agronomy

Article

Assessment of Photoperiod Sensitivity and the Effect of Sowing Date on Dry-Season Sorghum Cultivars in Southern Chad

Gapili Naoura [1], Yves Emendack [2,*], Nerbéwendé Sawadogo [3], Nadjiam Djirabaye [1], Ramadjita Tabo [4], Haydee Laza [5] and Eyanawa A. Atchozou [6]

[1] Institute Tchadien de Recherche Agronomique pour le Développement (ITRAD), N'Djaména P.O. Box 5400, Chad
[2] Cropping Systems Research Laboratory, Agricultural Research Service, United States Department of Agriculture, Lubbock, TX 79415, USA
[3] Equipe Génétique et Amélioration des Plantes, Laboratoire Biosciences, Université Joseph KI-ZERBO, Ouagadougou P.O. Box 7021, Burkina Faso
[4] International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Bamako P.O. Box 320, Mali
[5] Department of Plant and Soil Sciences, Texas Tech University, Lubbock, TX 79409, USA
[6] Institute Togolais de Recherche Agronomique, Lomé P.O. Box 1163, Togo
* Correspondence: yves.emendack@usda.gov

Abstract: The cultivation of dry-season sorghum on residual moisture in West and Central Africa is highly affected by sowing dates and ecotypes used. Fifty-five dry-season sorghum ecotypes collected from three zones in southern Chadian were sown on two dates, early and late, in 2013 and 2014, in an α-Lattice, and replicated five times to evaluate the effect of sowing date on potential yield, flowering time, and other agro-morphological traits and to determine their photoperiod sensitivity. Trials were conducted in the research fields at the Agricultural Research Extension Farm in Youé, Chad. Year, sowing date, and their interaction significantly affected most of the assessed traits. Delaying sowing significantly decreased potential yield, duration of vegetative phase, and other agro-morphological traits, except staygreen. All cultivars were photoperiodic with late sowing requiring a lower cumulative growing degree unit to flower. The flowering window was not affected by sowing dates across cultivars; however, the flowering time was affected by a decrease in daylength, but not low night temperatures. Generally, late sowing decreased potential yield across cultivars. However, this decrease varied with the region of origin, with seven cultivars having average potential yields at or above the regional potential yield of 1 t/ha, irrespective of year or sowing dates.

Keywords: dry-season sorghum; photoperiod sensitivity; temperature; daylength; growing degree units; potential yield

check for updates

Citation: Naoura, G.; Emendack, Y.; Sawadogo, N.; Djirabaye, N.; Tabo, R.; Laza, H.; Atchozou, E.A. Assessment of Photoperiod Sensitivity and the Effect of Sowing Date on Dry-Season Sorghum Cultivars in Southern Chad. *Agronomy* **2023**, *13*, 932. https://doi.org/10.3390/agronomy13030932

Academic Editors: Junfei Gu and Guanfu Fu

Received: 18 January 2023
Revised: 15 March 2023
Accepted: 16 March 2023
Published: 21 March 2023

1. Introduction

About half of the world's food calories are provided by the five major cereal crops, viz., wheat, rice, maize, pearl millet, and sorghum [1]. Sorghum (*Sorghum bicolor* L. Moench) is a major staple cereal crop in the savannah zone of West and Central Africa, where it is typically grown under low-input conditions. The cultivation of sorghum in Africa is predominantly during the rainy season (termed rainy-season sorghum). However, a significant part is cultivated during the dry season (termed dry-season sorghum) and plays an important role in West and Central Africa. This dry-season sorghum is usually sowed in the middle or at the end of the rainy season and the crop is grown on residual soil moisture [2,3].

In Chad, dry-season sorghum is the third most important cereal crop, both in terms of area planted and production, and important agronomic and phenotypic diversity exist in ecotypes used by farmers [2,4]. Dry-season sorghum in Chad is cultivated in the south-western part, around lakes and flooded areas of three main regions (Mayo Kebbi Est, Mayo

Kebbi Ouest, and Tandjilé). It is cultivated around Lake Chad in the western part, Lake Fitri in the central, and the huge, flooded area of the Salamat region in the southeastern part [5]. This cereal crop grows very well on vertisol (30–60% clay), heavy and light alluviums, red, gray, and yellow loams, and sandy soils and is established in floodplains, wetlands, inland valleys, and on lake shores [6,7]. Farmers traditionally grow the crop at low plant densities (10,000 to 14,000 plants/ha) to reduce the risk of water stress [8,9].

Sorghum is a short-day plant, and variation in its response to photoperiod and temperatures makes it adaptable to a wide range of different environments [10]. As one of the most drought-tolerant crop species, sorghum is an important model system for studying physiological and molecular mechanisms underlying tolerance to abiotic stresses [11,12]. Temperature and photoperiod are known to interact with genotype and other aspects of the environment to determine the yield potential of crops by affecting the duration of the vegetative and reproductive stages of growth [13–15]. Dry-season sorghum is probably a short-day plant [16,17], and it is characterized as drought tolerant because of its capacity to develop on residual soil [18]. Dry-season sorghum is characterized as a short-day, low temperature (15–30 °C), and cold night cultivator, grown during the dry and cold harmattan period [19].

Photoperiod (daylength) sensitivity has been shown to affect the duration of plant's vegetative phase based on sowing dates. The duration of the vegetative phase is increased by daylength <8 h possibly due to trophic (nutritional, assimilation) constraints [20]. According to [21], the relationships between daylength and the duration of the vegetative phase, which ends with floral initiation, are complex and depend on temperature. Photoperiod by temperature interactions could affect the estimation of temperature responses [22]. One of the most important factors that play an important part in yield is the optimum sowing date. Basically, for each product, there is a good planting time which if delayed can cause yield loss [23]. In fact, optimal regulation of the timing of floral transition is critically important for reproductive success and crop yield [24]. The dry-season sorghum in Chad is cultivated in the Sudanese and Sahelian zone, where rainfall ranges between 200 and 1200 mm, and it is difficult to predict the start of effective rains at the beginning of the cropping season. Dry-season sorghum is known to be transplanted in flood areas after receding of flood water [25], and a good time to uproot the seedling to be transplanted is between 30 and 40 days after sowing [2]. One of the main challenges to cultivating dry-season sorghum is the identification of an optimum sowing date to ensure vigorous plants for transplanting after flooding. According to [26], sowing time/date is a basic requirement to yield determination. Early or late sowing of a crop substantially affects yield and yield components [27].

Studies on how sowing dates will affect dry-season sorghum cultivation in southern Chad are highly needed to characterize the genotypic response to photoperiod sensitivity based on the effects of daylength and temperature on crop growth and development. The current study was conducted to evaluate the effect of sowing date on the duration of the vegetative phase, biomass, and yield and to characterize the photoperiod sensitivity of Chadian dry-season sorghum cultivars. We hypothesized that the sowing date would affect yield and yield components of dry-season sorghum cultivars, and the interaction of temperature and daylength would affect the duration of the vegetative phase.

2. Materials and Methods

2.1. Plant Material

Fifty-five cultivars of dry-season sorghum from the Bébédjia germplasm were used for this study. The genotypes in this germplasm were collected in 2012, from villages in three important zones of production of dry-season sorghum in southern Chad (18 in Moyo Kebbi East, MKE; 15 in Mayo Kebbi West, MKW; and 22 in Tandjilé, TDJ), with annual rainfall ranging from 892 mm to 1118 mm (Supplementary Table S1). These materials were collected by Chadian scientists from the Chadian Institute of Agronomy and Development (ITRAD) as part of ongoing research projects on dry-season sorghum in the regions around the Chad basin. Experiments were conducted at the Agricultural Research Farms of ITRAD, the National Agricultural Research Unit of Chad following the guidelines set by the Ministry of Agriculture, for the collection, protection, and use of local and regional plant germplasms for local and national research and development purposes.

2.2. Experiment Design, Crop Cultivation, and Rainfall

A field study was conducted at the Agricultural Research Farm in Youé (12°24′29″ N, 1°21′9.6″ E) of the Chadian Institute of Agricultural Research for Development, in Chad, during the 2013 and 2014 growing seasons. Fifty-five dry-season sorghum accessions previously described in [2] were sown in an α-Lattice design and replicated five times. Seeds were manually sown during the peak of the rainy season, usually at the end of July through September. Seeds were sown on two dates: 30 July and 31 August, and 21 August and 15 September for early and late sowing dates in 2013 and 2014, respectively. Seedlings were uprooted 30 and 49 days after sowing (at the end of the rainy season) and transplanted into three rows of 18.0 m length, 1.2 m inter-row spacing, and 0.2 m seedling spacing (Table 1). Each accession was seeded into a 4.0 m^2 plot, and standard management practices were implemented. No fertilizer was applied, and one hand hoeing was enough to control weeds. The duration of the growing season (in days) for both early and late planting was longer in 2013 than in 2014 by 30 and 19 days, respectively.

Table 1. Sowing date, transplanting date, harvest date, and duration of the growing season of dry-season sorghum grown at Youé research farms in Chad in 2013 and 2014.

Year	Sowing	Sowing Date	Transplant Date	Days before Transplanting	Harvest Dates	Duration of Growing Season
2013	Early	30 July	17 September	49	19 February	₸ 203
	Late	21 August	5 October	45	27 February	189
2014	Early	31 August	7 October	37	20 February	173
	Late	15 September	15 October	30	2 March	170

₸ indicates the number of days from seeding to harvesting.

Youé lies in Chad's Sudanese zone, characterized by annual rainfall of 700–1100 mm. Seasonal rainfall was 927.5 mm in 2013 and 517.2 mm in 2014 (Figure 1). The month of August had the highest rainfall in both years (238.0 mm in 2013 and 213.5 mm in 2014). Rainfall ended in October with the lowest amount in both seasons (37.0 mm in 2013 and 4.0 mm in 2014).

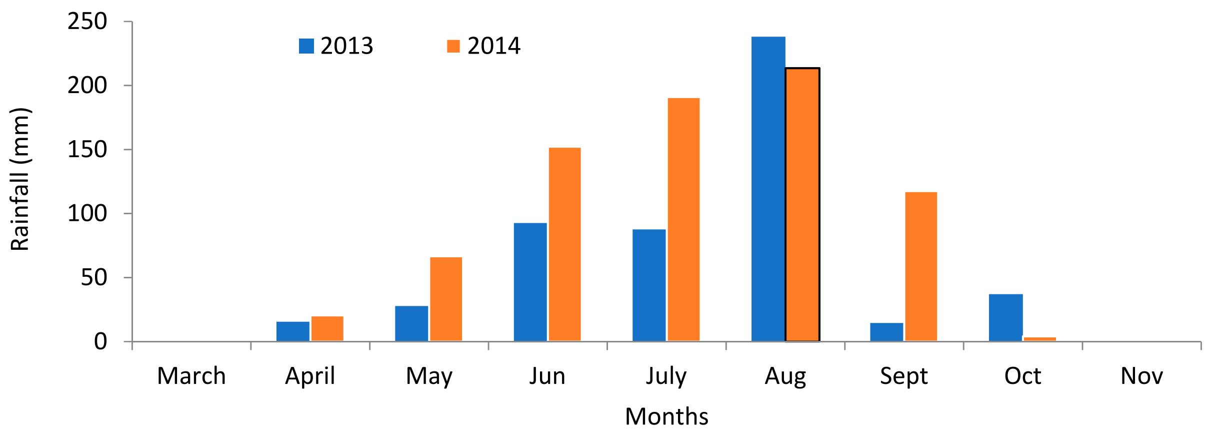

Figure 1. Seasonal rainfall in 2013 and 2014 for dry-season sorghum grown at Youé research farms in Chad.

2.3. Temperature and Daylength Conditions

Temperature and daylength were recorded at an onsite weather station at Youé Experimental Farm. In addition, temperature and daylength were taken from NASA Power

Prediction of Worldwide Energy Resources (power.larc.nasa.gov, accessed on 15 March 2023). The seasonal average maximum (T_{max}) and minimum (T_{min}) air temperatures (Figure 2) were slightly higher in 2013 (36.2 and 23.2 °C) than in 2014 (35.8 and 22.9 °C), respectively. Average monthly temperatures were lowest during sowing (late July to early September), which was the peak of the rainy season in both years. The average monthly T_{max} during the interval from transplanting (mid-September to mid-October) to harvest (mid-February to early March) was higher than the average seasonal T_{max} in both years. Monthly rainfalls were the lowest during this interval in both seasons. Likewise, the average monthly T_{min} was the lowest in the harmattan months of December, January, and February in both years.

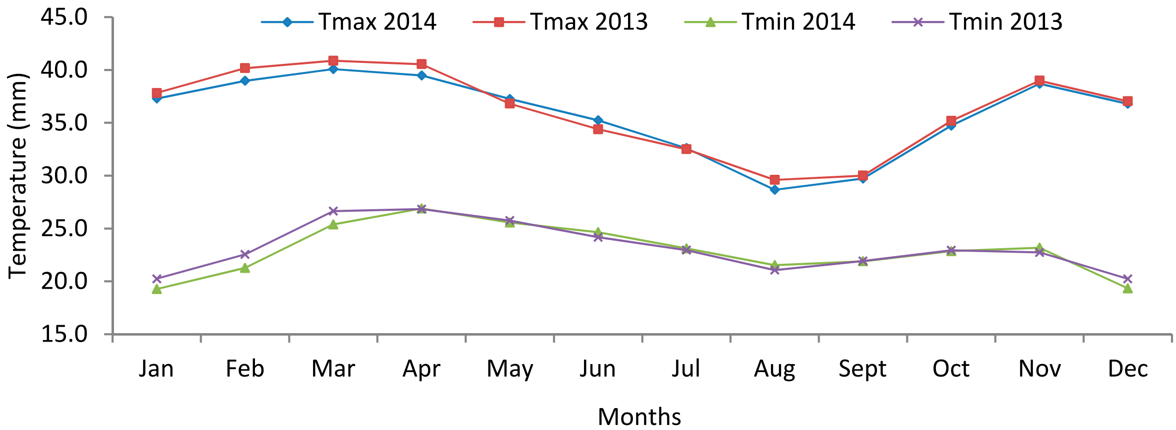

Figure 2. Average seasonal air temperatures (maximum and minimum) in 2013 and 2014 at Youé research farms in Chad.

Daylength ranged from 7 h 54 min to 11 h 32 min in 2013 and from 8 h 7 min to 10 h 58 min in 2014, with August having the least daylength in both years (Figure 3). Thus, the photoperiod conditions were similar in both years and never differed by more than 35 min (April) across the year. Day length was lower during planting and transplanting and increased with crop growth and development in both seasons.

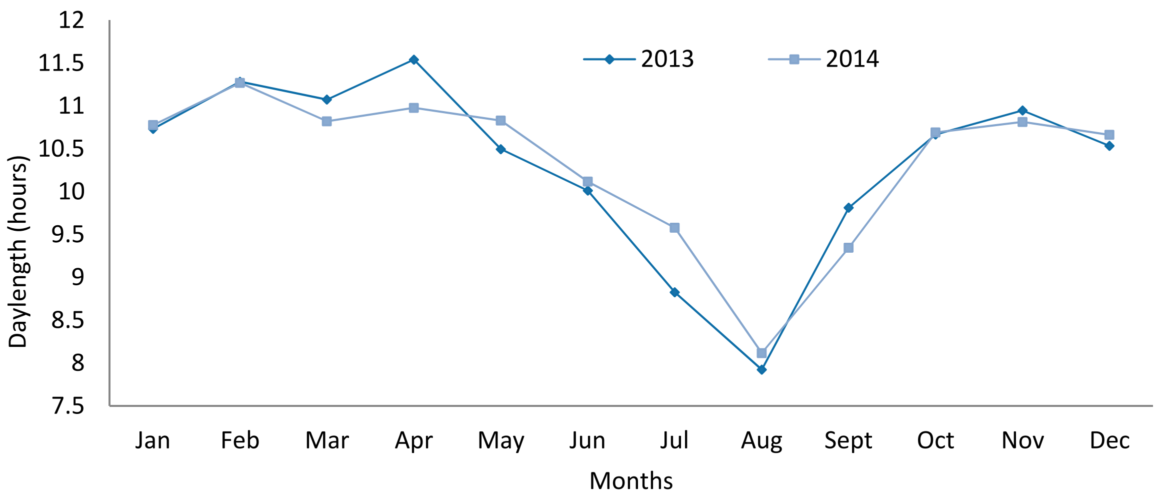

Figure 3. Average monthly daylength in 2013 and 2014 growing seasons for dry-season sorghum at Youé research farms in Chad.

2.4. Data Collection

Morphological and phenological traits recorded were quantitative in nature and were assessed from five plants per plot within each replication of an accession. The traits included number of days to exertion of flag leaf ligule (NFL) and number of days to flowering (NFW), defined as the number of days when 50% of the plants within a row showed ligule of flag leaf and reached flowers, respectively. Plant height (PHT) was measured at maturity from the plant base to the tip of the panicle. The stem diameter (SDI) was measured 30 cm from the plant base. Perultimate leaf length (PSL) was measured from the base of the leaf to its tip and the perultimate leaf width (PLW) was measured at the widest part of the leaf. The number of green leaves (NGL; the leaf is considered green if 75% of the leaf area is green) at harvest was counted to determine the staygreen (STG). The panicle length (PAL) was measured from the base to the tip of the panicle and panicle width (PAW) was measured at the widest part of the panicle. At maturity, panicles were harvested and sun- and air-dried for 10 days. Panicle weight (PWT; the weight of the main stem panicle), panicle grain weight (PGW; the weight of main panicle grains), hundred grain weight (HGW; the weight of 100 grains), and potential yield (PYI; the weight of grains per hectare at 14% moisture content) were determined.

The level of photoperiod sensitivity of all accessions was assessed using the photoperiod sensitivity index (*Kp*), based on the decrease in the duration (in days) of the vegetative phase between the two sowing dates:

$$Kp = \frac{\mathrm{NFL1} - \mathrm{NFL2}}{\mathrm{D2} - \mathrm{D1}}$$

where NFL1 and NFL2 are the duration from sowing to 50% appearance of flag leaf ligule for the first (early) and the second (late) sowing dates, respectively, and D1 and D2 are the first (early) and second (late) sowing dates in Julian days [28]. *Kp* is expected to vary from 0 for photoperiod-insensitive cultivars that do not change the duration of their vegetative phase with sowing date, to 1.0 for the most strongly photoperiod-sensitive cultivars that reduce their vegetative phase to the same extent as the delay in sowing, thus keeping the calendar date of flowering constant.

The timing and duration of each growth stage in a plant requires a specific heat unit otherwise called the growing degree unit (GDU) which varies with daily temperatures. A growing degree day is when the average daily temperature is at least one degree above the base temperature (10 °C in sorghum), below which development stops. Studies have shown that the cumulative growing degree unit or growing degree days in sorghum varies with developmental stages [27,29,30] and genetic background [27]. GDU was cumulatively calculated at flowering for each planting date in both seasons as:

$$\mathrm{GDU} = \frac{\mathrm{T}_{\mathrm{max}} + \mathrm{T}_{\mathrm{min}}}{2} - \mathrm{T}_{\mathrm{base}}$$

where $\mathrm{T}_{\mathrm{max}}$ and $\mathrm{T}_{\mathrm{min}}$ are the daily temperature maximum and minimum, respectively, and $\mathrm{T}_{\mathrm{base}}$ is the base temperature for sorghum (10 °C).

2.5. Data Analysis

Data were subjected to analysis of variance in GenStat software version 12.1, using the general linear model procedure. Planting dates and cultivars were considered as fixed effects, and years and blocks were treated as random effects in the model. The coefficient of variation (CV) was estimated to show the extent of variation among each treatment combination. Repeatability (h^2) was calculated for each trial using a formula appropriate for unbalanced data sets as described in [31].

3. Results

3.1. Analysis of Variance of Dry-Season Sorghum Traits Assessed

The sowing date (S), cultivar (C), year (Y), and their interactive effects were tested through analysis of variance for the two years (Table 2). Cultivar explained slightly more variation than year and sowing date. Almost all traits assessed were affected ($p < 0.001$) by year, only plant height showed no significant difference ($p = 0.96$) between the two years. Nonetheless, plant height was highly influenced ($p < 0.001$) by sowing date and cultivar, likewise by year × sowing date interaction. Potential yield showed high variation ($p < 0.001$) in year, sowing date, and sowing date × cultivar interaction; nonetheless, this variation was slightly significant ($p = 0.02$) between cultivars. Repeatability estimates (h^2) ranged from 3.33% for days to flowering to 95.7% for panicle length. Most traits had high h^2 values greater than 70%, except days to flowering (3.33%), days to the appearance of flag leaf ligule (5.17%), and steam diameter (8.21%). There was significant variability among cultivars in all assessed traits, except stem diameter.

Table 2. *p*-values from ANOVA for assessed traits of 55 Chadian dry-season sorghum as affected by year (Y), sowing date (S), and the cultivar (C), with mean values plus/minus standard error (SE).

Traits	**Year (Y)**	**Sowing Date (S)**	**Cultivar (C)**	**Y × S**	**Y × C**	**S × C**	h^2 **(%)**	**Mean ± SE.**
SDI	<0.001 ***	0.849 ^{ns}	0.913 ^{ns}	0.026 *	0.319 ^{ns}	0.875 ^{ns}	8.2	2.47 ± 1.3
PWT	<0.001 ***	<0.001 ***	<0.001 ***	0.013 *	0.970 ^{ns}	<0.001 ***	80.5	575 ± 59.0
PHT	0.096 ^{ns}	<0.001 ***	<0.001 ***	<0.001 ***	0.286 ^{ns}	0.187 ^{ns}	94.8	168 ± 24.0
PLW	<0.001 ***	0.196 ^{ns}	<0.001 ***	0.457 ^{ns}	0.003 **	0.886 ^{ns}	81.0	8.97 ± 2.8
PAW	<0.001 ***	<0.001 ***	<0.001 ***	0.033 *	0.002 **	0.345 ^{ns}	71.8	7.90 ± 0.7
PSL	<0.001 ***	<0.001 ***	<0.001 ***	<0.001 ***	0.582 ^{ns}	0.305 ^{ns}	88.4	60 ± 6.3
PAL	<0.001 ***	0.140 ^{ns}	<0.001 ***	0.737 ^{ns}	<0.001 ***	<0.001 ***	95.7	18.57 ± 3.7
NIN	0.004 **	<0.001 ***	<0.001 ***	<0.001 ***	<0.001 ***	0.013 *	76.8	12.66 ± 2.0
FLL	<0.001 ***	<0.001 ***	<0.001 ***	<0.001 ***	0.999 ^{ns}	0.999 ^{ns}	5.2	113 ± 4.1
NFW	<0.001 ***	<0.001 ***	<0.001 ***	<0.001 ***	0.999 ^{ns}	0.999 ^{ns}	3.3	117 ± 4.1
PGW	<0.001 ***	<0.001 ***	<0.001 ***	0.273 ^{ns}	0.916 ^{ns}	<0.001 ***	82.6	417 ± 38.9
STG	0.215 ^{ns}	0.341 ^{ns}	<0.001 ***	0.472 ^{ns}	0.341 ^{ns}	0.312 ^{ns}	85.2	55 ± 8.7
HGW	0.421	0.032 *	<0.001 ***	0.321 ^{ns}	0.245 ^{ns}	0.125 ^{ns}	79	4.63 ± 0.8
PYI	<0.001 ***	<0.001 ***	0.020 *	0.711 ^{ns}	0.941 ^{ns}	<0.001 ***	81.8	0.86 ± 0.1

*, **, *** indicate significance at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively; ns indicates no significant difference. SDI (cm), steam diameter; PWT (g), weight of the main panicle; PHT (cm), plant height; PLW (cm), perultimate leaf width; PAW (cm), panicle width; PSL (cm), perultimate leaf sheath length; PAL (cm), panicle length; NIN, number of internodes; FLL (days), days to appearance of flag leaf ligule; NFW (days), number of days to flowering; PGW (g), weight of grains of the main panicle; HGW (g), hundred grain weight; STG (%), staygreen percent; PYI (t/ha), potential yield.

Results indicated that the early sowing date (S1) significantly increased growth components than the late sowing date (S2) in two years of experiment (Table 3). Regarding the two years of the experiment, though plant height showed no significant difference ($p = 0.096$; see Table 2) within accessions, plants were taller in the early sowing date in both years. Plants from early sowing (181.5 cm) in 2013 were taller than those from early sowing (172.0 cm) in 2014. Although the late sowing date (15 September) in 2014 was more delayed than that (21 August) in 2013, late sowing plants were taller (165.6 cm) in 2014 than (154.3 cm) in 2013. Other traits, such as PSL, NIN, PAL, PAW, PWT, PGW, PYI, FLL, and NFW, were also enhanced by early sowing in both years. On the contrary, staygreen percent and perultimate leaf width traits showed increased value under late sowing date in both years. The stem diameter was slightly higher under early sowing than late sowing in 2013, but the reverse was true in 2014.

3.2. Duration of Vegetative Phase

Differences in sowing dates showed variations in the duration of the vegetative phase (emergence of flag leaf ligule) (Figure 4) in both years. The vegetative phase was lengthened by early sowing across all varieties in both seasons, more so in 2013 than in 2014. The duration of the vegetative phase for all cultivars under late sowing was shorter in 2014 than in 2013. There were cultivar (cv) variations in the lengthening/shortening of the vegetative phase, and the difference between early versus late sowing was greater in 2014 than in 2013, irrespective of the cultivar.

Table 3. Mean values plus/minus standard error (SE) and coefficients of variation for 14 traits assessed on 55 Chadian dry-season sorghum cultivars sown at different sowing dates (S1, early and S2, late) in the 2013 and 2014 growing seasons at the Youé research farms in Chad.

Traits	2013				2014			
	Mean + SE		CV		Mean + SE		CV	
	S1	S2	S1	S2	S1	S2	S1	S2
PSL (cm)	61.9 ± 5.9	52.2 ± 7.96	9.5	15.3	64 ± 5.4	62.47 ± 5.8	8.5	9.3
PLW (cm)	9.3 ± 0.6	9.5 ± 0.5	5.9	5.7	8.52 ± 0.9	8.65 ± 0.8	11.2	9.1
PHT (cm)	182 ± 35.8	154 ± 31.5	19.7	20.4	172 ± 37.9	165.6 ± 30.9	22.1	18.7
SDI (cm)	2.6 ± 1.0	2.4 ± 1.5	38.2	62.2	2.4 ± 1.5	2.5 ± 1.36	32.9	30.4
NIN	12.6 ± 2.2	11.4 ± 1.6	17.6	13.9	13.92 ± 2.4	12.7 ± 1.6	17.1	12.6
PAL (cm)	18.1 ± 1.4	17.4 ± 6.2	7.8	35.5	19.5 ± 5.7	19.3 ± 5.4	29.1	28.1
PAW (cm)	8.4 ± 0.5	7.4 ± 0.8	6.2	10.2	7.95 ± 0.9	7.3 ± 0.8	11.4	10.5
FLL (days)	135 ± 4.3	120 ± 4.3	3.2	3.6	103 ± 3.1	96.3 ± 4.6	3.0	4.8
NFW (days)	137 ± 3.7	123 ± 4.7	2.7	3.9	108.6 ± 3.7	101.9 ± 4.4	3.3	3.4
PWT (g)	618 ± 64.4	583 ± 54.3	28.2	23.2	624.1 ± 68.7	475.4 ± 58.2	31.8	27.0
PGW (g)	464 ± 45.8	425.8 ± 36.1	35.7	27.3	437.5 ± 56.4	344.1 ± 38.9	37.3	31.7
HGW (g)	4.4 ± 0.8	4.35 ± 0.9	17.1	20.0	4.72 ± 0.9	5.05 ± 0.8	18.6	16.4
PYI (t/ha)	0.9 ± 0.3	0.85 ± 0.2	35.7	27.3	0.88 ± 0.3	0.77 ± 0.2	37.3	30.3
STG (%)	52.8 ± 5.9	76.2 ± 8.5	11.2	11.2	45.0 ± 14.1	47.78 ± 10.2	31.4	21.4

PSL, perultimate leaf sheath length; PLW, perultimate leaf width; PHT, plant height; SDI, stem diameter; NIN, number of internodes; PAL, panicle length; PAW, panicle width; FLL, days to appearance of flag leaf ligule; NFW, number of days to flowering; PWT, weight of the main panicle; PGW, weight of grains of the main panicle; HGW, hundred grain weight; PYI, potential yield; STG, staygreen percent.

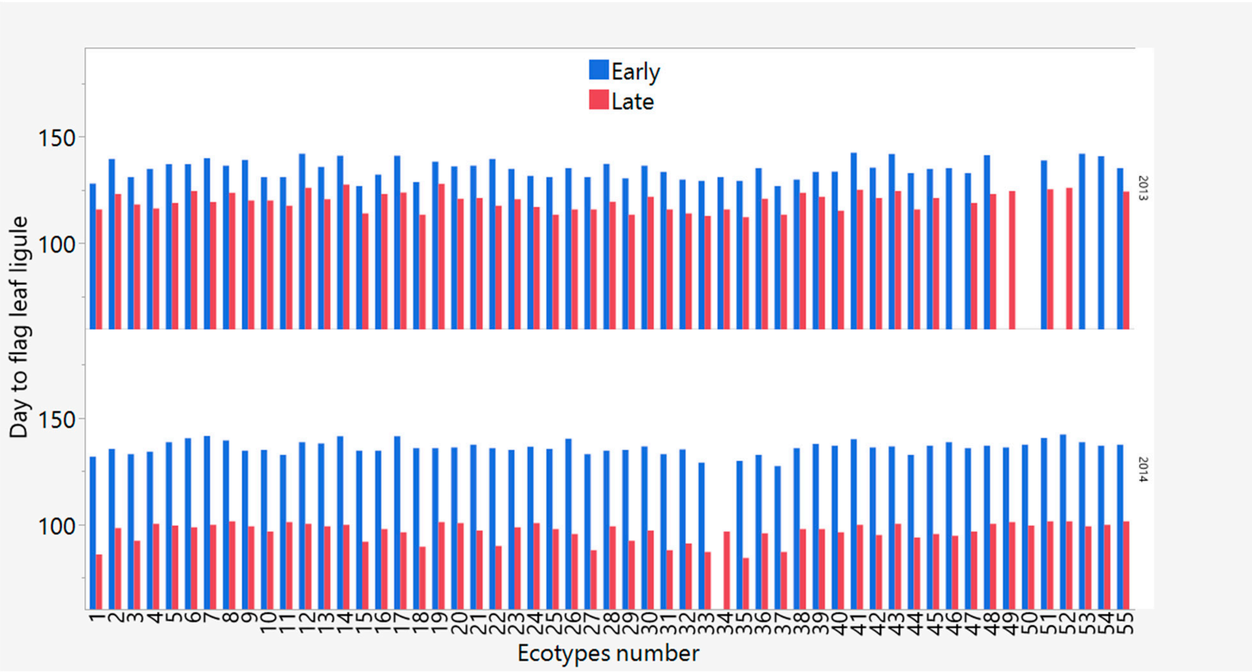

Figure 4. Duration of vegetative phase as affected by different sowing dates for Chadian dry-season sorghum accessions, grown at the Youé research farms in Chad in 2013 and 2014.

The photoperiod sensitivity index (*Kp*) and number of days to 50% appearance of flag leaf ligule (NFL) varied significantly across years (Table 4). In 2013, variance component analysis indicated significant ($p < 0.0001$) main effects of accessions for NFL in both early (S1) and late (S2) sowing dates but not on *Kp* ($p = 0.013$). Likewise, the results of variance components analysis conducted in 2014 indicated significant accession effects for NFL in S2 ($p < 0.0001$), S1 ($p = 0.0023$), and *Kp* ($p = 0.001$). The coefficient of variation was very low for NFL in both years of the experiment. The coefficient of variation ranged from 3.1 (NFL in early sowing date) to 19.0 (*Kp*) in 2013 and from 3.0 (NFL early sowing date) to 52.6 (*Kp*) in 2014.

Table 4. Mean values plus/minus standard error of days to appearance of flag leaf ligule and photoperiod sensitivity index for 55 Chadian dry-season sorghum accessions, under early and late sowing dates in 2013 and 2014, at the Youé research farms in Chad.

	2013			2014		
	NFL		*Kp*	NFL		*Kp*
	S1	S2		S1	S2	
Minima	127	112	0.29	94	84	0.04
Maximum	142	128	0.95	108	101	0.84
Mean	135 ± 4.2	119 ± 4.3	0.72 ± 0.1	103 ± 3.0	96 ± 4.2	0.43 ± 0.2
CV	3.1	3.6	19.0	3.0	4.9 ***	52.6 ***
p-values	<0.0001 ***	<0.0001 ***	0.013	0.0023	<0.0001 ***	0.001

NFL, days to appearance of flag leaf ligule; *Kp*, index of photoperiod sensitivity; S1, early sowing date; S2, later sowing date. *** indicate significance at $p < 0.001$.

Photoperiod sensitivity index (*Kp*) varied highly across years (Figure 5). In 2013, most accessions (41) had *Kp* values ranging from 0.6 to 0.9. Only a few accessions (8) had *Kp* values less than 0.6, and 4 accessions had *Kp* values close to 1. In 2014, most accessions (43) had *Kp* values under 0.6, and only a few accessions (11) had high *Kp* values ranging from 0.6 to 0.9.

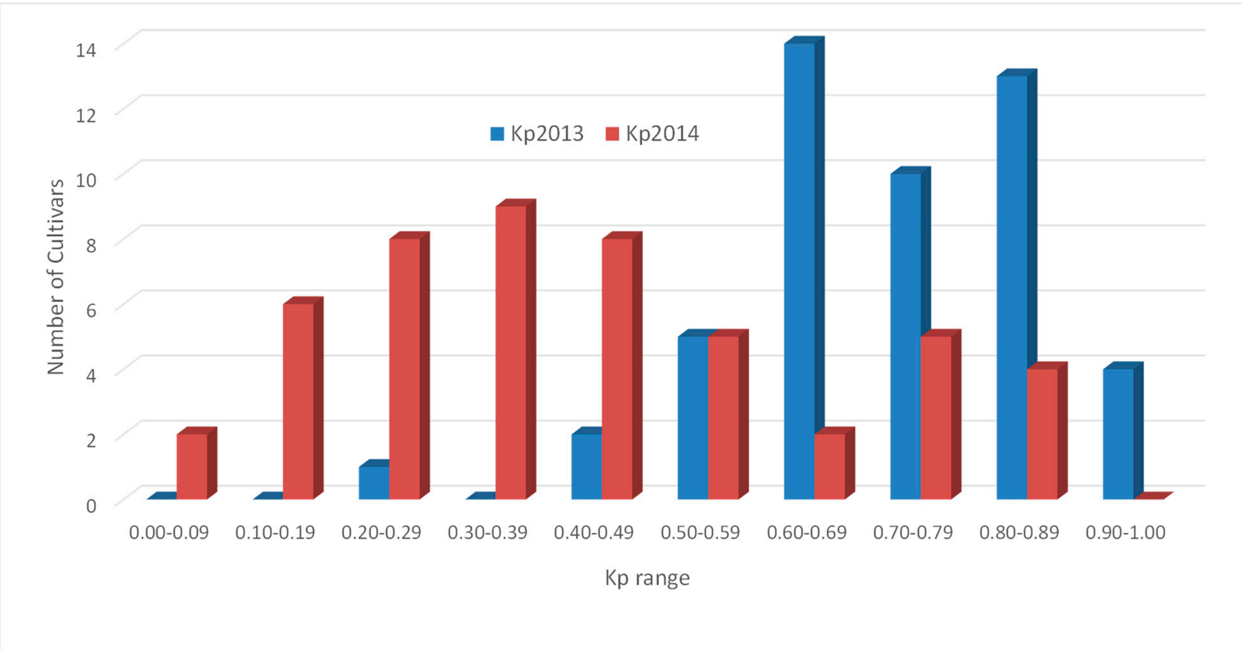

Figure 5. Photoperiod sensitivity index for Chadian dry-season sorghum accessions sown at the Youé research farms in Chad in 2013 and 2014.

3.3. Flowering Time, Day Length, Temperature, and Growing Degree Units

3.3.1. Flowering Window

In 2013, flowering (50% anthesis) occurred in the month of December (Figure 6). For the early sowing date, the flowering window was 16 days (6–21 December), and 18 days (13–30 December) for the late sowing date. For the early sowing date, 24 accessions flowered within the first 7 days (6–12 December), and 20 accessions flowered during the last 7 days (15–21 December) of the flowering window. On the other hand, 11 accessions flowered during the first 7 days (13–19 December), and 30 accessions flowered during the last 7 days (24–30 December) for the late sowing date. There were 21 days between early sowing and late sowing dates in 2013. However, only a 7- and 9-day difference was observed between the first and last flowering, respectively, for early versus late sowing dates.

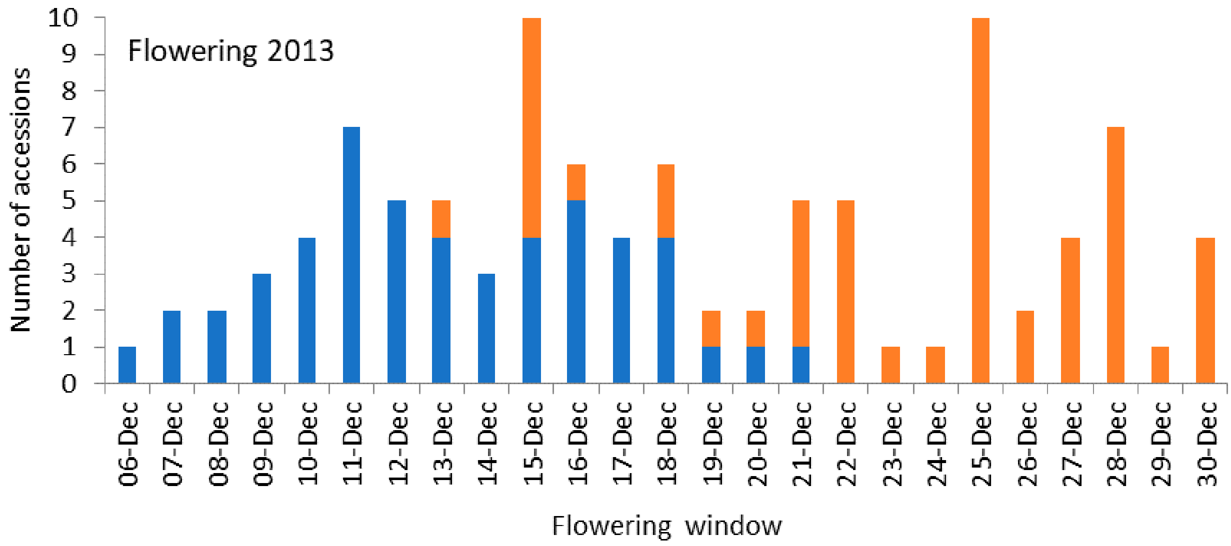

Figure 6. Histogram of time to 50% flowering for Chadian dry-season sorghum accessions sown early (blue bars) and late (red bars) in 2013 at the Youé research farms in Chad.

Just as in 2013, flowering in 2014 occurred in the month of December irrespective of the sowing date (Figure 7). In early sowing, the flowering window was 17 days (9–25 December) compared to 18 days (13–30 December) in the late sowing date. Though there was a 15-day difference between early and late sowing dates, only a 4- and 5-day difference was observed between the first and last flowering, respectively, for early versus late sowing dates.

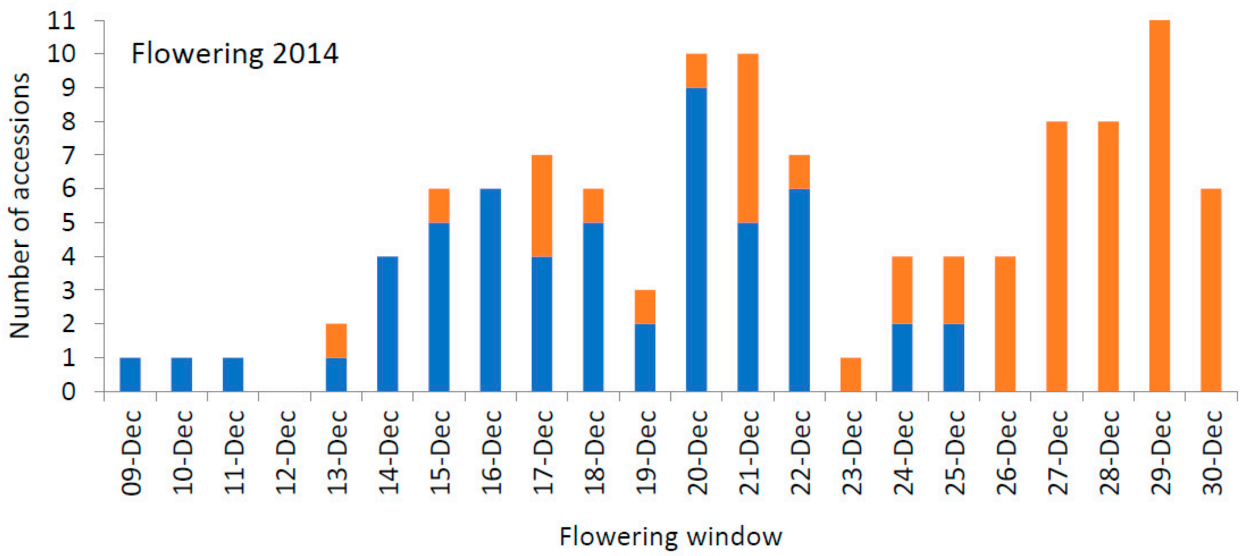

Figure 7. Histogram of time to 50% flowering for Chadian dry-season sorghum accessions sown early (blue bars) and late (red bars) in 2013 at the Youé research farms in Chad.

3.3.2. Daylength during Flowering Window

During the flowering window in December, the monthly average of daylength (DL) ran around 10 and 11 h/day (Figure 8). On December 6, the day of first flowering in the 2013 experiment, daylength was 10.8 h/day, and on December 9, the day of first flowering in the 2014 experiment, DL was 10.75 h/day. During the first flowering (13 December) of the second sowing date, DL was 10.5 h/day (2013) and 9.8 h/day (2014).

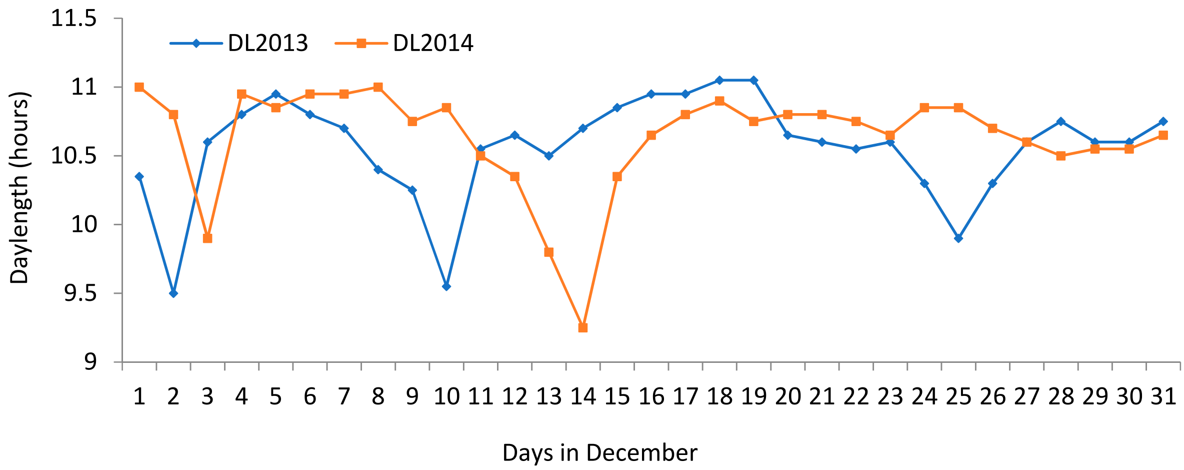

Figure 8. Daylength variation during the flowering window in December for Chadian dry-season sorghum sown at the Youé research farms, Chad, in 2013 and 2014.

During December 2013 and December 2014, the monthly average DL was around 10 and 11 h/day. In 2013, the shorter DL was 2 December (9.5 h/day), followed by 10 December (9.55 h/day), 25 December (9.9 h/day), and for the rest of December it was more than 10 h/day. In 2014, the shorter daylength was 14 December (9.25 h/day), followed by 13 December (9.8 h/day), 3 December (9.9 h/day), and for the rest of December DL was more than 10 h. Thus, during the flowering window, the monthly average DL ran between 10 and 11 h/day.

3.3.3. Average Minimal and Maximal Air Temperature during Flowering Window

During the flowering window in December, the minimal and maximal daily air temperatures varied slightly across the two growing seasons (Figure 9). In December 2013, the minimal and maximal daily air temperatures ranged from 14.0 to 26.0 °C and from 32.5 to 40.3 °C, respectively. Likewise, in December 2014, daily air temperatures ranged from 16.5 to 21.6 °C for minimal and from 33.0 to 39.4 °C for maximal.

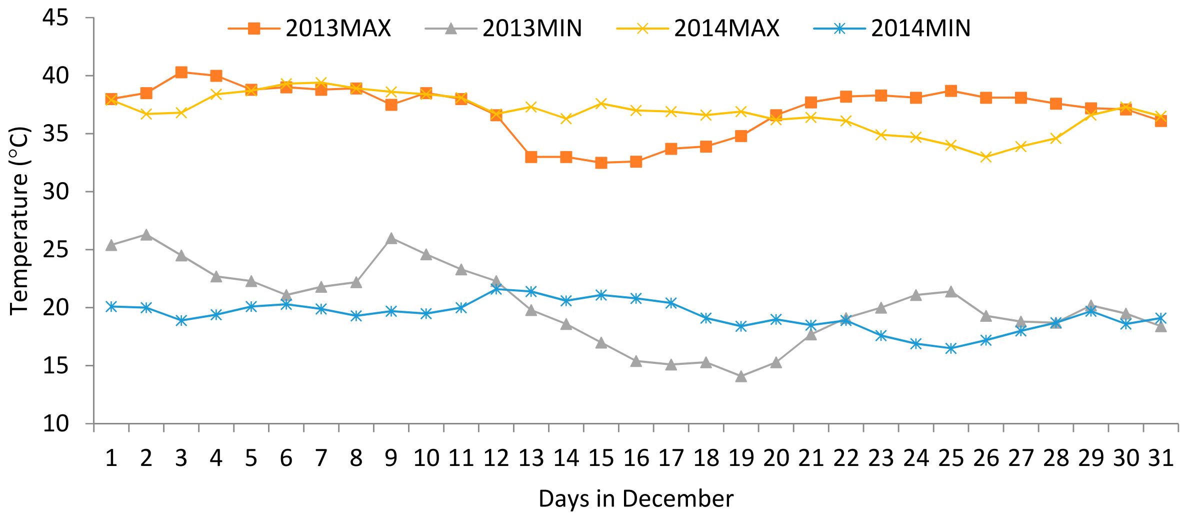

Figure 9. Daily maximum and minimum air temperatures during the flowering window in December for Chadian dry-season sorghum sown at the Youé research farms, Chad, in 2013 and 2014.

The first flowering in 2013 occurred on December 6 for the early sowing when the minimal and maximal daily air temperatures were 20.3 and 39.3 °C, respectively. For the late sowing, the first flowering occurred on December 13 when the minimal and maximal daily air temperatures were 19.8 and 33.0 °C, respectively. In the second year of the experiment (2014), the first flowering, for the early sowing date, started on December 9 when the minimal and maximal daily air temperatures were 19.7 and 38.6 °C, respectively, and for the late sowing, the first flowering started on December 13 when the minimal and maximal daily air temperatures were 21.4 and 37.3 °C, respectively.

3.3.4. Growing Degree Units for Flowering Window

The mean cumulative growing degree units (cGDUs) during the flowering window varied between sowing dates and years (Table 5). Regardless of years, the mean cGDUs of earlier sowing dates were higher than those for late sowing dates. Comparatively, the mean cGDUs during the flowering window for both sowing dates in 2013 were higher than those in 2014. Early sowing in 2013 needed the highest cGDUs (2468) for flowering. Late sowing in 2014 needed the lowest cGDUs (1935) to flower in both years. The earliest flowering occurred during late sowing in 2014 (1717 cGDUs), whereas the latest flowering was during early sowing in 2013 (2576).

Table 5. Minima, maxima, and mean cumulative growing degree units, cGDUs, during the flowering window for Chadian dry-season sorghum sown early and late at the Youé research farms, Chad, in 2013 and 2014.

Year	Sowing Date	Minima	Maxima	Mean ± SE	CV
2013	Early	2352	2576	2468 ± 62	2.51
	Late	2132	2423	2301 ± 83	3.60
2014	Early	1872	2144	2044 ± 64	3.11
	Late	1717	2012	1935 ± 78	4.02
	Mean ± SE	2018 ± 52	2289 ± 61	2187 ± 67	3.31

3.4. Regional Potential Yields and Sowing Dates

The average potential yield (t/ha at 14% moisture content) was significantly affected ($p < 0.05$) by sowing dates irrespective of years and regions of cultivar collection (Table 6). Mean potential yields were higher in 2013 than in 2014 irrespective of sowing dates. Analysis of variance of regional average potential yield showed significant differences among cultivars from Tandjilé (TJ) for early sowing dates in 2013 and 2014 and late sowing dates in 2013. Cultivars from Mayo Kebbi East (MKE) showed significant potential yield difference only during early sowing in both years, whereas no such difference in potential yield was observed among cultivars from Mayo Kebbi West (MKW) irrespective of sowing dates in both years. The coefficient of variation for accession based on their origin and clustered sowing dates showed high values ranging from 16.6% to 49.31%, indicating the variation for the mean value of accessions belonging to the same origin.

Table 6. Variations of mean potential yield (t/ha at 14% moisture content) of Chadian dry-season sorghum from three regions sown early and late at the Youé research farms, Chad, in 2013 and 2014.

		2013					2014				
Region	**SD**	**Min.**	**Max.**	**Mean ± SE**	**CV**	***p*-Value**	**Min.**	**Max.**	**Mean ± SE**	**CV**	***p*-Value**
TJ	Early	0.38	1.58	0.93 ± 0.29	30.8	0.0019	0.32	1.68	0.84 ± 0.41	49.3	0.0001
	Late	0.34	1.45	0.82 ± 0.25	30.9	0.0011	0.12	0.90	0.55 ± 0.18	32.2	0.3678 ^{ns}
MKE	Early	0.63	1.58	0.96 ± 0.31	31.8	0.0001	0.53	1.48	0.90 ± 0.27	29.6	0.0136
	Late	0.62	1.22	0.84 ± 0.14	16.6	0.2415 ^{ns}	0.40	1.00	0.73 ± 0.17	22.6	0.3371 ^{ns}
MKW	Early	0.28	1.53	0.92 ± 0.40	43.2	0.0846 ^{ns}	0.34	1.36	0.86 ± 0.29	33.3	0.0520 ^{ns}
	Late	0.15	1.50	0.84 ± 0.36	42.6	0.2198 ^{ns}	0.36	1.12	0.84 ± 0.23	27.4	0.0651 ^{ns}
Mean ± SE	Early	0.43	1.56	0.94 ± 0.32	33.9	0.0001	0.40	1.52	0.86 ± 0.33	38.6	0.0001
	Late	0.37	1.39	0.83 ± 0.25	30.2	0.0012	0.29	1.04	0.69 ± 0.22	32.2	0.0023

SD, sowing date; Min., minima; Max., maxima; CV, coefficient of variation; SE, standard error of mean. ns indicates no significant difference.

Late sowing decreased the average potential yield in both years. The regional mean potential yield across both years ranged from 0.55 t/ha to 0.96 t/ha for late-sown accessions from TJ in 2014 to early-sown accessions from MKE in 2013, respectively. The highest potential yield (1.68 t/ha) was recorded in accessions from TJ, sown early in 2014. Contrariwise, the highest potential yield in MKE (1.58 t/ha) and MKW (1.53 t/ha) accessions was recorded from early sowing in 2013. The lowest potential yield (0.12 t/ha) was also observed in TJ accessions, sown late in 2014. The lowest potential yield (0.40 t/ha) for MKE accessions was recorded from late sowing in 2014, while the lowest potential yield (0.15 t/ha) in MKW accessions was recorded from late sowing in 2013. Cultivars #4 (Farine), #16 (Gogmi, red flour), #19 (Gogoumi, white flour), #36 (Glinding), #39 (Donglon rouge), #44 (Vounging Membou), and #51 (Dalassi) ranked top with average potential yield across sowing dates in both years greater than 1.0 t/ha (Supplementary Table S1).

4. Discussion

The primary objective of the current study was to assess the effect of planting date on variability in average grain potential yield, duration of vegetative phase, and biomass production, especially regarding temperature and daylength, for photoperiodic dry-season sorghum cultivars in southeastern Chad. Knowledge of this variability could be helpful in determining the most suitable planting date(s) for dry-season sorghum cultivars in Chad.

The results of analysis of variance data showed that there was a statistically significant effect on all accessed traits by sowing date and year, at a 1% probability level. The repeatability obtained for all assessed traits was generally high, and according to [32], high repeatability indicates the statistical relevance of this dataset and the quality of the data obtained from the two-year experiments. The results indicated that the early sowing date significantly increased all assessed growth components (except staygreen) than the late sowing date in two years of experiment. According to [33], the number of organs produced by sweet sorghum plants was significantly influenced by sowing dates. The same result was found by many authors about rained grain sorghum [34,35], sweet sorghum [36], strawberry [37], and cowpea [38].

The vegetative phase was lengthened by early sowing, and for the same variety, a difference of more than 40 days was observed in the duration of the vegetative phase. When practicing early sowing, the duration of the vegetative phase was longer for the accessions with higher photoperiod sensitivity, which according to [33] produced more organs. On the other hand, ref. [16] stated that the vegetative duration of sorghum becomes shorter as the sowing date is moved later into the year.

Photoperiod sensitivity remains an important characteristic for the adaptation of African sorghum landraces to the climatic resources of their environment [39]. The study showed that the photoperiod sensitivity index varied significantly across years and sowing dates. In 2013, 77% of accessions showed high photoperiod sensitivity, with *Kp* ranging from 0.6 to 0.9, and four accessions had *Kp* value close to 1. In 2014, most accessions (79%) showed low photoperiod sensitivity (*Kp* values under 0.6), and only 20% of accessions had high photoperiod sensitivity index (*Kp* values ranged from 0.6 to 0.9). This different reaction of photoperiod sensitivity for the same cultivars in 2013 and 2014 could be explained by the duration between early and late sowing dates in the two years. In fact, the early and late sowing dates had a 3-week span in 2013, compared to a 2-week span in 2014. Moreover, the respective early and late sowing dates in 2013 (30 July and 21 August) were earlier than in 2014 (31 August and 15 September), and the results showed that the flowering window was similar, occurring in December in both years. The flowering dates for early and late sowing dates across both years were nearly identical. In fact, all assessed cultivars irrespective of the sowing date flowered between 6 and 30 December. In a situation of decreasing daylength, dry-season sorghum flowered at approximately the same period irrespective of the sowing date [17]. However, this varies according to the extent of flood and period of the water withdrawal.

In December, daylength varied from 9.5 to 11.1 h/day, and ranged from 9.3 to 11.0 h/day, in 2013 and 2014, respectively. In 2013, the first flowering started on 6 December, when daylength was 10.8 h/day, and the 2 days prior first flowering (4 and 5 December) had daylength of 10.9 and 11 h/day, respectively. Likewise, in 2014, the first flowering occurred on 9 December, with daylength of 10.75 h/day. Daylength was 10.95 and 11 h/day 2 days prior to the first flowering, 7 and 8 December, respectively, in 2014. Thus, the dry-season sorghum cultivars assessed seemed to have a daylength threshold for flowering initiation between 10.75 and 10.8 h/day. According to [40], when the daylength becomes short (≤12 h/day), the sorghum plant differentiates from vegetative to reproductive growth. In the current study, flowering occurred in December, when the critical photoperiod decreased to 10.5 h/day. According to [18], all dry-season sorghum cultivars are most probably short-day photoperiodic plants. According to [20], the effects of daylength as follows: the duration of the vegetative phase is increased by daylength <8 h/day, possibly due to trophic (nutritional, assimilation) constraints.

According to [41], the date of flowering is mainly controlled by temperature and photoperiod and is therefore only affected by water deficit through increased canopy temperature and was linked to stomatal closure. In the current study, during the flowering window in December, maximal air temperature varied from 32.5 to 40.3 °C, with an average of 37.0 °C and 33 to 39.4 °C with an average of 36.8 °C in 2013 and 2014, respectively. The minimal air temperature in December 2013 varied from 14.1 to 26.3 °C, with an average of 20.2 °C, and in December 2014, it varied from 16.5 to 21.4 °C, with an average of 19.3 °C. Flowering time and physiological maturity are characteristics controlled by the genetic makeup of the plant and other environmental factors, especially temperatures [42]. The mean optimum temperature range for sorghum is 25–28 °C for reproductive growth [43]. According to [18], another originality suspected of dry-season sorghum is their low sensibility to low night air temperatures, which explains their ability to grow and fruit in the middle of the cold dry season, unlike rainy sorghum. Although cold temperatures late in the season have been shown to reduce grain sorghum yield by directly affecting reproductive processes [44], this does not seem to be the case in dry-season sorghum.

Cumulative growing degree units (cGDUs) are a measure of the accumulation of threshold heat units for plant growth and are used to predict plant development and vary with daily temperatures [30]. This study showed that the cGDUs required for flowering in dry-season sorghum differed between early- and late-maturing cultivars and varied according to the sowing date. To reach flowering following early sowing, slightly >2500 cGDUs had accumulated for the late-maturing cultivars, compared to <2400 cGDU for the early-maturing group. However, following late sowing, flowering occurred at about 2000 cGDUs accumulation for late-maturing cultivars and between 1700 and 1800 cGDUs for early-maturing cultivars. This study showed higher cGDUs compared with [27], which found that flowering for early planted non-photosensitive grain sorghum occurred at 1491–1728 cGDUs. The exact timing between sorghum growth stages can vary depending on sorghum products [45], plant population, sowing dates, and environmental and the growing conditions of the production region [27].

The study showed that the average potential yield was increased by early sowing date, and this varied among cultivars, sowing dates, and year of the experiment. However, the average potential grain yield did not significantly differ among cultivars from the same origin. The average potential yields were 0.94 and 0.86 t/ha, and 0.83 and 0.69 t/ha for early and late sowing in 2013 and 2014, respectively. A previous study on dry-season sorghum found that the yield is usually low from 0.3 to 0.8 t/ha depending on the season and cultivar used [46]. Studies conducted in northern Cameroon observed that delayed transplanting of dry-season sorghum caused yield reduction [47]. A study [48] on the different effects of planting dates showed that delayed planting caused a significant decrease in grain yield.

5. Conclusions

Dry-season sorghum being the third most important cereal crop grown in Chad, the current study showed that there was phenotypic variability for the agro-morphological traits assessed in the panel of dry-season sorghum ecotypes collected from different villages in the three important zones of production in southern Chad. These differences were significantly highlighted when the crop was sown early than when sown late. Potential grain yield, duration of vegetative phase, and biomass were negatively affected by the late sowing date, whereas the other agronomic and phenotypic traits assessed, except staygreen, were enhanced by early sowing. Though all ecotypes were photoperiodic, the sowing date did not affect the flowering window. However, flowering time was affected by a decrease in daylength but not by low night temperatures. Ecotypes #4 (Farine), #16 (Gogmi, red flour), #19 (Gogoumi, white flour), #36 (Glinding), #39 (Donglon rouge), #44 (Vounging Membou), and #51 (Dalassi) ranked top with average potential yield across sowing dates in both years greater than the regional potential yield of 1.0 t/ha. In addition to being comparatively high potential yielders, Farine, Gogoumi, and Vounging also exhibited reasonable staygreen potential in both years, making them viable candidates for breeding to improve dry-season sorghum potential yield under the semi-arid regions of southern Chad and other regions in West and Central Africa.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/agronomy13030932/s1, Table S1: Cultivars number and name, region and village of origin, rainfall (mm/10 years), and potential yield (PY; t/ha) of Chadian dry-season sorghum sown early (S1) and late (S2) at the Youé research farms, Chad, in 2013 and 2014.

Author Contributions: Conceptualization, G.N. and Y.E.; methodology, G.N., H.L., E.A.A. and N.D.; investigation, G.N., N.S. and R.T.; writing-original draft preparation, G.N.; writing-review and editing, Y.E. and H.L. Statistics, G.N., N.S., N.D. and Y.E. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available because it belongs to the Chadian Institute of Agronomic Research for Development.

Acknowledgments: The authors are grateful to Madjita Bruno, Ganezoune Michel, and Hinimbi Eli for their field and data collection assistance.

Conflicts of Interest: The authors declare no competing interest.

References

1. Reynolds, M.P.; Quilligan, E.; Aggarwal, P.K.; Bansal, K.C.; Cavalieri, A.J.; Chapman, S.C.; Chapotin, S.M.; Datta, S.K.; Duveiller, E.; Gill, K.S.; et al. An integrated approach to maintaining cereal productivity under climate change. Glob. *Food Secur.* **2016**, *8*, 9–18. [CrossRef]
2. Gapili, N.; Nerbewende, S.; Eyanawa, A.A.; Emendack, Y.Y.; Hassan, M.A.; Djinodji, R.; Doyam, N.A.; Nadjiam, D.; Tabo, R.; Haydee, E.L. Assessment of agro-morphological variability of dry-season sorghum cultivars in Chad as novel sources of drought tolerance. *Sci. Rep.* **2019**, *9*, 19581. [CrossRef]
3. Fokou, Y.O.; Saïdou, A.-A.; Kanmegne, G.; Berkoula, O.; Audebert, A.; Sine, B.; Fonceka, D.; Joly, H. Two contrasting patterns of crop seasonal adaptation revealed by a common garden experiment on flood recession sorghum in the Sahel. Austr. J. *Crop Sci.* **2020**, *14*, 871–879. [CrossRef]
4. Gapili, N.; Djinodji, R.; Djondang, K.; Doyam, N.A. Ethnobotanic study and characterization of the farming system of the accessions of dry season sorghum in south of Chad. *J. Appl. Environ. Biol. Sci.* **2016**, *6*, 109–114.
5. Raimond, C. *Terres Inondées et Sorgho Repiqué: Évolution des Espaces Agricoles et Pastoraux Dans le Bassin du lac Tchad*; Université Paris 1: Paris, France, 1999.
6. *Panar SeedSorghum Production Series*; Panar Seed (PTY) Ltd.: Greytown, South Africa, 2008.
7. Sidibé, Y.; Williams, T.O.; Kolavalli, S. *Flood Recession Agriculture for Food Security in Northern Ghana*; GSSP Working Paper; International Food Policy Research Institute; IFPRI-Accra: Accra, Ghana, 2016. [CrossRef]
8. Rao, M.R.; Ndikawa, R.; Singh, L. Progress of sorghum agronomic research in Far North Province of Cameroon. In Proceedings of the Third Regional Sorghum Workshop, Maroua, Cameroon, 20–23 September 1988; pp. 53–66.

9. Carsky, R.J. *Survey of Chemical Characteristics of Topsoil (0–30 cm) in Dry Season Sorghum Fields*; TLU Technical Note No 10. National Cereals Research and Extension Project; Institute of Agronomic Research: Maroua, Cameroon, 1993.
10. Craufurd, P.Q.; Mahalakshmi, V.; Bidinger, F.R.; Mukuru, S.Z.; Chantereau, J.; Omanga, P.A.; Qi, A.; Roberts, E.H.; Ellis, R.H.; Summerfield, R.J.; et al. Adaptation of sorghum: Characterization of genotypic flowering responses to temperature and photoperiod. *Theor. Appl. Genet.* **1999**, *99*, 900–911. [CrossRef]
11. Deresea, S.A.; Shimelisa, H.; Mwadzingenia, L.; Lainga, M. Agro-morphological characterization and selection of sorghum landraces. *Acta Agric. Scand. Sect. B Soil Plant Sci.* **2018**, *68*, 585–595. [CrossRef]
12. Doggett, H. *Sorghum*; Longman Scientific & Technical: Harlow, UK, 1988; p. 512.
13. Ehlers, J.D.; Hall, A.E. Genotypic classification of cowpea based on responses to heat and photoperiod. *Crop Sci.* **1996**, *36*, 673–679. [CrossRef]
14. Summerfield, R.J.; Wien, H.C. Effects of photoperiod and air temperature on growth and yield of economic legumes. In *Advances in Legume Science*; Summerfield, R.J., Bunting, A.H., Eds.; HMSO: London, UK, 1980; pp. 17–36.
15. Handley, P.; Summerfield, R.J.; Robbins, E.H. Effects of temperature and photoperiod on reproductive development of selected grain legume crops. In *The Physiology, Genetics, and Nodulation of Temperate Legumes*; Davies, D.R., Garth-Jones, D., Eds.; Pitman Books: London, UK, 1982; pp. 19–41.
16. Viguier, P. *Les Sorghos et Leur Culture au Soudan Français*; Grande Imprimerie Africaine: Dakar, Senegal, 1947; p. 80.
17. Barrault, J.; Eckebil, J.P.; Vaille, J. Point des travaux de l'IRAT sur les sorghos repiqués du Nord-Cameroun. *Agron. Trop.* **1972**, *27*, 791–814.
18. Chantereau, J. Connaissance et utilisation de la diversité des sorghos de décrue en Afrique de l'Ouest et du Centre au CIRAD. In *Importance du Sorgho de Décrue: Superficie, Production et Rendement. Réunion de Travail du 11 au 15 mars 2001 à Nouakchott*; Agence Espagnole de Coopération Internationale: Madrid, Spain, 2002; ISBN 84-7232-898-8:123–129.
19. Balami, A.A.; Dada, M.M.; Mohammed, I.A. Design of a Tractor operated dry-season sorghum (MASAKWA) Transplanting Machine. *IOSR J. Eng. Mar.* **2012**, *2*, 414–419.
20. Horie, T. Crop ontogeny and development. In *Physiology and Determination of Crop Yield*; ASA–CSSA–SSSA: Madison, WI, USA, 1994; pp. 153–167.
21. Clerget, B.; Dingkuhn, M.; Chantereau, J.; Hemberger, J.; Louarn, G.; Vaksmann, M. Does panicle initiation in tropical sorghum depend on day-to-day change in photoperiod? *Field Crops Res.* **2004**, *88*, 11–27. [CrossRef]
22. Roberts, E.H.; Summerfield, R.J. Measurements and prediction of flowering in annual crops. In *Manipulation of Flowering*; Atherton, J.G., Ed.; Butterworths: London, UK, 1987; pp. 17–50.
23. Omid-Beigi, R. *Approaches to Processing Plants 2000 Volume I*, 2nd ed.; Publication Designers: Teheran, Iran, 2000.
24. Yang, S.; Weers, B.D.; Morishige, D.T.; Mullet, J.E. CONSTANS is a photoperiod regulated activator of flowering in sorghum. *BMC Plant Biol.* **2014**, *14*, 148. [CrossRef]
25. Zach, B.; Kirsht, H.; Ohr, D. *Masakwa Dry Season Cropping in the Chad Basin*; Berichte de Soriderfo Rschungsbereichs 268, Band 8: Frankfurt-a.M., Germany, 1996; pp. 349–356.
26. Mahmoud, T.S.M.; Nabila, E.K.; Abou, R.M.S.; Eisa, R.A. Effect of planting dates and different growing media on seed germination and growth of pistachio seedlings. *Bull. Natl. Res. Cent.* **2019**, *43*, 133. [CrossRef]
27. Emendack, Y.Y.; Sanchez, J.; Hayes, C.M.; Nesbitt, M.; Laza, H.E.; Burke, J.B. Seed-to-seed early-season cold resiliency in sorghum. *Sci. Rep.* **2021**, *11*, 7801. [CrossRef]
28. Kouressy, M.O.; Niangado, M.; Vaksmann, F.; Reyniers, N. Etude de la variabilité phénologique des mils du Mali et de son utilisation pour l'amélioration variétale. In *Le Future des Céréales Photopériodiques Pour Une Production Durable en Afrique semi-Aride*; CIRAD and CeSIA: Florence, Italy, 1998; pp. 123–127.
29. Miller, P.; Lanier, W.; Brandt, S. *Using Growing Degree Days to Predict Plant Stages*; Montana State University Extension Services: Montguide, MT, USA, 2001; MT200103 AG 7/2001.
30. Gerik, T.; Bean, B.; Vanderlip, R. Sorghum growth and development. Productive rotation on Farms in Texas. *Tex. AgriLife Ext. Publ.* **2003**, *B-6137*, 703.
31. Piepho, H.-P.; Mohring, J. Computing heritability and selection response from unbalanced plant breeding trials. *Genetics* **2007**, *177*, 1881–1888. [CrossRef]
32. Rattunde, H.F.W.; Michel, S.; Leiser, W.L.; Piepho, H.-P.; Diallo, C.; vom Brocke, K.; Diallo, B.; Haussmann, B.I.G.; Weltzien, E. Farmer participatory early generation yield testing of sorghum in West Africa: Possibilities to optimize genetic gains for yield in farmers' fields. *Crop Sci.* **2016**, *56*, 1–13. [CrossRef]
33. Tovignan, T.K.; Fonceka, D.; Ndoyeb, I.; Ndiaga Luquet, C.D. The sowing date and post-flowering water status affect the sugar and grain production of photoperiodic, sweet sorghum through the regulation of sink size and leaf area dynamics. *Field Crops Res.* **2016**, *192*, 67–77. [CrossRef]
34. Kamara, A.Y.; Ekeleme, F.; Chikoye, D.; Omoigui, L.O. Planting date and cultivar effects on grain yield in dryland corn production. *Agron. J.* **2009**, *101*, 91–98. [CrossRef]
35. Lotfi, A.; Frnia, A.; Maleki, A.; Naseri, R.; Moradi, M.; Ghasemi, M.; Yari, V. The effects of planting date and plant spacing on yield and yield components of Fennel Bull. *Env. Pharmacol. Life Sci.* **2013**, *2*, 78–84.
36. Erickson, J.E.; Helsel, Z.R.; Woodard, K.R.; Vendramini, J.M.B.; Wang, Y.; Sollenberger, L.E.; Gilbert, R.A. Planting date affects biomass and brix of sweet sorghum grown for biofuel across Florida. *Agron. J.* **2011**, *103*, 1827–1837. [CrossRef]

37. Chaitanya, P.; Gomasta, J.; Hossain, M.M. Effects of planting dates and variety on growth and yield of strawberry. *Int. J. Hort Agric. Food Sci.* **2017**, *1*, 4. [CrossRef]
38. Ezeaku, E.; Mbah, B.N.; Baiyeri, K.P. Planting date and cultivar effects on growth and yield performance of cowpea (*Vigna unguiculata* (L.) Walp). *Afric. J. Plant Sci.* **2015**, *9*, 439–448. [CrossRef]
39. Chantereau, J.; Trouche, G.; Rami, J.F.; Deu, M.; Barro, C.K.; Grivet, L. RFLP mapping of QTLs for photoperiod response in tropical sorghum. *Euphytica* **2001**, *120*, 183–194. [CrossRef]
40. Reddy, B.V.S.; Reddy, P.S.; Sadananda, A.R.; Dinakaran, E.; Kumar, A.A.; Deshpande, S.P.; Rao, P.S.; Sharma, H.C.; Sharma, R.; Krishnamurthy, L.; et al. Postrainy season sorghum: Constraints and breeding approaches. *SAT eJournal* **2012**, *10*, 1–12.
41. Andres, F.; Coupland, G. The genetics basis of flowering responses to seasonal cues. *Nat. Rev. Gen.* **2012**, *13*, 627–639. [CrossRef] [PubMed]
42. Lacape, M.; Wery, J.; Annerose, D. Relationships between plant and soil water status in five field-grown cotton (*Gossypium hirsutum* L.) cultivars. *Field Crops Res.* **1998**, *57*, 29–43. [CrossRef]
43. Maiti, R.K. *Sorghum Science 2019*; Science Publishers: Beirut, Lebanon, 2019.
44. Maulana, F.; Tesfaye, T.T. Cold Temperature episode at seedling and flowering stages reduces growth and yield components in Sorghum. *Crop Sci.* **2013**, *53*, 564–574. [CrossRef]
45. Lyons, S.E.; Ketterings, Q.M.; Godwin, G.S.; Cherney, J.H.; Meisinger, J.J.; Kilcer, T.F. Double-Cropping with Forage Sorghum and Forage Triticale in New York. *Agron. J.* **2019**, *111*, 3374–3382. [CrossRef]
46. Djonnewa, A.; Dangi, O.P. Improvement of Transplanted Sorghum. In Proceedings of the Third Regional Sorghum Workshop, Moroua, Cameroon, 20–23 September 1988; pp. 48–52.
47. Tabo, R.; Olabanji, O.G.; Ajayi, O.; Flower, D.J. Effect of plant population on the growth and yield of sorghum varieties grown on vertisol. *African J. Crop Sci.* **2002**, *10*, 31–38. [CrossRef]
48. Johnson, B.L.; Mckay, K.R.; Schneiter, A.A.; Hanson, B.K.; Schatz, B.G. Influence of planting date on canola and crambe production. *J. Product. Agric.* **1995**, *8*, 594–599. [CrossRef]