), to measure the photoperiod sensitivity of the genotypes (23).

Table 1. List of genotypes and agro-climatic origins of the collection

Climatic zones	Number of genotypes	Genotype Codes
Sub-Sahelian	16	SKA3; YOU4; KBA1; PBO5; BKO3; YOU1; YOH4; BZI1; GBI4; YOH3; SPI2; PLA1; PBO4; BKO1; YOU5; PGO3.
North Sudanian	9	BIP4; BKB1; BKB2; BKB4; KBZ1; KBZ4; MBO7; MDE5; MTC2.
Southern Sudanian	5	SBR1; SBR5; SBR7; STO5; STO2.

Cultivations techniques

Sowing trials took place on 26 June and 20 July, 2019 respectively, i.e., a difference of 24 days between the sowing dates, on plots previously ploughed with a tractor and levelled. These 2 dates correspond to the usual sowing periods in case of early and late rains. A first manual weeding followed by a thinning of 1 plant per hole was undertaken 2 weeks after sowing. NPK mineral fertilizer 14-23-14 and urea were applied at the same dose of 100 kg/ha (12) respectively 7 days after thinning and simultaneously during the ridging of the field at the morphogenesis stage.

Data collection

Data were collected on 10 agro-morphological traits. The morphological traits measured were the number of productive tillers (NPT), main stem diameter (DIS), plant height (PHT), length (INL) and number of internodes (NIN). The number of days from sowing to flag leaf appearance (NDS), number of days from sowing to flowering (NDF), panicle weight (PAW), panicle grain weight (WGP) and 100-grain weight (HGW) were the agronomic traits measured. The duration of daily photoperiod variations (alternating days and nights) has been obtained also (34).

Statistical analysis

The Excel spreadsheet was used to enter the collected data, calculate the averages, produce the graphs and calculate the photoperiodism coefficient (Kp) according to the formula (23, 35).

$$Kp = \frac{(NDS1 - NDS2)}{ID1 - D2I}$$

It corresponds, in fact, to the ratio of the difference in the sowing-appearance times of the ligule of the flag leaf of the main stem between the first and second sowing dates (NDS1-NDS2) to the difference between the two sowing dates, expressed in Julian calendar (23, 35). The photoperiod coefficient Kp thus varies from 0 (for genotypes insensitive to photoperiod variation) to 1 for very photosensitive genotypes because the shortening of the vegetative period compensates for the sowing offset by grouping flowering at the same date.

Analysis of daily photoperiod variation data using R software version 1.5-10 allowed the determination of annual variations in photoperiodicity (long days, short days). Analysis of variance (ANOVA) was performed using Xlstat 2016 software to assess the effect of sowing dates and differences between genotypes for the different traits studied.

Results

Variation in morphological traits of genotypes

The results of the analysis of variance reported in Table 2 revealed variability in morphological traits of the 30 sweet grain sorghum genotypes studied and a significant effect of sowing date on their expression Indeed, most of the morphological traits except the number of productive tillers (pr =0.88) and main stem diameter (pr = 0.086) discriminated significantly between genotypes at 5%.

The sowing date factor strongly influenced the expression of the performance of morphological traits (pr <0.0001) except for internode length trait (pr = 0.522). This influence resulted in a significant decrease in the mean values of morphological traits (D2-D1 < 0) in the range of -10.86% to -34.17% for delayed sowing. Plant height ranged from 3.3 to 3.92 m at the first sowing date compared to 2.3 m to 3.15 m at the delayed sowing date with mean stem diameters ranging from 2.2 to 2.5 cm and 1.9 to 2.3 cm between the first and second sowing dates respectively. The plants produced an average of 1.46 productive tillers and 15 internodes at the first sowing date compared to 0.97 productive tillers and 11 internodes at the delayed sowing date.

Table 2. Morphological traits variation of the genotypes according to the sowing dates

Traits		NPT	DIS (cm)	PHT (cm)	NIN	INL (cm)
Minimum	D1	0.7	2.2	290.3	14.4	17.7
	D2	0.4	1.9	230	10.9	16
Maximum	D1	2.2	2.5	392	16.5	23.3
	D2	1.6	2.3	314.7	12.5	22.9
Mean	D1	1.46	2.4	348.91	15.11	20.5
	D2	0.97	2.1	282.51	11.56	21.23
ΔD	D2-D1	-0.5	-0.26	-66.4	-3.55	0.72
Variation	(ΔD/D1) ∗100	-34.17	-10.86	-19.03	-23.5	3.5
Genotype	F	0.69	1.45	5.95	3.18	4.06
	Pr.	0.88	0.086	<0.0001	<0.0001	0.019
Date	F	27.57	259.93	294.69	34.99	0.56
	Pr.	<0.0001	<0.0001	<0.0001	<0.0001	0.522
Date x Genotype	F	1.34	1.21	1.84	3.53	0.88
	Pr.	0.013	0.24	0.012	<0.0001	0.640

D1: first sowing date; **D2**: second sowing date; **ΔD**: difference in mean values between sowing dates; **F**: value file; **Pr**: probability of the factor; **NPT**: number of productive tillers; **PHT**: plant height; **DIS**: stem diameter; **NIN**: number of internodes; **INL**: internode length.

The sowing date x genotype interaction was significant for the traits number of productive tillers, plant height and the number of internodes and not statistically significant for the main stem diameter and internode length (Table 2).

Variation in agronomic traits of genotypes

The results of the analysis of variance reported in Table 3 revealed a variation in mean values of the agronomic traits of the measured genotypes between the 2 sowing dates. All genotypes showed highly significant differences for all agronomic traits assessed between the first and second sowing dates.

Phenological traits such as days to flowering and days to flag leaf appearance showed a significant reduction of the cycle by about 14 days at the second sowing date. Days to flag leaf appearance and days to flowering ranged from 64.3 to 74.7 days and 75.3 to 87.7 days respectively at the first sowing date compared to 48 to 62.3 days and 58 to 69 days at the second sowing date. In addition, a significant decrease in the average values of panicle weight per cluster, panicle kernel weight and hundred kernel weight were recorded. The weight of panicles per genotype varied from 206.5 to 342 g and from 138.4 to 321.1 g between the first and second planting dates respectively. Panicle grain weight/genotype ranged from 177.1 to 299.1 g on the first and 100.2 to 250 g on the second planting date. Thus, between the first and second sowing dates, the mean values of the panicles weight/genotype varied from 274.16 g to 227.99 g, of the panicle grain weight from 232.36 g to 188.37 g and the 100-grain weight from 4.6 g to 3.3 g. The performance of the three traits decreased by 17%, 19% and 8.3% respectively, when sowing was delayed. The sowing date x genotype interaction was signifi-

Table 3. Performance of agronomic traits of genotypes at both sowing dates

Traits		**NDS (days)**	**NDF (days)**	**HGW (g)**	**PAW (g)**	**WGP (g)**
Minimum	D1	64.3	75.3	3.8	206.5	177.1
	D2	48	58	3.4	138.4	100.2
Maximum	D1	74.7	87.7	5.2	342.0	299.1
	D2	62.3	69	4.7	321.1	250.9
Mean	D1	71.3	80.1	4.6	274.16	232.36
	D2	57.48	66.07	3.3	227.99	188.37
ΔD	D2-D1	-13.81	-14.05	-0.35	-46.17	-43.99
Variation	(ΔD/D1)*100	-19.36	-17.53	-8.3	-16.84	-18.93
Genotype	F	6.52	3.96	16.35	1.13	1.66
	Pr.	<0.0001	<0.0001	<0.0001	0.31	0.03
Date	F	2533.20	1498.682	44.83	22.56	38.82
	Pr.	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Date x Genotype	F	2.19	3.82	5.97	1.43	1.82
	Pr.	0.002	<0.0001	<0.0001	0.095	0.013

D1: first sowing date; **D2**: second sowing date; **ΔD**: difference in mean values between sowing dates; **F**: value file; **Pr**: probability of the factor; **NDS**: number of days from sowing to appearance of the flag leaf; **NDF**: number of sowing-flowering days; **HGW**: 100-grain weight; **PAW**: panicle weight; **WGP**: panicle grain weight.

cant for all agronomic traits measured except panicle weight.

Evolution of the vegetative period of the genotypes

The results of the evolution of the sowing-flag leaf cycle (NDS) of the genotypes in the 2 trials are shown in Fig. 3. Indeed, in both trials, the sowing-flag leaf cycle showed a quasi-similar variation for the same genotypes with however, different amplitudes. At the second sowing date (curve B), all genotypes expressed a lower cycle compared to the first sowing date (curve A).

The cycle difference of the genotypes for each sowing date is however smaller compared to that of the 24-days sowing date shift. KBZ1, KBZ4, GBI4, STO5, YOU1 and YOH3, reduced their cycle slightly at the second sowing date, which is reflected in the weak closeness of the 2

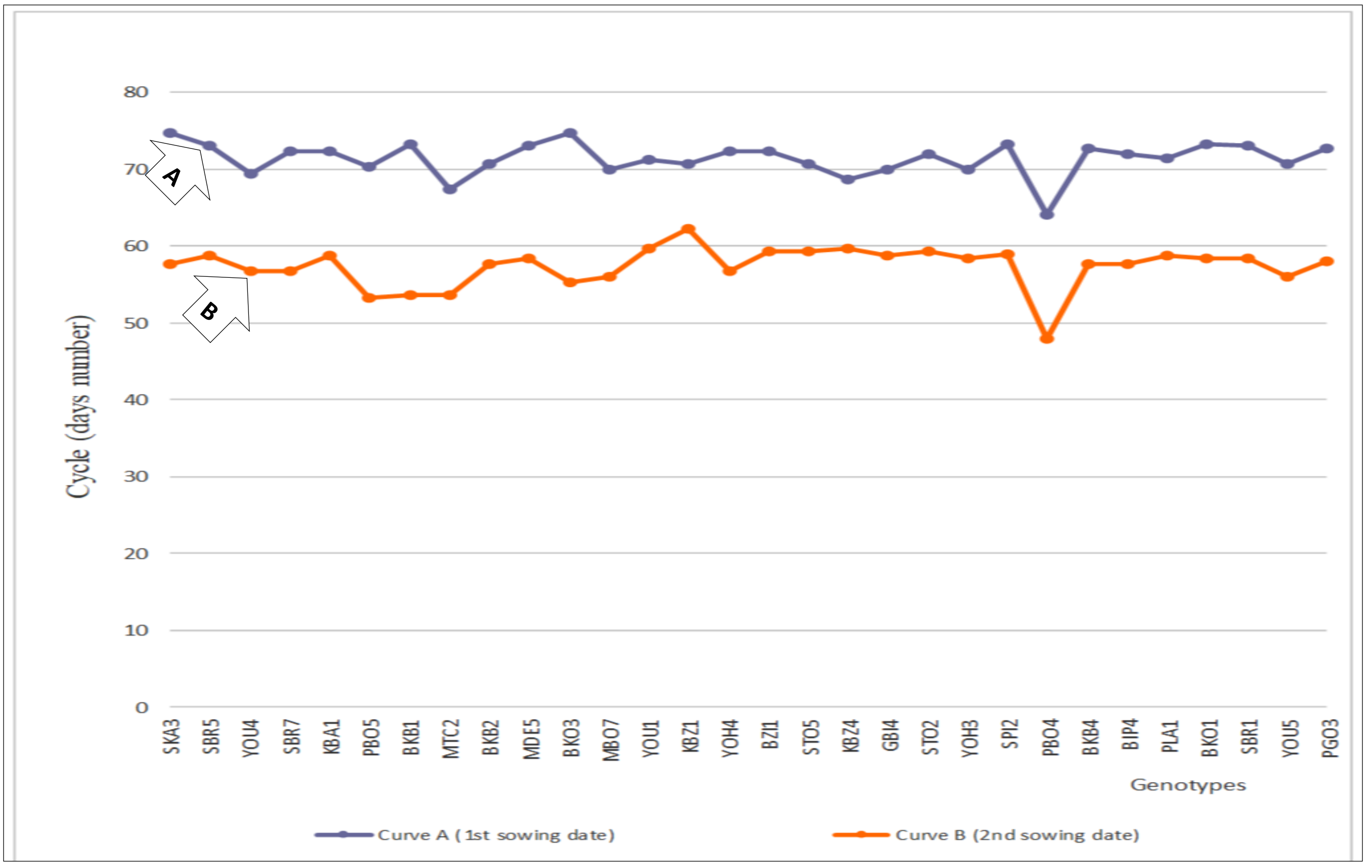

Fig. 3. Variation in the duration of the vegetative phase between the two sowing dates. **A**: evolution curve of the number of days sowing-appearance of flag leaves at the first sowing date; **B**: evolution curve of the number of days sowing-appearance of flag leaves on the second sowing date.

curves. The genotypes KBZ1 and BKB1 occupied extreme positions with gaps of 8.4 and 19.6 days respectively between the 2 sowing dates.

Evolution of flowering during the two sowing dates

The evolution of flowering for the 2 sowing dates over time was reported in Fig. 4. For the first sowing date (curve A), flowering started 76 days after sowing (DAS), on 11 September 2019 for the earlier genotype (PBO4). The number of flowering genotypes increased until 15 September, then decreased in the following days and recovered intensively until 19 September (84 days). For the second sowing date (Curve B), flowering started at 58 days (September 17th) for the earliest genotype (PBO4) and reached its optimum on 23 September. It stabilized in 2 days (September 23 and 25) and then dropped very quickly to end on September 27th (68 days). A gap of 06 days between the beginning of flowering (from 11 to 17 September) and a gap of 08 days between the end of flowering (from 19 to 27 September) of the 2 sowing dates was recorded.

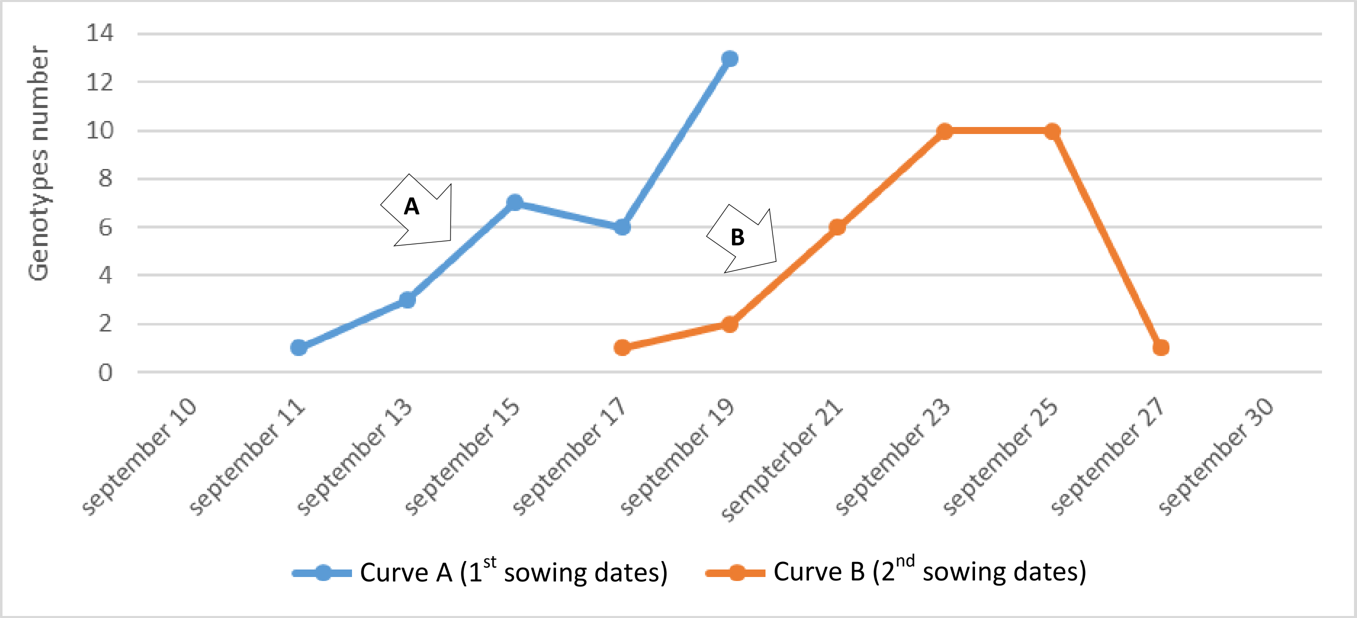

Fig. 4. Curves of the development of flowering for the two sowing dates. **A**: Curve of the development of flowering at the first sowing date; **B**: flowering evolution curve at the second sowing date.

The monthly average day lengths in a 24 h cycle corresponding to the variation in photoperiod recorded in Fig. 5 show that days are indeed longer than nights from May to August (>12 h 30 mins). Flowering, thus began when the average day length fell below an inductive photoperiod of less than 12 h 15 mins.

Variation of the photoperiod coefficient

The results in Table 4 showed that all genotypes reacted to the difference in sowing date by reducing the cycle. Genotype KBZ1 with a cycle reduction of 08 days was the least photoperiodic (Kp = 0.35) and genotype BKB2 was the most photoperiodic (Kp = 0.82) with a cycle reduction of 20

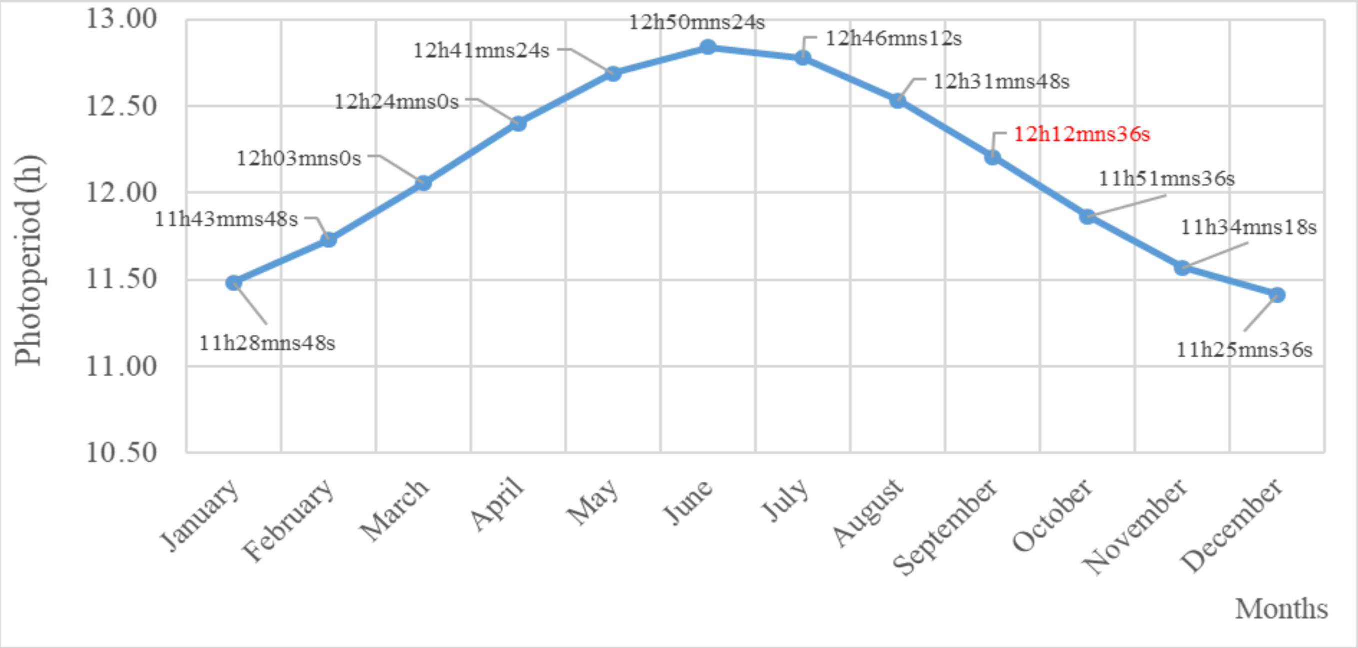

Fig. 5. Curve of the evolution of the daily average monthly photoperiod duration.

Table 4. Variation in photoperiodism coefficient of studied sweet grain sorghum genotypes

Genotypes	NDS1	NDS2	NDS1 - NDS2	Kp	DSP
KBZ1	70.7	62.3	8.4	0.35	*LoS*
KBZ4	68.7	59.7	9	0.38	*LoS*
GBI4	70	58.7	11.3	0.47	*LoS*
STO5	70.7	59.3	11.4	0.48	*LoS*
YOU1	71	59.6	11.4	0.48	*LoS*
YOH3	70	58.3	11.7	0.49	*LoS*
PLA1	71.3	58.7	12.6	0.53	*MoS*
YOU4	69.3	56.7	12.6	0.53	*MoS*
STO2	72	59.3	12.7	0.53	*MoS*
BKB2	70.7	57.7	13	0.54	*MoS*
BZI1	72.3	59.3	13	0.54	*MoS*
KBA1	72.3	58.7	13.6	0.57	*MoS*
MTC2	67.3	53.7	13.6	0.57	*MoS*
MBO7	70	56	14.33	0.58	*MoS*
BIP4	72	57.7	14.3	0.60	*HoS*
SPI2	73.3	59	14.3	0.60	*HoS*
SBR5	73	58.7	14.3	0.60	*HoS*
SBR1	73	58.3	14.7	0.61	*HoS*
PGO3	72.7	58	14.7	0.61	*HoS*
YOU5	70.7	56	14.7	0.61	*HoS*
MDE5	73	58.3	14.7	0.61	*HoS*
BKO1	73.3	58.3	15	0.63	*HoS*
BKB4	72.7	57.7	15	0.63	*HoS*
SBR7	72.3	56.7	15.6	0.65	*HoS*
PBO4	64	48	16	0.7	*HoS*
YOH4	72.3	56.7	17	0.71	*HoS*
PBO5	70.3	53.3	17	0.71	*HoS*
SKA3	74.7	57.7	17	0.71	*HoS*
BKB1	73.3	53.7	19.6	0.82	*VHS*

NDS1: Number of sowing days – the appearance of the flag leaf on the main stem from the first sowing date; **NDS2**: Number of sowing days – the appearance of the flag leaf on the main stem of the second sowing date; **Kp**: photoperiod coefficient; **DSP**: degree of photoperiod sensitivity; **L**a**S**: low photoperiod sensitivity; **MoS**: moderate photoperiod sensitivity; **HoS**: high photoperiod sensitivity; VH**S**: very high photoperiod sensitivity

days. The cycle was reduced by an average of 14 days overall and the average photoperiodic coefficient was 0.59. Four groups of sensitivity to photoperiod variation were identified. Thus, 20% of the genotypes showed low sensitivity ($0.3 \le Kp < 0.5$), and 26.67% moderate sensitivity ($0.5 \le Kp < 0.6$). A large number of genotypes, i.e. 46.67% showed high sensitivity ($0.6 \le Kp \le 0.8$) and a very small proportion (6.67%) showed very high sensitivity ($0.7 < Kp < 1$) to photoperiod variation.

Discussion

Variation in morphological traits of genotypes

The variability of most morphological traits except for the characters, number of productive tillers (NPT) and stem diameter (DIS) observed within the germplasm is similar to the results reported earlier (8). Indeed, these genotypes come from different agro-ecological zones of collection (8). The variability of the genotypes was also reflected in the response to sowing date shift. Indeed, most morphological traits, except the length of internode (INL), were strongly influenced by the sowing date. This, variation was reflected in a significant decrease in the performance of the traits at the second sowing date. Delayed sowing resulted in a reduction in the size of vegetative organs of the genotypes varying by 10.86%, 34.1%, 19.03% and 25.5% respectively for the diameter and height of the main stem (DIS and PHT), the number of internodes (NIN) and the number of productive tillers (NPT). This reduction in the size of vegetative organs of the genotypes at the second sowing date observed in this study would be much more related to the number of internodes and stem thickness than to the internode length, which was not significantly affected by the sowing date ($P = 0.522$). This result corroborates the statements of (36) that the reduction in size is a direct result of the reduction in the number of phytomeres produced but rarely in their size. The reduction in the average number of useful tillers at the second date would be related to the fact that the tillers could not accumulate enough photosynthates to ensure grain formation following the delay in sowing.

Variation in agronomic traits of genotypes

Moreover, the variability of most agronomic traits, with the exception of the panicle weight/bunch (PAW) trait, observed within the plant material studied, indicates the presence of significant variability within the sweet grain sorghum genotypes of Burkina Faso. This variability is believed to be due to the farmer's production system, which consists in producing seeds by mass selection, resulting in population varieties with a broad genetic base (37). The variability of genotypes was strongly revealed in the response to the shift in sowing date. Indeed, all agronomic parameters were strongly influenced by sowing date ($P < 0.0001$). The variation of all agronomic traits could reflect the importance of the effect of environmental factors such as rainfall regime, temperature, humidity, insolation and photoperiod on the aptitude of annual crop species. These climatic factors are characterized by high spatio-temporal variability and unpredictability in Sahelian regions (38, 39). The cycle would be the main parameter between sowing dates that is strongly influenced, affecting the expression of other morphological and agronomic traits. Phenology, in fact, is strongly affected by sowing date, which influences the variation in the rate of development of vegetative organs and grain production (27, 40, 41). However, several authors have reported that the phenology of photoperiod-sensitive sorghum is also influenced by the variation in photoperiod duration (42, 43). Indeed, sensitivity to photoperiod variation is a characteristic of local sorghum varieties allowing it to naturally adjust its cycle length to the likely duration of the rainy season (25, 36). Shifting the sowing date resulted in a variation of the cycle from medium (70-80 days) to relatively long (> 80 days) when sowing is early and from very short (50-60 days) to short (60-70 days) when sowing is delayed. The variation in doughy 100-grain weight (HGW) is thought to be due to a difference in the concentration of water in the grain related to the staggered harvesting time of the different genotypes. The decrease in panicle and grain weight per cluster (PAW and WGP) at the second sowing date could be explained by the shortened cycle of the genotypes at the delayed sowing (24).

Evolution of the vegetative period of the genotypes

The reduction of the vegetative period by about 8 to 20 days of all genotypes at the second sowing date shows a reduction of the cycle when sowing is delayed. This could reflect a sensitivity of the genotypes studied to photoperiod variation, because the reduction of the sowing-flowering cycle when sowing is delayed is one of the characteristics of photoperiodic plants (25, 38). Previous studies have shown a reduction in growth during late sowing regardless of water availability or other resources (36, 44, 45) and little variation in photoperiod near the equator (23). However, the results of this study show that sweet grain sorghum is very sensitive to photoperiod variation and its cycle can be modified by very small photoperiod variations of the order of a few minutes (20 mins) or other climatic factors. Indeed, the decrease in rainfall (130 mm) and atmospheric humidity (72%) and the rapid increase in temperature to 29 °C and insolation duration to about 08 h recorded in September coincided with the floral initiation period. These variations in the external environment would have acted as a signal to lift inhibition that caused the genotypes to stop vegetative development in favor of reproductive development. Earlier studies by (46, 47) reported that the triggering of panicle initiation is mainly under the dual dependence of photoperiod and temperature. Furthermore, (45, 46) have pointed out that the issue of photoperiod cannot be treated independently of temperature and even humidity. There is successively a transition from apical to floral meristem triggered by the variation of photoperiod and then initiation of flowering provided by temperature. Thus, this increase in temperature, which coincided with the end of the rains, created a warm climate that slowed down the vegetative development of the plants. This would have triggered an action on the inhibitory genes of the vegetative phase, as at least 2 major and several minor genes control the vegetative cycle according to (23, 48). The present study shows that, in fact, photosensitive sorghum plants are maintained in the vegetative state when days are long (>12 h 30 mins), until the day length reaches a critical threshold below 12 h 15 mins. Moreover, this interruption is made without taking into account the full development of the plant but acts as a distress signal that intervenes to allow the transition from the vegetative to the reproductive phase in order to ensure the sustainability of the species (40).

Evolution of flowering during the two sowing dates

The difference of six (06) days for the beginning and eight (08) days for the end of flowering between the 2 sowing dates shows that all the genotypes studied are photoperiodic. Indeed, in non-photosensitive species, the difference in sowing date is compensated for at flowering date (23, 49). A sowing date shift of 24 days will result in a 24-day shift in the flowering date of the second sowing date compared to the first sowing date. This is not the case in the present study. Similar results on photoperiodism have been reported for West African sorghum (23), grain sorghum (1, 5, 24) and sweet stalk sorghum from Burkina Faso (50). The shortening of the cycle at the second sowing date immediately resulted in a clustered flowering in 17 days of the genotypes from both sowing dates combined towards the end of the rainy season. This specificity of photoperiodic plants to interrupt the development of vegetative growth in favor of grain production (20, 24, 40), would give them an important evolutionary advantage due to the continental climate of the area, characterized by a strong interannual variation in rainfall regime. A variety is considered adapted to a zone if it flowers 2-3 weeks before the rainy season ends (45). In reality, grain yield and quality are closely linked to the flowering date, as grain of varieties that flower too early is attacked by birds and damaged by molds and insects. Varieties that flower too late deplete soil water reserves before grain filling is complete.

Variation of the photoperiod coefficient

Analysis of the results of the photoperiodism coefficients (Kp) shows a high sensitivity of sweet grain sorghum to photoperiod variation ($0.35 \leq Kp < 0.9$). Earlier studies by (24) found an average photoperiodism coefficient of 0.40 for ordinary grain sorghum which is relatively low compared to that of sweet grain sorghum ($Kp = 0.59$). This difference could be explained by the greater time lag of 30 days between sowing dates compared to 24 days in the present study, but it also reflects the great capacity of sweet grain sorghum to adapt to environmental conditions. Indeed, (50) found an average coefficient of variation of 0.54 for a 24 day sowing interval in sweet stalk sorghum. The results of the present study also show that the earliness of the genotypes is not related to the degree of sensitivity to photoperiod variation but rather to a more intense meristematic activity and rapid panicle development. This characteristic provides sweet grain sorghum with a possibility of continuous production. Earlier studies (23) reported that when highly photosensitive sorghums are sown under low photoperiods, the duration of the vegetative period is minimal and its value represents the intrinsic earliness of the variety. In addition to rainy season production, sweet grain sorghum could be sown in early January to be harvested before the end of March in Burkina Faso.

Conclusion

The study showed that all agro-morphological traits were influenced by variation in sowing date except for internode length. Delayed sowing resulted in a significant reduction in phenological, morphological and agronomic traits. Phenology was most affected by the sowing date. All sweet grain sorghum genotypes studied were sensitive to photoperiod variation and significantly reduced their cycle when sowing was delayed by 24 days. The coefficient of photoperiodism varied from genotype to another. KBZ1 was the least photoperiodic ($Kp = 0.35$) while BKB1 was the most photoperiodic ($Kp = 0.82$). The results of this study could contribute to the definition of the cropping calendar of sweet grain sorghum.

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Authors contributions

This work was carried out in collaboration with all authors. All authors read and approved the final manuscript. IY also provided the English translation.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

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