



Effect of Different Sowing Norms and Row Spacing on Yield and Yield Components of Safflower (*Carthamus tinctorius* L.) in a High-altitude Environment under Irrigated Conditions

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ABSTRACT

Background: This study specifically investigated how different combinations of row spacing and sowing norms affect the yield and agronomic traits of the oilseed crop, safflower (*Carthamus tinctorius* L.).

Methods: The study was conducted in 2017 and 2018 using the 'Dinçer' and 'Yenice' safflower genotypes. A factorial experiment was performed involving three different row spacing treatments (20, 40 and 60 cm) and three different sowing norm treatments (20, 40 and 60 kg ha⁻¹). The parameters examined included plant height, number of branches, number of heads, number of seeds per head, 1000-seed weight, seed yield, oil content and oil yield. The effects of the treatments were statistically evaluated across different planting distances.

Result: The row spacing treatment significantly affected all the examined parameters. The 40 cm row spacing was particularly effective, causing a decrease in plant height and branching while significantly increasing 1000-seed weight, seed yield, oil content and oil yield compared to the 20 and 60 cm spacings. Similarly, the sowing norms significantly affected all measured characteristics. The combination of 40 cm row spacing and 60 kg ha⁻¹ sowing norm yielded the best results for seed yield, indicating that frequent sowing practices can significantly boost safflower productivity and optimize oil yield under irrigated, semi-arid conditions.

Key words: *Carthamus tinctorius*, Row spacing, Safflower, Seed yield, Sowing norm.

INTRODUCTION

Safflower is one of the few crops that can be grown economically in arid and semi-arid regions (Reddy *et al.*, 2003). Medicinal and aromatic plants play an important role in protecting health (Bayraktar *et al.*, 2020a; Bozok *et al.*, 2025) and managing diseases with their anti-inflammatory (Bayraktar *et al.*, 2020b; Bayraktar *et al.*, 2021), antimicrobial (Ülker *et al.*, 2023; Orkun and Bayraktar, 2025c) and anticarcinogenic (Bayraktar and Bayraktar, 2019) effects. These plants also exhibit significant antidiabetic properties (Çelikel *et al.*, 2024; Orkun and Bayraktar, 2025a; Orkun and Bayraktar, 2025b), thanks to their phytochemical compounds and high antioxidant contents (Bayraktar *et al.*, 2023; Orkun and Bayraktar, 2025d; Ozcan *et al.*, 2024; Gül *et al.*, 2024; Ozcan *et al.*, 2026).

It is also an oilseed crop of global importance due to its advantages such as non-selectiveness to soil, suitability for agricultural mechanization, low input costs and high oil quality (Delshad *et al.*, 2018). Safflower plays a critical role in preventing vegetable oil deficits, yet it often fails to reach its full yield potential due to traditional production methods. Therefore, optimizing agricultural factors (agronomy) will provide a significant contribution to oil production (Çalışkan and Çalışkan, 2018).

Good agronomic practices, together with high-yielding varieties, form the basis for obtaining high yields per unit area; where the optimum plant number and distribution are determined by varietal characteristics (Kayın *et al.*, 2024; Sefaoğlu and Ozer, 2022). Since plant density and

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distribution determine safflower yield and quality, appropriate agricultural practices (Such as planting norm and row spacing) are known to significantly increase the seed and oil yield (Sefaoğlu and Özer, 2022). Low seed density delays maturation as individual plants produce more branches and heads, which extends the overall flowering and seed-filling period. Additionally, it reduces weed competition because the sparse canopy fails to provide sufficient ground cover to suppress weed growth. Conversely, excessive seed density, especially in years with low rainfall, increases disease rates by creating a more humid microclimate within the dense canopy and restricting airflow between plants. This increased competition for limited resources and moisture also

reduces seed and oil yields (Berglund *et al.*, 1998; Sefaoğlu and Özer, 2022). This study focused on optimizing the commercial cultivation of safflower in the semi-arid eastern anatolia region, where this plant species is new. The primary objective was to investigate how row spacing and sowing norm (Plant density) affect the yield and agronomic traits of different safflower varieties under irrigated conditions, ultimately determining the best combination for production in this specific climate.

MATERIALS AND METHODS

Agronomic practices and traits measured

The two-year study (2017-2018) was conducted in Erzurum, Eastern Anatolia (1663 m altitude, 41°67'E, 39°97'N), which has a semi-arid climate (meteorological data are presented in Fig 1). Meteorological data indicated that growing season temperatures remained consistent across both years. However, 2018 was characterized by a higher total precipitation of 285.9 mm, whereas 2017 received only 94.0 mm, falling below the long-term average. The experimental soil was characterized as clayey-loamy with a slightly alkaline reaction (pH 7.1-7.4). Chemical analysis revealed that the soil was medium in organic matter, sufficient in potassium, but low in phosphorus, with values ranging from 3.32 to 3.52 kg da⁻¹. The experiment utilized a randomized complete block design with three replications, arranged as a split-split-plot factorial. The factors studied included two safflower cultivars (Dinçer and yenice in main plots), three row spacings (20, 40 and 60 cm in subplots) and three sowing norms (20, 40 and 60 kg ha⁻¹ in sub-subplots). Sowing was done in mid-May of both years. Fertilization involved the application of 40 kg ha⁻¹ triple superphosphate and 60 kg ha⁻¹ ammonium sulfate. Each plot consisted of 4 rows of 5 m length. Harvesting was done on September 30 in both years, with samples collected from the middle 2 rows to eliminate edge effects and the seeds were subsequently separated by machine threshing.

Statistical analysis

All the data were analyzed using the SPSS package ((SPSS, Version 20.0, SPSS Inc, Chicago, IL, USA). When the F-test indicated statistical significance at the P=0.05 level, the protected least significant difference (Protected DUNCAN) was used to separate the means (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Significant annual differences ($P<0.01$) were observed for all traits, with the 2018 season yielding higher seed and oil yields due to favorable precipitation and temperature conditions. In contrast, the drier and hotter 2017 season negatively affected safflower growth and key yield components, such as plant height and branch number, due to rainfall deficit and heat stress. These environmental variations significantly influenced the performance of both 'Dinçer' and 'Yenice' cultivars, with 2018 providing better conditions for seed filling and oil accumulation.

Plant height

Plant height was significantly affected by year, cultivar, row spacing, sowing norm and the cultivar $\times$ row interaction ($P<0.01$) (Table 1). Plant height was substantially greater in 2018 (84.9 cm) than in 2017 (64.2 cm) due to more favorable climatic factors (Montemurro *et al.*, 2007; Fig 1). The Dinçer cultivar was 6.8 cm taller than Yenice. The highest plant height was achieved at the 20 cm row spacing and 60 kg ha⁻¹ sowing norm, while the shortest was at 40 cm spacing and 20 kg ha⁻¹ application. This indicates that increased plant density stimulates vertical growth by intensifying competition for sunlight (Moghaddasi and Omid, 2015; Uke *et al.*, 2017).

Branch number

Branch number exhibited significant effects from year, cultivar, row spacing, sowing norm and the cultivar $\times$ row and row $\times$ norm interactions ($P<0.01$). The highest average branch number was recorded in 2018 (6.2 pieces),

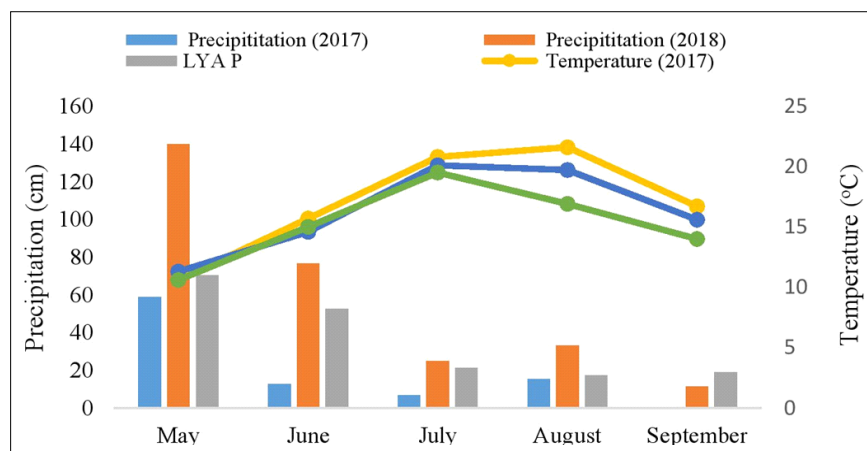


Fig 1: Some important climatic data of the study area for 2017-2018.

attributable to the high and uniform rainfall distribution during the growing season. The Dinçer variety (5.9 pieces) generally produced more branches (Table 1). Branch number significantly varied inversely with plant density: it increased with wider row spacing (60 cm yielded the highest value) but decreased significantly as the sowing norm was increased (20 kg ha⁻¹ yielded the lowest). This observed reduction in branching in dense plantings is likely due to reduced light penetration and increased competition (Sharif and Omid, 2016), as the plant prioritizes vertical growth over lateral development.

Head number

The head number, a critical yield factor, was significantly influenced by year, sowing norm and cultivar × row interaction ($P<0.01$) and by cultivar ($P<0.05$). The average head count in 2018 (14.4) was significantly higher than in 2017 (11.0) due to more favorable ecological conditions, specifically beneficial rainfall and temperature (Table 1), (Fig 1). The Dinçer cultivar produced the maximum number of

heads. While the effect of different row spacing was statistically insignificant, the head number exhibited a clear inverse relationship with seeding density. The highest number of heads (13.3 pieces) was obtained at the lowest sowing norm (20 kg ha⁻¹) and the lowest (12.4 pieces) was obtained at the highest norm (60 kg ha⁻¹). This density-dependent decrease is consistent with previous reports that increased sowing norm reduces the number of heads due to intensified plant competition (Moghaddasi and Omid, 2015; Uke *et al.*, 2017).

Seed number

The number of seeds per head was significantly influenced by year, cultivar, sowing norm and the two-way interactions row spacing × cultivar and row spacing × sowing norm ($P<0.01$); row spacing alone was also significant ($P<0.05$). The highest seed count was recorded in 2018 (25.3 seeds) and the Dinçer cultivar produced the maximum number of seeds per head (24.5 pieces) due to genetic differences (Table 1). A wider 60 cm row spacing maximized seed

Table 1: Different parameters of safflower cultivars grown at different row spacing and planting rates.

Treatments		Plant height (cm)	Branch number (no plant ⁻¹)	Head number (no plant ⁻¹)	Seed number (no plant ⁻¹)
Year	2017	64.2 ^b	5.0 ^b	11.0 ^b	23.0 ^b
	2018	84.9 ^a	6.2 ^a	14.4 ^a	25.3 ^a
Cultivar	Dinçer	71.1 ^b	5.9 ^a	13.3 ^a	24.5 ^a
	Yenice	77.9 ^a	5.3 ^b	12.7 ^b	23.8 ^b
Row spacing (cm)	20	75.3 ^b	5.2 ^c	12.6	23.9 ^b
	40	69.3 ^c	5.6 ^b	13.1	24.1 ^{ab}
	60	78.9 ^a	6.0 ^a	13.3	24.5 ^a
Sowing norms (kg ha ⁻¹)	20	70.9 ^b	6.3 ^a	13.6 ^a	25.1 ^a
	40	75.1 ^a	5.4 ^b	13.0 ^b	24.1 ^b
	60	77.5 ^a	5.1 ^c	12.4 ^b	23.2 ^c
Variation sources	DF				
Year (Y)	1	**	**	**	**
Cultivar (C)	1	**	**	*	**
Row spacing (RS)	2	**	**	ns	*
Planting rate (PR)	2	**	**	**	**
C×Y	1	ns	ns	ns	ns
C×RS	2	**	**	**	**
C×PR	2	ns	ns	ns	**
Y×RS	2	ns	ns	ns	ns
Y×PR	2	ns	ns	ns	ns
RS×PR	4	ns	**	ns	**
C×Y×RS	2	ns	ns	ns	ns
Y×RS×PR	4	ns	ns	ns	ns
C×RS×PR	4	ns	*	ns	**
C×Y×PR	2	ns	ns	ns	ns
C×Y×RS×PR	4	ns	ns	ns	ns

*Significant at 5% level ($P<0.05$); **Significant at 1% ($P<0.01$). The difference between the averages shown in different letters is significant.

number (Likely by enhancing branching *via* increased red light reception), while increasing the sowing norm significantly reduced the count (lowest at 60 kg ha⁻¹ with 23.2 seeds) a reduction attributed to high plant density causing a post-flowering water deficit (Sefaoglu and Ozer, 2022; Calışkan and Calışkan, 2018).

1000 seed weight

The Thousand Seed Weight (TSW), a key yield determinant, was significantly affected by year, cultivar, row spacing, sowing norm and all two- and three-way interactions (Table 2). TSW was substantially higher in 2018 (45.3 g) than in 2017 (41.0 g), which is attributed to sufficient rainfall and suitable temperatures during the critical July 2018 flowering period (Beyyavas *et al.*, 2011). TSW showed an inverse relationship with both row spacing (highest at the narrowest 20 cm with 44.4 g) and sowing norm. This negative response to high density is likely due to intensified competition slowing metabolic activities during the seed-filling stage (Zarei *et al.*, 2011; Caliskan and Caliskan, 2018).

Seed yield

Seed yield, which is the cumulative result of various yield components and external factors, was significantly affected by year, variety, row spacing and sowing norm treatments (Table 2), ($P < 0.01$). The effects of all interactions, except row spacing x sowing norm, were insignificant (Table 2). Seed yield exhibited significant genotypic differences (Bella *et al.*, 2019), with Dinçer (1360.9 kg ha⁻¹) outperforming Yenice (1190.0 kg ha⁻¹). Contrary to expectations, the first trial year yielded approximately 170.1 kg ha⁻¹ higher than the second. This lower yield in the second year is likely attributed to climatic factors (Vicianova *et al.*, 2020), specifically irregular rainfall and adverse temperatures during critical growth stages (emergence, flowering and grain-filling), negatively impacting key yield components (Sefaoglu and Ozer, 2022). Seed yield decreased as row spacing increased (1420.6 kg ha⁻¹ at 20 cm vs. 1160.7 kg ha⁻¹ at 60 cm), demonstrating that wider spacing leads to increased yield components but a lower overall yield per

Table 2: Different parameters of safflower cultivars grown at different row spacing and planting rates.

Treatments		1000 seed weight (g)	Seed yield (kg ha ⁻¹)	Seed oil concentration (g kg ⁻¹)	Oil yield (kg ha ⁻¹)
Year	2017	41.0 ^b	1190.8 ^b	22.0 ^b	260.5 ^b
	2018	45.3 ^a	1360.9 ^a	24.2 ^a	330.3 ^a
Cultivar	Dinçer	43.8 ^a	1370.7 ^a	23.7 ^a	320.9 ^a
	Yenice	42.4 ^b	1190.0 ^b	22.6 ^b	260.9 ^b
Row spacing (cm)	20	41.8 ^c	1420.6 ^a	23.4 ^b	330.5 ^a
	40	43.1 ^b	1250.7 ^b	24.1 ^a	300.4 ^b
	60	44.4 ^a	1160.7 ^c	21.9 ^c	250.7 ^c
Sowing norms (kg ha ⁻¹)	20	44.4 ^a	1230.1 ^b	23.4 ^a	290.1 ^b
	40	42.7 ^b	1250.6 ^b	23.2 ^a	290.4 ^b
	60	42.3 ^b	1360.2 ^a	22.7 ^b	310.2 ^a
Variation sources	DF				
Year (Y)	1	**	**	**	**
Cultivar (C)	1	**	**	**	**
Row spacing (RS)	2	**	**	**	**
Planting rate (PR)	2	**	**	**	**
C×Y	1	ns	ns	ns	*
C×RS	2	**	ns	**	**
C×PR	2	**	ns	ns	ns
Y×RS	2	ns	ns	ns	ns
Y×PR	2	ns	ns	ns	ns
RS×PR	4	ns	**	**	**
C×Y×RS	2	ns	ns	ns	ns
Y×RS×PR	4	ns	ns	ns	ns
C×RS×PR	4	**	ns	**	ns
C×Y×PR	2	ns	ns	ns	ns
C×Y×RS×PR	4	ns	ns	ns	ns

*Significant at 5% level ($P < 0.05$); **Significant at 1% ($P < 0.01$). The difference between the averages shown in different letters is significant.

unit area. Conversely, seed yield increased consistently with the increase in sowing norm, peaking at 1360.2 kg ha⁻¹ with the 60 kg ha⁻¹ norm (Fig 2). This finding aligns with studies reporting that higher sowing norms increase yield (Ahadi *et al.*, 2011), although other research suggests wider spacing enhances light utilization and reduces competition, leading to higher individual plant yield (Berglund *et al.*, 1998; Zarei *et al.*, 2011).

Seed oil concentration

Seed oil concentration was significantly affected by all treatments, as well as the cultivar × row spacing and row spacing × sowing norm interactions ($P < 0.01$) (Fig 3), (Table 2). Oil content is highly dependent on genotype (Kose and Bilir, 2017; Kayın *et al.*, 2024) and climatic conditions, notably temperature during the grain filling period (Weiss, 2000). The higher crude oil ratio observed in 2018 (Wetter year) is attributed to significantly higher total rainfall in May, June and July compared to 2017 (Table 2). Among row spacings, the highest oil content was obtained at 40 cm. While the oil ratio showed no significant change between the 20 and 40 kg ha⁻¹ sowing norms, it was unexpectedly higher in the densest planting (60 kg ha⁻¹). This highlights that environmental factors, particularly adequate moisture

during critical stages, often override simple agronomic density effects in determining seed oil quality (Fig 3).

Oil yield

Oil yield was significantly affected by all factors, reflecting the combined influence of oil concentration and seed yield (Table 2), (Fig 3). Due to its superior genetic structure, the Dinçer cultivar produced the highest oil yield. The lower oil yield in the first year is attributed to irregular and insufficient rainfall. Oil yield showed a density-dependent response, with the lowest yield recorded at the widest 60 cm row spacing and the highest (330.5 kg ha⁻¹) obtained at the narrowest 20 cm spacing. Furthermore, oil yield increased proportionally with the sowing norm, reaching its maximum at 60 kg ha⁻¹. This pattern indicates that seed yield per unit area is the primary factor driving the final oil yield, outweighing the minor changes in oil concentration.

Principal component analysis (PCA)

The principal component analysis (PCA) identified two effective components (with eigen values > 1) (Fig 4). These components explained the majority of the total variance in both cultivars: 98.7% in Dinçer (First: 28.3%, Second: 70.4%) and 97.6% in Yenice (First: 22.3%, Second: 75.3%). In the Dinçer cultivar, the treatment combinations of

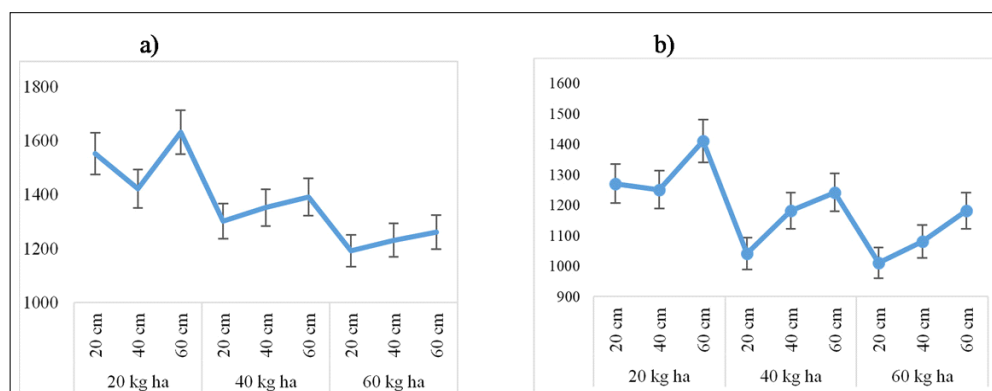


Fig 2: The effect of genotypes × sowing date interaction on seed yield of (a) Dinçer and (b) Yenice genotypes.

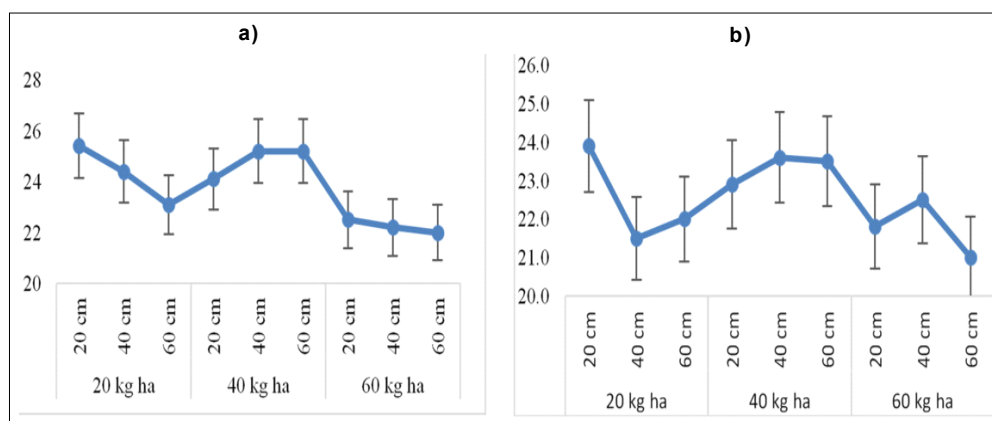


Fig 3: The effect of genotypes × sowing date interaction on seed oil percentage of (a) Dinçer and (b) Yenice genotypes.

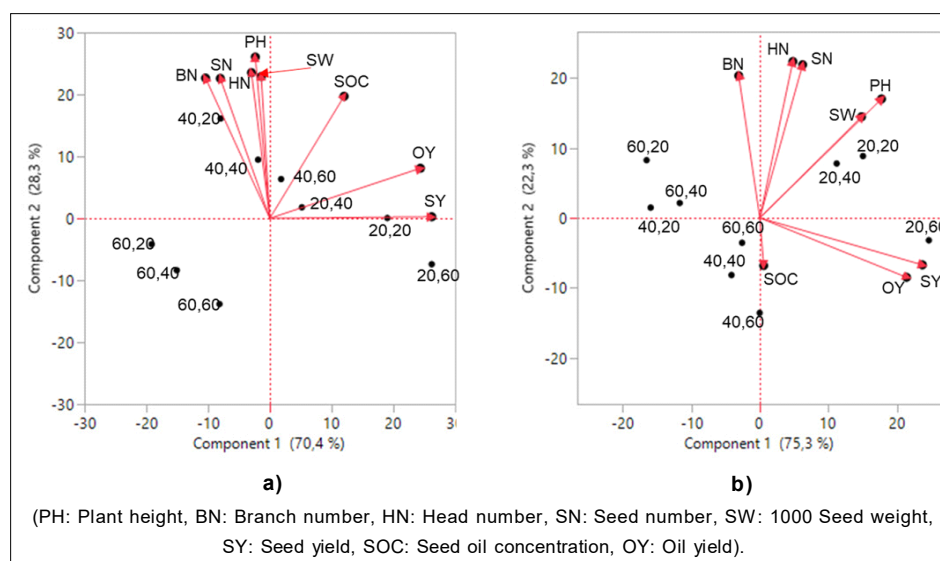


Fig 4: The results of the dendrogram based on cluster analysis and the biplot of the first and second components from the principal component analysis (PCA) for the two genotypes (a- Yenice, b- Dinçer).

40 cm row spacing with 20 kg ha⁻¹ and 40 kg ha⁻¹ sowing norms clustered together, showing strong correlations with branch number, head number and plant height. In contrast, 40×60 cm and 20×40 cm distances were associated with the major yield components: 1000-seed weight, seed oil concentration, oil yield and seed yield. For the Yenice cultivar, the 20×20 cm and 20×40 cm distances clustered, correlating strongly with a wider range of traits including plant height, seed number, thousand seed weight and head number. Additionally, the highest sowing norms (60×2 kg ha⁻¹ and 60×4 kg ha⁻¹) correlated strongly with branch number, while the 20×6 kg ha⁻¹ distance showed high correlations with seed oil concentration, oil yield and seed yield (Fig 3; Fig 4).

CONCLUSION

The study demonstrates that safflower yield and quality are significantly influenced by row spacing and sowing norms in high-altitude, irrigated environments. While wider row spacing (60 cm) improved individual plant traits such as branch and head number, it resulted in a lower overall seed and oil yield per unit area. The 40 cm row spacing provided the most balanced performance, yielding the highest results for seed yield, oil content and oil yield. Regarding plant density, the 60 kg ha⁻¹ sowing norm was found to be the most effective for maximizing total productivity. Consequently, the study concludes that a combination of 40 cm row spacing and a 60 kg ha⁻¹ sowing norm is the optimal configuration for achieving maximum yield and suitability for mechanized production under these specific climatic conditions.

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Disclaimers

The content and its accuracy is the sole responsibility of the authors. It does not reflect institutional views and no liability is accepted for any losses from its use.

Informed consent

Since this study involved only commercial cell lines and did not involve any human participants, biological materials, or personal data, clinical trial registration and informed consent were not required.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper. The research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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