Evaluation of Some Growth and Yield Traits of Safflower Crop (Carthamus tinctorius L.) as Influenced by Sowing Dates and Row Spacing

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Abstract

This study was carried out during the winter growing season 2024-2025 at two locations; Duhok, which is located between longitudes 42.8478(°E), latitude 36.8608(°N), and elevation 500 masl is 500 meters above Sea level (masl) and Zakho, which is located at 42.69 (°E) longitude, 37.15 (°N) latitude and 439 masl, 60 Km from the center of Duhok city, to evaluate the effect of sowing dates (late November, late December and late January), row spacing (15,30,45, and 60) cm, and location on some earlier growth traits of safflower. A factorial experiment on Randomized Complete Block Design (R.C.B.D) with three replications was designed. The study findings showed significant differences between factors, so, late November gave the highest value of plant height, height of the lowest head, number of days from sowing to 50% flowering and chlorophyll content with values: 90 cm, 66.5 cm, 164 days and 65.7 SPAD respectively, while late January gave the highest number of branches and number of heads per plant with values: 10.2 branches and 23.7 heads respectively. Row spacing, 60 cm gave the highest value of field emergence, chlorophyll content, number of branches, and number of heads per plant, with 88.3%, 67.2, 11.1 branches, and 26.6 heads, respectively, excluding plant height, in which the 30 cm row spacing gave the highest average with 90.5 cm. The interaction of Zakho location in late January with 60 cm gave the highest value of number of branches and number of heads per plant (13.3 branches and 46.6 heads per plant), while in Zakho at late November with 15 cm recorded the highest average of plant heigh and height of the lowest head (107.7 cm and 85.6 cm), respectively.

Keywords: safflower, sowing dates, row spacing, Duhok and Zakho .

***This paper is a part of the MSc study for the first author**

Introduction

Safflower (Carthamus tinctorius L.) is an annual, highly branched, herbaceous plant, self-pollinated and of Asteraceae family [26]. It is a major global oilseed crop [14], and is highly tolerant to drought, heat, cold, and salinity [10], making it one of the most drought-tolerant oilseed crops [32]. Cultivated mainly for its seeds and flowers, safflower provides edible oil, birdseed, dye, and medicinal uses [9]. Its seeds contain 25–45% oil, mostly unsaturated fatty acids oleic (ω-9) and linoleic (ω-6) constituting 90% of total fatty acids, while the rest are saturated [5 .[

Safflower is also valued for healthier oil-lower in saturated fats than olive and canola oil [4]. Oleic acid helps prevent coronary artery disease, while linoleic acid lowers cholesterol

[6]. The oil is used in paints, linoleum, and varnishes [2], and petals provide non-toxic food colorants like carthamidin and carthamine [9]. It also holds potential for biofuels and pharmaceuticals [23]. Safflower extracts are pharmacologically significant and contain compounds like tannins, serotonin, luteolin, and acacetin with properties such as antioxidant, antibacterial, and anti-inflammatory effects [13]. Its petals have 16 amino acids, minerals, and vitamins B1, B2, C, and E, used to improve circulation, relieve pain, regulate menstruation, and heal fractures [19.[

Iran is one of its centers of origin [17], although its native range includes southern Turkey, western Iran, Iraq, Syria, and Jordan. It is cultivated in over 20 countries—India, the USA, Mexico, and Kazakhstan being the top producers—across more than 700,000 hectares and yields 600,000–700,000 metric tons annually [11]. Kazakhstan led global production in 2019 with 34.87%. In 2022, production rose to 995,508 tons [11]. Other producers include Turkey, Iran, Syria, Argentina, and China. Yields vary between 0.5 and 1.7 tons.ha-1 depending on planting time, cultivar, temperature, and water [11,31.[

In Iraq, safflower production declined due to political instability, poor land management, and market issues. Attempts in 1972–1973 and 1978–1979 failed due to disease, irrigation issues, and lack of farmer interest [10,15]. Challenges include pests, diseases, climate stress, limited seed quality, water scarcity, and weak infrastructure. Enhancing farming practices and support could improve production and profitability.

Safflower growth is affected by genotype, environment, and agronomic factors [12]. Among them, sowing date is vital [18,27]. Delayed sowing reduces yields due to shortened vegetative growth and higher flowering temperatures [7]. Proper timing aligned with optimal temperature and rainfall ensures vegetative growth. Studies confirm that planting date impacts oil content and yield [30.[

Row spacing also plays a key role: narrower spacing enhances yields by improving plant distribution and reducing competition [31]. Denser planting improves nutrient uptake, light absorption, and weed control [24]. Field trials show row spacing and seeding rate significantly affect growth and yield traits [19]. In Iran, 15 cm row spacing is recommended [21.[

Accordingly, this study was suggested to determine the effect of different sowing dates and planting densities on safflower's development under varying environmental conditions .

Materials and Methods

This study was conducted during the winter growing season 2024–2025 at two locations: the first at Duhok (Research Farm of Department of Field Crops, College of Agricultural Engineering Sciences), located at 42.8478°E longitude, 36.8608°N latitude, and 500 meters above sea level (masl), and the second at Zakho (Agricultural Research Center), located at 42.69°E longitude, 37.15°N latitude, and 439 masl, 60 km from Duhok city. The meteorological data were recorded at both locations (Table 1). Also, the soil samples from both locations were collected randomly at (0-30) cm depth after tillage and before sowing (Table 2). The field was ploughed twice (primary and secondary tillage), and leveled manually. A factorial experiment using a Randomized Complete Block Design (R.C.B.D) with three factors and three replications was applied. The experiment involved three factors: three sowing dates (late November, late December, and late January), and four row spacings (15, 30, 45, and 60 cm), and two locations (Duhok and Zakho). Plots measured 2x3 m, with 0.5 m between plots and 1 m between replications. Each unit had 5 lines with row spacing of 15, 30, 45, and 60 cm. Before planting,

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Diammonium Phosphate (DAP) fertilizer (N:P 18:46%) was applied at 120 kg. ha^{-1} at both locations [33]. The Safflower variety "Gilla" was obtained from Salahaddin University, College of Agricultural Engineering Sciences. Seeds were sown manually, two seeds per hole, at 2–3 cm depth, spaced by 15 cm between plants and variable row spacing [22]. Each line contained 14 seeds; thus, each plot had 70 plants. After emergence, thinning was done at the rosette stage, retaining one healthy plant per hole. There were 12 treatments and thus 36 experimental units at each location. Nitrogen fertilizer (urea, 46% N) was applied three times at 150 kg. ha^{-1}: one-third after emergence, one-third at elongation, and one-third at flowering [33]. Supplementary irrigation was provided as needed, and weeds were controlled manually twice during the rosette and elongation stages. All other standard safflower cultivation practices were followed during the experiment. Five plants were taken randomly from the three middle lines of each plot for a parameter measurement of earlier traits of safflower plant: plant height, height of the lowest head, chlorophyll content, number of primary branches.plant-1, number of heads.plant-1 and number of days from sowing to flowering. The data were statistically analyzed according to the above design, using analysis of variance. The means were compared using Duncan's multiple range test at 5% probability [3]. All the data were tabulated and statistically Analyzed with computer using [29 .[

Table 1. Metrological record for both locations during the growing season of (2024-2025.(

Months	Temperature (°C)				Rainfall (mm)		Relative humidity %	
	Minimum		Maximum					
	Zakho	Duhok	Zakho	Duhok	Zakho	Duhok	Zakho	Duhok
November 2024	10.1	9.5	20.1	20.3	30.9	37.9	56	65
December 2024	5.4	5.2	15.9	15.9	19.8	11.3	56	60
January 2025	4.3	4.2	16.2	15.8	5.3	9.3	49	56
February 2025	2.8	2.6	12.7	12.4	52.6	45.9	44	56
March 2025	11.1	10.2	23.2	22.3	11.6	15.3	35	46
April 2025	15.0	14.9	25.6	25.5	38.4	57.7	44	45
May 2025	20.7	20.1	34.5	34.4	10.5	9.9	23	32

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Table 2. Physical and chemical properties of soil in both locations

Parameters	Locations	
	Sumail	Zakho
pH	7.75	8.03
EC ($dS.m^{-1}$)	0.31	0.271
Available Potassium (mg/kg)	15.66	109
Available Phosphorus (mg/kg)	4.43	9
Available Nitrogen (mg/kg)	74	112
Organic Matter %	1.48	0.605
$CaCO_3$ %	18.52	7.909
Clay %	48.802	17.6
Silt %	45.427	43.5
Sand %	5.771	58.1
Soil Texture	Silty clay	Sandy loam

The soil properties tests were conducted at the Agricultural Consultant Bureau / University of Duhok (2025.(

*EC: Electric Conductivity.

Results and Discussion

Effect of sowing dates and row spacing on plant height (cm) of safflower

The results showed that safflower plant height experienced significant changes because of variations in sowing date and row spacing, and location factors. According to the Table (4) results Zakho produced the highest plants which reached 102.3 cm while Duhok plants reached only 74.6 cm, which demonstrated a significant location-related difference. [1] demonstrated that early sowing under suitable conditions in Nineveh resulted in significant increases in safflower plant height. Zakho demonstrated superior growth performance because its microclimate and soil characteristics provided optimal conditions for stem growth during the entire growth period (Tables 1 and 2.(

The sowing date did not show statistically significant differences; however, the highest average plant height was 90.0 cm achieved by late November. The data supports previous research by [28] and [14], whom determined that the November 13th and 23rd planting dates in Erbil and Duhok areas created the tallest plants. The authors explained this through extended growth periods and improved harmony between plants and temperature and moisture conditions .

The height of plants received significant influence from the spacing between rows. Data showed that plants at 30 cm spacing grew tallest with an average height of 90.5 cm while the next tallest plants were at 60 cm

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spacing with 89.7 cm and then the 15 cm spacing plants at 88.0 cm; the shortest plants grew at 45 cm spacing with an average height of 85.7 cm. Plants growing at 45 cm spacing reached the shortest average height of 85.7 cm. The taller plants in closer spaced conditions likely result from competing plants for light which causes them to extend their growth in order to avoid being shaded. The pattern matches the results from [25] who determined that closer spacing makes plants taller because of competition yet this effect does not guarantee better yields .

The combination effects reveal important knowledge about the situation. The tallest plants reached 107.7 cm when Zakho was planted in late November with 15 cm spacing showing how early planting with closer spacing produces positive results in optimal conditions. [12] stated that timely sowing enables plants to reach their full vegetative development which matches these findings. Duhok's late January sowing, combined with 45 cm spacing produced the shortest plants at 67.1 cm as suboptimal timing and wider spacing under less favorable conditions severely limited vertical growth.

These findings emphasize the need to customize cultivation approaches based on local environmental factors and planting periods to achieve optimal plant health and structure in safflower production.

Table 3. Analysis of variance for the studied traits

Source of Variance	Probability of significance					
	Plant Height (cm)	Height of lowest head (cm)	Days to 50% flowering	Chlorophyll content (SPAD)	Number of branches per plant	Number of heads per plant
Locations (L)	< 0.0001	< 0.0001	0.1057	< 0.0001	< 0.0001	< 0.0001
Sowing dates (SD)	0.4253	0.3463	< 0.0001	0.9872	0.0028	0.0874
Row spacing (RS)	0.4241	0.0108	0.5970	0.2441	< 0.0001	0.0011
L * SD	0.6375	0.7422	0.0010	0.3253	0.1989	< 0.0001
L * RS	0.3241	0.1083	0.6415	0.8533	0.7656	< 0.0001
SD * RS	0.3691	0.8989	0.9834	0.6048	0.8078	0.0096
L * SD * RS	0.1814	0.5977	0.8653	0.4107	0.2055	< 0.0001

Table 4. Effect of sowing dates and row spacing on plant height (cm) of safflower in Duhok and Zakho locations

Locations	Sowing dates	Row spacings				Locations * sowing dates	Mean of Locations
		15 cm	30 cm	45 cm	60 cm		
Duhok	Late November	70.1 de	80.4 de	80.2 de	69.0 e	74.9 b	74.6 b
	Late December	71.2 de	69.8 e	75.6 de	79.5 de	74.0 b	
	Late January	71.9 de	79.2 de	67.1 e	81.9 cde	75.0 b	
Zakho	Late November	107.7	107.6 a	102 ab	103.3	105.2 a	102.3 a

		a			ab		
	Late December	107.2 a	105.3 a	87.5 bcd	96.9 abc	99.2 a	
	Late January	100 ab	100.5 ab	102 ab	107.6 a	102.5 a	
Mean of row spacing		88.0 a	90.5 a	85.7 a	89.7 a	**Mean of sowing dates**	
Locations * row spacing	Duhok	71.1 b	76.5 b	74.3 b	76.8 b		
	Zakho	105.0 a	104.5 a	97.2 a	102.6 a		
sowing dates * row spacing	Late November	88.9 ab	94 ab	91.1 ab	86.1 ab	Late November	90.0 a
	Late December	89.2 ab	87.5 ab	81.6 b	88.2 ab	Late December	86.6 a
	Late January	86.0 ab	89.8 ab	84.6 ab	94.75 a	Late January	88.8 a

*In each row or volume, the values sharing the same letter are not statistically different at the probability of 0.05.

Effect of sowing dates and row spacing on height of lowest head (cm) of safflower

Safflower plants need their lowest head height measured because it serves as a key morphological characteristic for evaluating both plant growth and mechanized harvesting operations. The present study demonstrates that three factors including sowing time and row distance and geographic area have major effects on this particular characteristic (Table 5). The lowest head height reached its maximum value at Zakho (73.4 cm) across all treatment groups but Duhok showed a considerably smaller measurement at 54.6 cm which demonstrates the effects of environmental factors on plant structure. [1] showed that safflower planted in Nineveh's agro-climatic environment achieved better vegetative growth through earlier planting dates hence explaining Zakho's superior performance.

Concerning sowing dates, the tallest height of the lowest head was observed in plants sown in late November (66.5 cm), followed closely by late January (63.1 cm), while late December sowing resulted in the shortest lowest-head height (62.4 cm). These results are in agreement with findings by [28], who found that early planting dates contributed to more vigorous growth and improved morphological features such as branch length and head position. Early sowings produce taller plants because they experience extended vegetative development stages alongside optimal weather conditions according to [12] who indicated that early planting results in improved stem and canopy formation which positions reproductive parts at higher positions.

Row spacing also played a significant role. The narrowest spacing (15 cm) produced the highest mean height of the lowest head (69.3 cm), followed by 30 cm (66.9 cm), whereas 45 cm spacing resulted in the lowest value (59.0 cm). The trend probably happens because of the effects of intra-specific competition; plants grown at narrower spacing tend to grow taller due to competition for light, thereby raising the height at which heads are formed. The morphological adaptations observed match the

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results from [25] who found increased stem elongation happens in dense planting arrangements to fight shading effects. Plants grown with more space tend to develop more branches and heads but this spacing also reduces competition which results in shorter plants and lower head placement.

The interaction between the factors further illustrates the need for integrated management. The highest value of the entire experiment (85.6 cm), was achieved by late November sowing with 15 cm spacing under Zakho, and also shows early sowing coupled with dense planting and ideal environmental conditions has a stronger potential effect on stem elongation and increased head height. [12] also confirmed the advantages of early sowing [12,28], and reinforces the importance of making adjustments to improve safflower to achieve structural traits involved increased plant height and elevated branches. By contrast, the lowest (47.7 cm) was noted by late December sowing with 30 cm spacing under Duhok, once again confirming the detriment of late sowing under unfavorable conditions.

In summary, the results clearly indicate that the height above ground of the lowest head in safflower is strongly dependent on planting time, row spacing and growing site. The earlier sowing and narrower spacing were in more suitable growing regions (e.g. Zakho), which could make improvements to mechanical harvesting and reduce losses in the field. This reflects earlier literature

planting practices and architecture and acclimatize to the environment.

Table 5. Effect of sowing dates and row spacing on the height of the lowest head (cm) of safflower in Duhok and Zakho locations

Locations	Sowing dates	Row spacings				Locations * sowing dates	Mean of Locations
		15 cm	30 cm	45 cm	60 cm		
Duhok	Late November	56.1 c-f	58.5 c-f	57.4 c-f	53.2 def	56.3 b	54.6 b
	Late December	56.2 c-f	47.7 f	51.2 ef	54.6 c-f	52.4 b	
	Late January	58.8 c-f	56.8 c-f	51 ef	53.6 def	55.0 b	
Zakho	Late November	85.6 a	84.5 a	67.5 a-f	69 a-e	76.6 a	73.4 a
	Late December	85.5 a	81.1 ab	59.1 c-f	63.7 b-f	72.3 a	
	Late January	73.8 abc	73 a-d	68.1 a-e	70 a-e	71.2 a	
Mean of row spacing		69.3 a	66.9 ab	59.0 c	60.7 bc	Mean of sowing dates	
Locations * row spacing	Duhok	57.0 cd	54.3 d	53.2 d	53.8 d		
	Zakho	81.6 a	79.5 a	64.9 bc	67.6 b		
sowing dates * row spacing	Late November	70.9 a	71.5 a	62.4 ab	61.1 ab	Late November	66.5 a
	Late December	70.9 a	64.4 ab	55.2 b	59.1 ab	Late December	62.4 a
	Late January	66.3 ab	64.9 ab	59.5 ab	61.8 ab	Late January	63.1 a

*In each row or volume, the values sharing the same letter are not statistically different at the probability of 0.05.

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Effect of sowing dates and row spacing on the number of days from sowing to 50% flowering of safflower

The duration from sowing to flowering is an important phenological trait that impacts the crop's adaptation to local agro-climatic conditions, and determines its management with environmental indicators. In the current study the number of days to flowering safflower was significantly affected by sowing dates, row spacing and location.

Table (6) showed that among the sowing dates, late November planting resulted in the longest duration to flowering, with an overall mean of 164 days, while late December sowing averaged 141.1 days, and late January sowing significantly accelerated flowering to 101.4 days. This pattern persisted in both regions and all row spacing levels, indicating the responsiveness of the crop to planting time. Our results aligned with [28], who determined safflower had a longer vegetative and pre-flowering stage with earlier sowing dates, especially in the cooler growing environment of northern Iraq. Likewise, [12] determined safflower planted in early December and early April had extended vegetative stage and pre-flowering stage making it take longer to flower while safflower planted later in season had shortened vegetative and pre-flowering patterns due to warmer temperatures allowing for rapid developmental stages. The general pattern of reduced phenological duration at a later sowing date is based on the understanding safflower is thermosensitive and that plants developed quicker during their phenological stages because growing degree days accumulated faster with increased soil temperature.

Location exerted a limited yet evident impact on safflower flowering time. As a whole, Duhok showed a somewhat longer to flowering (135.9 days) than Zakho (135.1 days), with minimal differences and not statistically significant. Thus, we can extrapolate that both of these sites had generally comparable environmental conditions during the key phenological windows; however, Duhok slightly tended to induce later flowering, potentially due to slightly cooler temperatures or moisture dynamics. [1] pointed out the part microclimates play may be relevant to flowering time, especially related to temperature and photoperiod sensitivity, which may account for slight variation between the sites.

Row spacing had a negligible, statistically insignificant effect on duration of flowering, with means range from 135.1-135.6 days at all spacings (15 to 60) cm, implying that plant density had little effect on the initiation of flowering, and it is likely this trait is regulated more by thermal time and photoperiod rather than induced stress from competition; similar conclusions were given by [25] who found that while spacing can impact morphological traits and yield components, it had no significant effect on safflower floral initiation timing.

The interaction between factors also showed that earlier sowings reliably delayed the time to flowering, while late sowing conditions were found to accelerate flowering. In a similar vein, [12] reported that safflower planting at a late establishment reduced the length of developmental phases which then affected total canopy cover and potential yield.

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Table 6. Effect of sowing dates and row spacing on number of days from sowing to 50% flowering of safflower in Duhok and Zakho.

Locations	Sowing dates	Row spacings 15 cm	30 cm	45 cm	60 cm	Locations * sowing dates	Mean of Locations
Duhok	Late November	164.3 ab	165 ab	165 ab	166 a	165.1 a	135.9 a
	Late December	142 cd	142.3 c	141.7 cd	142 cd	142 c	
	Late January	100.7 e	100.7 e	100.7 e	100 e	100.5 f	
Zakho	Late November	163.7 ab	163.3 ab	163 ab	162 b	163 b	135.1 a
	Late December	140.7 cd	141 cd	138.7 d	140.3 cd	140.2 d	
	Late January	102.3 e	103 e	101.3 e	102.3 e	102.3 e	
Mean of row spacing		135.6 a	135.6 a	135.1 a	135.4 a		
Locations * row spacing	Duhok	135.7 a	136 a	135.8 a	136 a	**Mean of sowing dates**	
	Zakho	135.6 a	135.8 a	134.3 a	134.9 a		
sowing dates * row spacing	Late November	164 a	164.2 a	164 a	164 a	Late November	164 a
	Late December	141.3 b	141.7 b	140.2 b	141.2 b	Late December	141.1 b
	Late January	101.5 c	101.8 c	101 c	101.2 c	Late January	101.4 c

*In each row or volume, the values sharing the same letter are not statistically different at the probability of 0.05.

Effect of sowing dates and row spacing on chlorophyll content (SPAD) of safflower

Table (7) indicated that chlorophyll content which was expressed in SPAD unit is an important physiological parameter and was related to photosynthetic capacity of the plant, thus impacting growth and productivity. In our study chlorophyll content of safflower was significantly affected by factors i.e., sowing date, row spacing, location, and their interactions .

For the two locations, Duhok had significantly higher mean chlorophyll content (70.7 SPAD) than Zakho (60.7 SPAD). It is possible that Duhok had better environmental conditions during most of the important vegetative stages, where potentially could have resulted in a shift of photosynthetic pigment accumulation, indicating improved growth conditions. This finding aligns with the interpretation of [1], who highlighted that safflower sown under the cooler and more stable climates of northern Iraq exhibited better vegetative vigor and physiological activity. The SPAD readings from Duhok suggest better chlorophyll preservation and possibly higher nitrogen availability, particularly under early sowing conditions.

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Regarding sowing dates, late November showed the highest chlorophyll content (65.7 SPAD), late December (65.9 SPAD), while late January had a slightly lower mean at (65.5 SPAD). Despite the general stability between sowing dates, it would appear that safflower maintains a stronger capacity to photosynthesize even though planting was late. There could be a marginal advantage for early trees in maintaining chlorophyll longer, but the point to be taken from this is safflower is still capable of maintaining a significantly high photosynthetic compacity albeit late planted. This observation coincides with [12] who stated that early sowing of a crop will inherently generate stronger physiological performance, including chlorophyll retention due to longer vegetative periods and more stable light and temperature when leaves were expanding. Throughout their study, [28] also reported that safflower plants that were sown in November did have greater physiological performance as evidenced from having more chlorophyll content and leaf area index.

The influence of row spacing on chlorophyll content was observed, but did not show as significant differences overall. Where the narrowest row spacing (15 cm) had the highest overall mean SPAD value (67.4), the 60 cm row spacing was 2nd (67.2), and the chlorophyll content for the 30 cm spacing was lower (61.6). The somewhat higher SPAD readings for narrower spacing may happen due to increased leaf shading and reduced light stress and chlorophyll degradation, which retains the green pigment. In contrast, very wide row spacing could expose crop foliage to solar radiation, causing potential breakdown of pigments. These observations were in partial agreement with [25,12.[

In conclusion, the findings showed that chlorophyll content in safflower is somewhat affected by sowing date and row spacing but strongly depends on growing environment (Location). The environmental conditions of Duhok produced higher SPAD values when combined with late November sowing and moderate to wider row spacing. These outcomes confirm findings from earlier research [1,12], and highlight the importance of optimizing sowing time and planting distance based on local environmental conditions to sustain photosynthetic efficiency and ensure robust vegetative development in safflower cultivation .

Table 7. Effect of sowing dates and row spacing on chlorophyll content (SPAD)of safflower in Duhok and Zakho.

Locations	Sowing dates	Row spacings				Locations * sowing dates	Mean of Locations
		15 cm	30 cm	45 cm	60 cm		
Duhok	Late November	74.1 abcd	62.6 abcd	75.2 abc	80.2 a	73.1 a	70.7 a
	Late December	78.3 ab	70.0 abcd	66.3 abcd	67.6 abcd	70.6 ab	
	Late January	63.3 abcd	67.4 abcd	69.6 abcd	73.7 abcd	68.5 abc	
Zakho	Late November	60.2 bcd	54.5 d	58.6 cd	60.2 bcd	58.4 d	60.7 b
	Late December	61.5 abcd	56.8 cd	70.3 abcd	56.3 cd	61.2 cd	
	Late January	67.0 abcd	57.9 cd	59.4 bcd	65.3 abcd	62.4 bcd	

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Mean of row spacing		67.4 a	61.6 a	66.6 a	67.2 a	**Mean of sowing dates**	
Locations * row spacing	Duhok	71.9 ab	66.7 abcd	70.4 abc	73.8 a		
	Zakho	62.9 bcd	56.4 d	62.8 bcd	60.6 cd		
sowing dates * row spacing	Late November	67.2 a	58.6 a	66.9 a	70.2 a	Late November	65.7 a
	Late December	69.9 a	63.4 a	68.3 a	62.0 a	Late December	65.9 a
	Late January	65.2 a	62.7 a	64.5 a	69.5 a	Late January	65.5 a

*In each row or volume, the values sharing the same letter are not statistically different at the probability of 0.05.

Effect of sowing dates and row spacing on the number of branches per plant of safflower

Table (8) demonstrates a significant influence of both sowing date and row spacing on the number of branches per safflower plant across both Duhok and Zakho locations. These findings align well with prior research and reinforce the critical role of agronomic practices in optimizing safflower architecture and yield components. Sowing date was also a key factor that determined branching, the maximum number of branches per plant (10.2) was obtained by sowing the plant in late January, while the late November sowing date recorded (9.2) branches per plant and the least number of branches were in the late December sowing date (8.8). These findings are consistent with [12] findings, who found that safflower plants that were sown as early in December and as late in April had substantially more branches (16.87 and 13.80 branches). The fewer branches following the later dates of sowing were likely related to the short duration of vegetative growth and the later dates were not as favorable at the corresponding later dates and may not be favorable environmentally. Likewise, [28] indicated that branches produced by different sowing dates were greater in earlier sowing dates compared to later sowing dates, especially in November under their climate conditions in Erbil and Duhok governorates. The location was also highly significant, whereby Zakho recorded branches per plant (10.5) that were significantly better than Duhok (8.2) branches per plant, which may reflect more favorable agro-climatic conditions in Zakho such as temperature regimes or soil moisture abundance during their early vegetative stages (Table 1,2). The improved regional factors influencing branching is similarly echoed in work by [1]), who noted that the vegetative growth with regards to branching was improved when sowing in November under the environmental conditions of Nineveh Province .

Row spacing also affected plant architecture. The widest spacing of 60 cm produced the highest average number of branches per plant (11.1) and the narrowest spacing of 15 cm produced the lowest average number of branches (8.3). This trend conforms to the findings of [16] who found that safflower plants planted at wide set (45 cm) row spacing displayed significantly greater numbers of primary and secondary branches than plants grown at narrow set spacing. The physiological explanation behind wider row spacing effect may be linked to decreased inter-plant competition and increased potential for better light interception, improved availability of nutrients and increased amount of lateral bud activation factors for more branching.

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The interaction between sowing date and row spacing further stressed the significant role of management interaction .

In summary, the results evaluated, reaffirmed previous studies and emphasized the importance of optimizing both management variables (sowing date and row width) going forward to increase safflower production. These results provide some support of the earlier value of caution, in emphasizing how a combination of early to mid-winter sowing date with wider row widths improves safflower plant architecture and may guarantee increased yield potential [12,16.[

Table 8. Effect of sowing dates and row spacing on number of branches.plant-1 of safflower in Duhok and Zakho.

Locations	Sowing dates	Row spacings				Locations * sowing dates	Mean of Locations
		15 cm	30 cm	45 cm	60 cm		
Duhok	Late November	6.8 hi	8.3 e-i	8.3 e-i	7.8 f-i	7.8 d	8.2 b
	Late December	6.2 i	7.2 ghi	8.5 e-i	10.4 b-f	8.1 d	
	Late January	7.7 ghi	7.7 ghi	8.7 e-i	11.4 a-d	8.9 cd	
Zakho	Late November	9.5 c-g	9.2 c-h	10.8 b-e	12.9 ab	10.6 ab	10.5 a
	Late December	8.8 d-i	8.9 d-h	9.7 c-g	10.7 b-e	9.6 bc	
	Late January	10.6 b-e	10.5 b-e	11.6 abc	13.3 a	11.5 a	
Mean of row spacing		8.3 c	8.6 c	9.6 b	11.1 a	Mean of sowing dates	
Locations * row spacing	Duhok	6.9 e	7.7 de	8.5 cd	9.9 bc		
	Zakho	9.6 bc	9.5 bc	10.7 b	12.3 a		
sowing dates * row spacing	Late November	8.2 de	8.8 cde	9.6 bcd	10.3 bc	Late November	9.2 b
	Late December	7.5 e	8.1 de	9.1 b-e	10.6 b	Late December	8.8 b
	Late January	9.2 b-e	9.1 b-e	10.2 bc	12.4 a	Late January	10.2 a

*In each row or volume, the values sharing the same letter are not statistically different at the probability of 0.05.

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Effect of sowing dates and row spacing on the number of heads per plant of safflower

The number of heads per plant is an important determinant of seed yield in safflower and its development is heavily influenced by agronomic practices, such as date of sowing and row spacing, and the climate characteristics of the growing region. The present study showed that this trait differed significantly among different sowing dates, row spacing, and locations (Table 9). The late November (21.2) and the lowest was flowering data from late December (19.0). These necessarily follow the observations reported by [28] that safflower had greater head development when assessed in terms of sowing dates in early winter (November 13th and November 23rd, respectively) in the environmental conditions of Erbil and Duhok. [12] reported early sowing dates on December 1st and April 1st had significantly more capitula per plant than sowing dates of December 31st and May 1st as a result of a longer vegetative period and being closer to favorable climatic conditions for the reproductive phase.

Location had a pronounced effect on head formation. Zakho was consistently superior in head formation and overall mean of 32.4 heads/plant was greater than that of Duhok (10.2 heads). The significant difference could probably be attributed to favorable agro-climatic conditions in Zakho, which likely included more favorable temperature ranges, rainfall distributions, and soil fertility levels (Table 1,2). Geographic variation is also noted to influence safflower performance in our case, [1] recognized better head production with November sowing dates in Nineveh due to better synchronization between environmental factors and crop phenology.

Row spacing was also an important factor in the production of heads per plant. All three row spacing's produced heads per plant with the widest row spacing (60 cm) having the highest average number of heads (26.6) compared to the narrowest row spacing (15 cm heads enough space for about 17.1 heads). Studies also have shown that wider row spacing can allow for more vegetative branching and reproductive structures and that when plants have more space there is lowered influx competition among the plant [20]. [25], pointed out how proper row spacing can improve light interception and photosynthetic efficiencies, and result in better capitula development .

The interaction of row spacing and sowing date further evidenced the requirement of temporal and spatial planting changes. [12] also referenced the importance of sowing day and spacing, to maximize head formation, as even [8] found that divergence away from optimal sowing day reduced vegetative capacity, thus restricting reproduction sites.

Overall, this study answer confirms both sowing day and row spacing considerably influence the number of heads per plant in safflower, whose influence is moderated by the local growing site environmental conditions. Before one rule out timing and distance under the conditions of this study provided viable lines of defense through late January sowing and 60cm spacing to maximize heads per plant particularly in Zakho.

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Table 9. Effect of sowing dates and row spacing on number of heads. Plant-1 of safflower in Duhok and Zakho locations

Locations	Sowing dates	Row spacings 15 cm	30 cm	45 cm	60 cm	Locations * sowing dates	Mean of Locations
Duhok	Late November	7.5 i	9.4 hi	11.5 ghi	7.5 i	9.0 c	10.2 b
	Late December	8.3 hi	7.9 hi	9.5 hi	12.3 ghi	9.5 c	
	Late January	9.5 hi	13 ghi	10.3 ghi	15.5 f-i	12.1 c	
Zakho	Late November	21.5 e-h	30.5 b-e	40.7 ab	40.7 ab	33.4 ab	32.4 a
	Late December	26 c-f	23.5 d-g	27.8 b-f	37 abc	28.6 b	
	Late January	29.7 b-e	29.7 b-e	35.2 a-d	46.5 a	35.3 a	
Mean of row spacing		17.1 d	19.0 c	22.5 b	26.6 a	Mean of sowing dates	
Locations * row spacing	Duhok	8.4 d	10.1 d	10.4 d	11.8 d		
	Zakho	25.7 c	27.9 bc	34.6 b	41.4 a		
sowing dates * row spacing	Late November	14.5 d	20.0 bcd	26.1 ab	24.1 abc	Late November	21.2 b
	Late December	17.2 bcd	15.7 cd	18.7 bcd	24.7 abc	Late December	19.0 c
	Late January	19.6 bcd	21.3 bcd	22.8 a-d	31.0 a	Late January	23.7 a

*In each row or volume, the values sharing the same letter are not statistically different at the probability of 0.05.

Conclusion

The findings of this study indicated that sowing date and row spacing had significant effects on several morphological and physiological traits of safflower under rainfed conditions. Specifically, late January sowing date increased the number of branches and capitula (heads), while late November sowing date increased the length of vegetative growth and elevated plant height and chlorophyll accumulation, both of which delayed flowering. Row spacing improved vegetative growth, it had a comparatively small influence on physiological traits . Zakho location outperformed for most of the studied traits, indicating the influence of site-specific agro-environmental factors. Both sowing dates and row spacing initiatives probably synergistically enhanced safflower production development. The research results remarkably indicate that optimizing performance requires assembling seed dates and spacing arrangements to climatic driven factors. This information offers a practical means of improving safflower production systems under rain fed regimes and increases the flexible management of sowing practices under variable environments.

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