

Determining the optimal planting date for irrigated *Sorghum bicolor* Moench in northern Tamaulipas, Mexico

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ABSTRACT

Objective: To identify the optimal sowing date for sorghum to achieve high grain yields under irrigated conditions in northern Tamaulipas, Mexico.

Design/Methodology/Approach: Five sorghum genotypes were evaluated across nine sowing dates, spaced 15 days apart from December 1 to April 1. The experiment was conducted in the municipality of Río Bravo, Tamaulipas, over two consecutive seasons (fall-winter 2022/2023 and 2023/2024). A randomized complete block design was used with three replications per treatment in a split-plot arrangement.

Results: During the optimal sowing period, the highest-yielding genotypes were ADV-G3247 (6.386 t ha⁻¹), DKS-821 (6.294 t ha⁻¹), P83G19 (5.857 t ha⁻¹), and RB-Williams (5.651 t ha⁻¹).

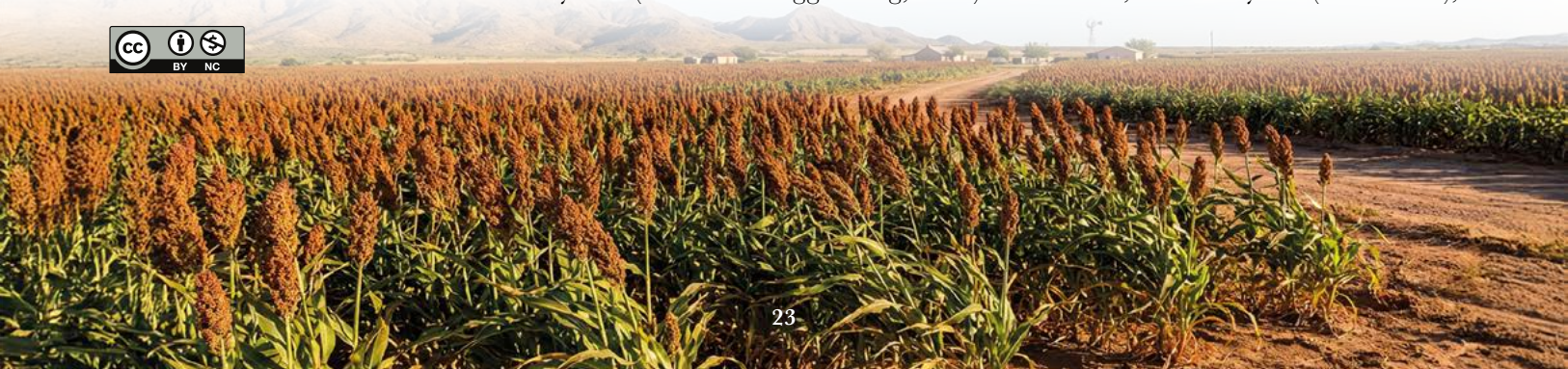
Study Limitations/Implications: The promotion of appropriate sowing dates in the state of Tamaulipas is highly recommended.

Findings/Conclusions: The sowing dates associated with the highest grain yields were between January 1 and February 16.

Keywords: *S. bicolor*, optimal sowing period, irrigation.

INTRODUCTION

Sorghum [*S. bicolor* (L.) Moench] is an important crop for food security in arid and semi-arid regions due to its tolerance to biotic and abiotic stress and good adaptation to low-fertility soils (Prasad & Staggenborg, 2011). Worldwide, in recent years (2016-2020),



sorghum was produced on 41.33 million hectares with a yield of 1,439 kg ha⁻¹ (FAO, 2022). In Mexico, sorghum is mainly used for grain and forage production and serves as a base for balanced feed formulation in the livestock sector. It is grown on an annual area of 1,427,202 ha (2017-2023 period), with an average yield of 3,442 kg ha⁻¹. In the state of Tamaulipas, the area sown with sorghum is 786,758 ha (55.12% of the national area), with a yield of 2,585 kg ha⁻¹ (SIAP, 2024). Extreme weather due to climate change, such as increased drought and high temperatures, has had a significant impact on crop yields. Climate change has influenced rainfall patterns, both in amount and frequency (Gorman, 2015). In northern Tamaulipas, sorghum is mainly affected by:

1. Drought and high temperatures (Galicia *et al.*, 2020), which occur during the reproductive stage of the plant and favor the development of charcoal rot caused by *Macrophomina phaseolina* (Tassi) Goid (Williams *et al.*, 2004). Rajendra *et al.*, 2021, indicated that drought and high temperatures are the most important abiotic factors limiting sorghum production in arid and semi-arid regions of the world.
2. Temperatures below 0 °C, which occur more frequently in early sowings (sub-zero temperatures occurred on December 24 and 25, 2022, and January 16 and 17, 2024).
3. Sorghum midge (*Contarinia sorghicola* (Coquillett)), which severely affects March sowings during the flowering stage (Rodríguez & Loera, 2006).

When selecting the optimal sowing date, it must be considered that the crop's critical periods do not coincide with drought and extreme high or low temperatures (Ekeleme *et al.*, 2011), as well as diseases, insects, and weeds (Ciampitti *et al.*, 2019). In northern Tamaulipas, under irrigated conditions, sowing is recommended from January 20 to March 8. However, in this region, the last field evaluations of sowing dates were carried out in 1981 (44 years ago), so it is necessary to determine the optimal sowing date to mitigate the effects caused by climate change (low and high temperatures, pests, and disease incidence). The aim of this study was to determine the best sowing period for sorghum to achieve high grain yields under irrigated conditions in northern Tamaulipas during the fall-winter (F-W) cropping season).

MATERIALS AND METHODS

Location and genetic material. The research was conducted during the 2022/2023 and 2023/2024 fall-winter cropping seasons at INIFAP-Río Bravo Experimental Station, located at 25° 57' 54" N, 98° 01' 03" W. The soil is Cambic Calcisol, with a 0.04% slope, low in organic matter, medium fertility with nitrogen and phosphorus deficiencies, and a pH above 7.5, at an elevation of 50 masl (Salinas *et al.*, 2006); annual rainfall is 648.3 mm and the mean annual temperature is 23.5 °C. In each cropping season, nine sowing dates were evaluated at 15-day intervals, starting from December 1 (Dec. 1, Dec. 16, Jan. 1, Jan. 16, Feb. 1, Feb. 16, Mar. 1, Mar. 16, Apr. 1). Five genotypes were evaluated on each date: four commercial hybrids and one open-pollinated variety (three

early-maturing: hybrid RB-Norteño, hybrid P83G19, and hybrid DKS 821; and two intermediate-maturing: variety RB-Williams and hybrid ADV-G3247).

Experimental design and agronomic management. A randomized complete block design was used with three replications per treatment, arranged in a split-plot design. The population density was 250,000 plants per hectare. Each experimental plot consisted of three rows, 5 m long and spaced 0.8 m apart. The useful plot was the central row trimmed to 3 m (1 m was removed at each end). Crop management followed the technological package recommended by INIFAP for grain sorghum cultivation.

Variables evaluated. Grain yield, days to flowering, days to physiological maturity, plant height, exertion, and panicle length.

Statistical analysis. A combined analysis of variance (ANOVA) was performed for the split-plot design using the following model:

$$Y_{ijkh} = \mu + T_i + \beta_j + (T\beta)_{ij} + Y_k + (TY)_{ik} + (T\beta Y)_{ijk} + \delta_h + (T\delta)_{ih} + (\beta\delta)_{jh} + (T\beta\delta)_{ijh} + (Y\delta)_{ih} + (TY\delta)_{ikh} + (\beta Y\delta)_{jkh} + (T\beta Y\delta)_{ijkh}$$

Where Y_{ijkh} is the response variable; μ is the overall mean; T_i , β_j , and $(T\beta)_{ij}$ represent the whole plot and correspond to blocks (factor A), main treatments (factor B, cropping seasons), and whole-plot error (AB), respectively; Y_k , $(TY)_{ik}$, and $(T\beta Y)_{ijk}$ represent the subplot and correspond to the subplot treatment (factor C, sowing dates), the AC and BC interactions, and the subplot error, respectively; δ_h and the remaining parameters correspond to the split-subplot and represent the split-subplot treatment (factor D, genotypes) and the remaining interactions. The four-way interaction $(T\beta Y\delta)_{ijkh}$ is referred to as the split-subplot error. Mean comparisons for agronomic traits were performed using Tukey's test ($p \leq 0.05$), with SAS software (SAS, 2006).

RESULTS AND DISCUSSION

In the evaluation conducted during the 2022/2023 fall-winter season, temperatures of -1 and 0 °C were recorded on December 24 and 25, 2022, respectively. These low temperatures damaged the foliage of the sowing dates of December 1 and December 16. Although the plants later recovered, the grain yield for these two sowing dates was statistically lower ($P \leq 0.01$) compared to the rest of the evaluated sowing dates. In the evaluation conducted during the 2023/2024 fall-winter season, temperatures of -2 °C were recorded on January 16 and 17, 2024, which completely destroyed the crops sown on December 1 and December 16, 2023. These results are consistent with those reported by Zander *et al.* (2021), who indicated that cold soil temperatures can limit yield when sorghum is sown too early. Based on this, the results for the remaining seven sowing dates ranging from January 1 to April 1 in both 2023 and 2024 are presented below. Table 1 shows the analysis of variance for grain yield. The F-value was highly significant ($F \leq 0.01$) for year, sowing date, and genotype, as well as for the year \times sowing date and year \times genotype interactions.

Table 1. ANOVA for grain yield (GY) of five sorghum genotypes (GEN) across seven planting dates (PD) under irrigation (IRR), in Río Bravo, Tamaulipas (Tam.), during the 2022/2023 and 2023/2024 fall-winter (F-W) cropping seasons.

Source of variation	DF	Mean square	F value
Block	2	1989786.7	8.10
Year	1	9874039.3	40.20**
Block*Year	2	508210.7	2.07
Date	6	21373782.8	87.03**
Year*Date	6	2117442.9	8.62**
Block*Date(Year)	24	389393.2	1.59
Genotype	4	10024034.6	40.81**
Year*Genotype	4	2382265.1	9.70**
Date*Genotype	24	1041761.7	4.24
Year*Date*Genotype	24	370213.9	1.51

DF=degrees of freedom, $R^2=0.9004$, Coefficient of variation=9.36, Mean grain yield=5.294 t ha⁻¹, * and **=significant at $P\leq 0.05$ and 0.01 , respectively.

Table 2 presents the mean comparison of grain yield for the 2022/2023 and 2023/2024 fall-winter cropping seasons. In the first season, the grain yield was 5.510 t ha⁻¹, while in the second season it was 5.077 t ha⁻¹ (statistically different yields at $P\leq 0.01$), representing a 7.86% reduction in grain yield.

Table 3 presents the mean comparison of the variables: grain yield (Figure 1), days to flowering initiation, days to physiological maturity, panicle peduncle length or exertion (cm), and panicle length (cm), for five sorghum genotypes across seven sowing dates under irrigated conditions during the 2022/2023 and 2023/2024 fall-winter seasons. Grain yield ranged from 3.784 t ha⁻¹ (April 1) to 6.275 t ha⁻¹ (February 1). The sowing dates with the highest grain yields were between January 1 and February 16 [the four dates within this period were statistically similar ($P\leq 0.01$), except for February 1, which was significantly superior to the rest, with 6.275 t ha⁻¹]. Contrasting data were reported by Herrera and Betancourt (1981) and Sosa (1982), who, based on sowing date evaluations in Río Bravo, Tamaulipas, found that the best grain yields were obtained between February 1 and March 15. Likewise, Montes (2010), using a regression model, determined that the optimal sowing period for irrigated sorghum in northern Tamaulipas was from February 4 to March 7. The differences between the sowing date results obtained in this study

Table 2. Mean comparison of grain yield for five sorghum genotypes across seven sowing dates under irrigation in Río Bravo, Tamaulipas, during the 2022/2023 and 2023/2024 fall-winter cropping seasons.

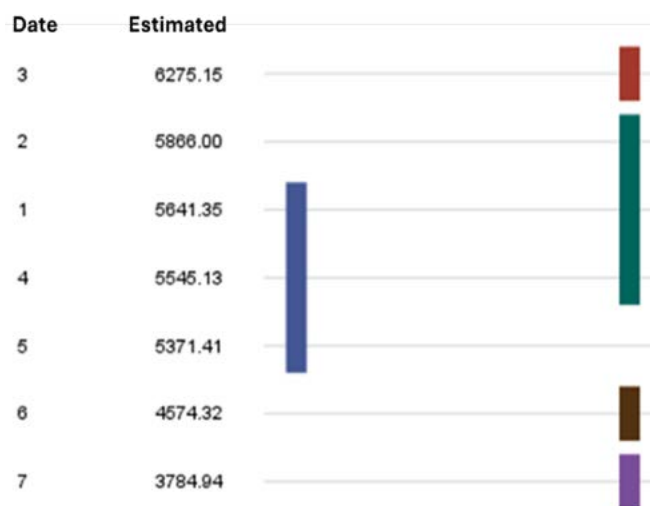
Cropping season	Grain yield (t ha ⁻¹)
F-W 2022/2023	5.510 a
F-W 2023/2024	5.077 b

Different letters indicate statistically significant differences (Tukey; $P\leq 0.01$).

Table 3. Comparison of means of agronomic variables, of five sorghum genotypes on seven planting dates under irrigation conditions, Río Bravo, Tam., cycles O-I 2022/2023 and O-I 2023/2024.

Sowing date	Yield t ha ⁻¹	Days to start flowering	Days to maturity	Plant height	Excerpt	Panicle length
01 Feb (3)	6.275 a	71.8 c	119.5 b	131.6 b	13.6 cd	26.9 ab
16 Ene (2)	5.868 b	79.9 b	130.1 a	133.4 b	19.3 ab	26.7 ab
01 Ene (1)	5.641 bc	86.5 a	135.9 a	132.4 b	20.7 a	24.9 b
16 Feb (4)	5.545 bc	63.7 d	111.2 c	136.8 ab	16.7 bc	27.4 a
01 Mar (5)	5.371 c	61.2 e	106.2 cd	123.5 c	12.3 d	26.6 ab
16 Mar (6)	4.574 d	57.9 f	99.4 de	143.1 a	14.2 cd	26.9 ab
01 Abr (7)	3.784 e	56.5 g	92.8 e	131.7 bc	8.1 e	25.3 ab

Different letters indicate a statistically significant difference (Tukey; $P \leq 0.01$).



Stocks covered by the same bar are not significantly different.

Figure 1. Mean comparison of grain yield for five sorghum genotypes across seven sowing dates under irrigated conditions in Río Bravo, Tamaulipas, during the 2022/2023 and 2023/2024 fall-winter seasons.

and previous findings (Herrera & Betancourt, 1981; Sosa, 1982; Montes, 2010) are due to the effects of climate change, particularly changes in temperature, resulting in an earlier optimal sowing window. During the identified optimal sowing period (January 1 to February 16), days to flowering ranged from 86.5 days (January 1) to 63.7 days (February 16); days to maturity from 135.9 days (January 1) to 111.2 days (February 16); plant height from 136.8 cm (February 16) to 131.6 cm (February 1); exertion from 20.7 cm (January 1) to 13.6 cm (February 1); and panicle length from 27.4 cm (February 16) to 24.9 cm (January 1). It was observed that with the increase in ambient temperature (average maximum temperatures during the two years of study were: January, 20.5 °C; February, 23 °C; March, 26 °C; April, 28 °C; May, 34 °C), the thermal units required for development accumulated in a shorter period, thereby shortening the crop's life cycle, reproductive period, and exertion, while increasing plant height and panicle

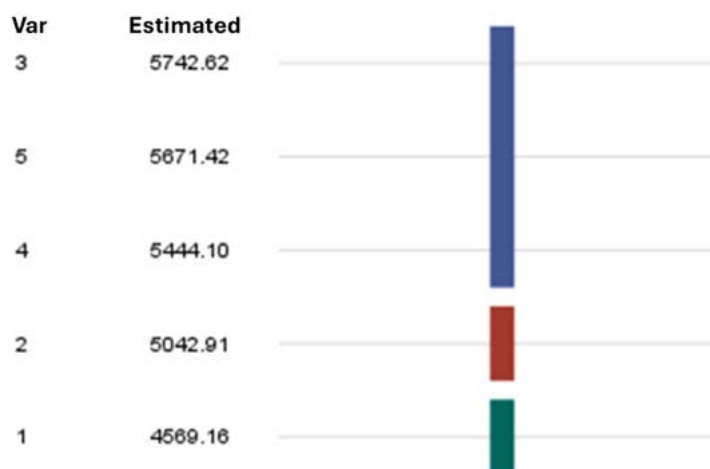
length. Therefore, the optimal sowing window shifted to the cooler period, which agrees with the findings reported by Ojeda-Bustamante *et al.* (2011). Statistically ($P \leq 0.01$), the lowest grain yields were observed on March 16 and April 1, when a severe infestation of sorghum midge, *Contarinia sorghicola* (Coquillet), occurred during the flowering stage, along with high temperatures that further shortened the crop cycle. Reports indicate that when high temperatures occur during flowering or grain filling, grain yields decline due to significant flower abortion, reduced seed set rate, and smaller seed size (Saeed & Francis, 1984).

Table 4 presents the mean comparison of grain yield. It was observed that all genotypes reached their maximum yield on the third sowing date, February 1, except for RB-Norteño, which achieved its highest yield on the second sowing date, January 16. Figure 2 shows that across the seven sowing dates, hybrid DKS-821 had the highest average grain yield with 5.742 t ha^{-1} , and was statistically similar ($P \leq 0.01$) to ADV-G3247 and P83G19, which yielded 5.671 and 5.444 t ha^{-1} , respectively. These genotypes were also statistically superior ($P \leq 0.01$) to RB-Williams and RB-Norteño, which had grain yields of 5.042 and 4.569 t ha^{-1} , respectively.

Table 4. Mean comparison of grain yield for five sorghum genotypes across seven sowing dates under irrigated conditions in Río Bravo, Tamaulipas, during the 2022/2023 and 2023/2024 fall-winter seasons.

Genotype	Sowing dates (grain yield t ha^{-1})							Average
	01 Ene	16 Ene	01 Feb	16 Feb	01 Mar	16 Mar	01 Abr	
DKS-821	6.040 b	5.961 b	6.843 a	6.335 a	5.860 a	4.760 b	4.397 a	5.742 a
ADV-G3247	6.410 a	6.416 a	7.062 a	5.656 b	5.345 b	5.127 a	3.680 b	5.671 a
P83G19	5.462 c	5.822 b	6.075 b	6.072 a	5.628 ab	4.732 b	4.314 a	5.444 a
RB-Williams	5.573 c	5.573 bc	6.207 b	5.253 c	5.679 a	4.143 c	2.663 c	5.042 b
RB-Norteño	4.719 d	5.348 c	5.186 c	4.408 d	4.343 c	4.108 c	3.869 b	4.569 c

Different letters indicate a statistically significant difference (Tukey; $P \leq 0.01$).



VAR: Varieties. Means covered by the same bar are not significantly different.

Figure 2. Mean comparison of grain yield for five sorghum genotypes across seven sowing dates under irrigated conditions in Río Bravo, Tamaulipas, during the 2022/2023 and 2023/2024 fall-winter seasons.

CONCLUSIONS

The period from January 1 to February 16 was identified as optimal for grain sorghum sowing under irrigated conditions in northern Tamaulipas during the fall-winter season, with yields ranging from 6.275 to 5.545 t ha⁻¹. Within the optimal sowing period, the genotypes with the highest grain yields were: ADV-G3247 (6.386 t ha⁻¹), DKS-821 (6.294 t ha⁻¹), P83G19 (5.857 t ha⁻¹), and RB-Williams (5.651 t ha⁻¹).

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