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The Effect of Irrigation in the Different Development Periods on Yield and Yield Components in Safflower (*Carthamus tinctorius* L.)

Halil MARAŞ [1], Belgin COŞGE ŞENKAL [2*]
[1] International Center for Livestock Research and Training, Ankara
[2] Yozgat Bozok University, Faculty of Agriculture, Department of Field Crops, Yozgat
*Corresponding author: belgin.senkal@yobu.edu.tr

Abstract
This study was conducted to determine the effects of the yield and yield components of some safflower cultivars of irrigation in different development periods. Six safflower (*Carthamus tinctorius* L.) cultivars (Remzibey, Balci, Dincer, Ayaz, Linas and Olas) were used as a material. Irrigation was done the stem elongation, pre- flowering, and post-flowering. This study investigated the effects of irrigation at different developmental stages on the yield and yield components of safflower cultivars. The highest plant height (47.30 cm), number of branches (4.3), number of heads (5.4), and oil ratio (32.92%) were obtained from the cv. Olas. The highest 1000-seed weight was recorded in cv. Dinçer. Irrigation applied after flowering and during stem elongation significantly increased plant height, number of branches, heads per plant, 1000-seed weight, and seed yield. However, oil ratio remained unaffected by irrigation treatments.

Research Article

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1. Introduction

Safflower (*Carthamus tinctorius* L., Family: Compositae) is native to northern Afghanistan, India, and Central Asia. It has been cultivated in India, China, and Japan since ancient times (Sharma et al., 2022). Safflower is an annual plant that grows to an average height of 80-130 cm and has spiny and spineless types. It has flowers in different colors such as yellow, white, red, and orange. The seeds are white, and cream colored with brown lines on them. It forms small heads at the ends of the side branches connected to the main branch. It has a pile-rooted structure; It can go deep into the soil. Safflower seeds contain 30-50% oil, and 90% of this oil consists of unsaturated fatty acids (oleic and linoleic acid). Safflower oil is used in the production of liquid cooking oil, margarine, and mayonnaise oils. In biodiesel production, oleic type safflower varieties are mostly used (Dajue and Mündel, 1996; Steberl et al., 2020; Adamska and Biernacka, 2021). Carthamine and carthamidin obtained from safflower flowers are significant as a natural dye source. For this reason, it is used as false saffron (Adamska and Biernacka, 2021). In South America, some European countries, and Japan, thornless types are used in cut and dried flowers (Pahlavani et al., 2004).

Safflower is particularly well-adapted to arid and semi-arid regions with low rainfall. However, irregular precipitation and insufficient irrigation practices limit its productivity. While safflower can survive under low water conditions, irrigation during the early vegetative, flowering, and seed development stages is critical for improving yield and oil ratio. (Jhansi et al., 2018; Sharma et al., 2022). In this context, to grow better, it is significant to determine the effects of the irrigation regime at different stages of the vegetation period on yield and seed oil ratio in areas where there is drought and water shortage.

This study was conducted to determine the effects of irrigation applied in different development periods on the yield, yield components and oil ratio of different safflower varieties.

2. Materials and Methods

2.1. Trial area

The field trial was established in Lalahan/Ankara/Türkiye (Figure 1). The altitude in the trial area is 1080 m, and the winter months are harsh, and the summer months are hot and dry. In 2017 when the trial was conducted, the total precipitation amount was 694.1 mm, the average temperature was 10.4 ˚C and the average relative humidity was 65.81%. During the vegetation period (May-September), total precipitation was 264.1 mm, average temperature was 18.2 ^{o}C and average relative humidity was 57.94% (Figure 2).

Lalahan district is located 25 km away from Ankara center. Altitude: 1080 m, 39°56′54″ N- 33°06′27″E

Figure 1. Location information of the trial area.

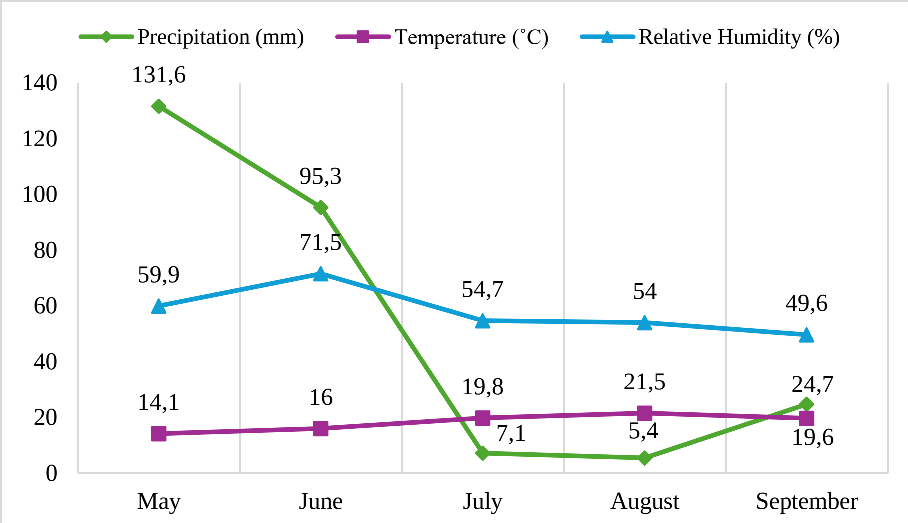

Figure 2. Climate data of the trial area (Vegetation Period).

The soil of the trial area has a clay loam structure, is slightly alkaline, salt-free, has low lime, zinc iron and organic matter ratio, the amount of nitrogen is insufficient, and the ratio of Cu, Mn and Mg is sufficient (Table 1).

Table 1. Some soil properties of the trial area

Soil Characteristics	Values	Soil Test Results
Structure	46.31%	Clay Loam
pH	7.33	Slightly Alkaline
Salt	0.03%	Saltless
Lime	1.6%	Less
Organic Matter	1.75%	Less
Nitrogen	0.09%	Poor
P_2O_5	42 kg da^{-1}	High
K_2O	120 kg da^{-1}	High
Fe	1.67 ppm	Less
Zn	0.24 ppm	Less
Cu	0.47 ppm	Sufficient
Mn	4.42 ppm	Sufficient
Ca	7.82 ppm	High
Mg	221.60 ppm	Sufficient

Table 2. General characteristics of cultivars used in this study.

Characteristics	Cultivars					
	Ayaz	**Dinçer**	**Remzibey**	**Balcı**	**Olas**	**Linas**
Spiny/Spineless	Less spiny	Spineless	Spiny	Spiny	Spiny	Spiny
Fower color	Red	Orange	Yellow	Yellow	Yellow	Orange
Plant height (cm)	100-120	90-110	60-80	70-100	70-80	85-90
Seed color	Cream	White	White	White	Cream	Cream
Seed oil ratio (%)	22-25	25-28	32-35	38-41	39-40	37-38

2.2. Plant materials

Six safflower cultivars were used as material in this study. Some characteristics of the cultivars are summarized in Table 2.

2.3. Experimental design and cultural practices

The research was established according to the Split Plots in Randomized Blocks Trial

Design with three replications. Planning was made to include cultivars on the main parcels and irrigation applications on the sub-parcels. In the experiment, the seeds were sown manually on May 8 in rows spaced 10 cm apart, with 30 cm between rows, without the use of any chemical fertilizer. Each plot had 5 rows, each with a row length of 5 meters. The first emergence was observed on May 19, and hoeing was conducted in the following period within the scope of weed control. Irrigation was conducted during the stem elongation, pre-flowering, and post-flowering periods (Table 3).

Table 3. Irrigation applications (IA)

Irrigation Period		Number of Irrigations
IA-1	Control	No irrigation
IA-2	Pre- Flowering	1
IA-3	Pre- Flowering	1
	Post-Flowering	1
	Stem elongation	1
IA-4	Pre- Flowering	1
	Post- Flowering	1
	Stem elongation	1
IA-5	Pre- Flowering	1
	Post- Flowering	2

The development periods in Table 3 were considered in determining irrigation times. For IA-5 (post-flowering), the second irrigation was determined according to the drying of the soil. Irrigation was performed for each plot with a 1" thick hose at a constant flow rate and for the same duration (Figure 3). The harvest was conducted on September 26.

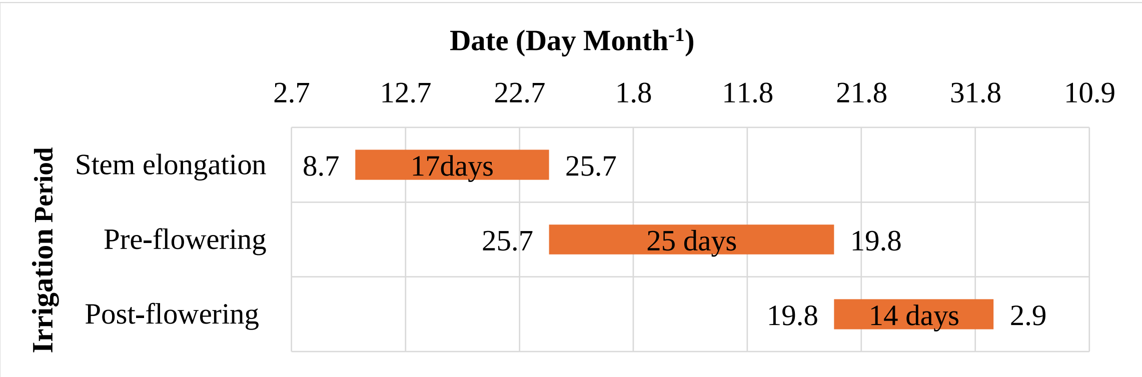

Figure 3. Irrigation period and time

Plants that had reached harvest maturity were harvested by hand on September 26, after the edge effects were removed from the plots, the grains were separated from their heads in the threshing machine. Plant height (cm), number of tables per plant (number) and number of branches per plant (number) for 10 plants randomly selected from each plot; Thousand seed weight (g), seed yield (kg da^{-1}) and oil ratio (%) were determined in each plot. The oil ratio was calculated as a percentage (%) based on dry matter by extraction method in the Soxhlet device (AOCS, 2009).

2.4. Statistical analysis

The data for the features examined in the study were made according to the Randomized Blocks Split Plots Trial Design using Variance (ANOVA) analysis, and the Least Significant Difference (LSD) test was used for the differences between the applications. Statistical analysis was performed using the MINITAB package program (Evans, 2009).

3. Results and Discussion

Statistically significant cultivar effects were recorded on plant height, number of heads per plant, seed yield and oil ratio, excluding the number of branches per plant (Table 4). The average plant height of the six safflower cultivars included in the research was measured as 44.01 cm. The cv. Olas had the longest plant height (47.30 cm). This was followed by cv. Linas, cv. Balcı and cv. Dinçer were statistically in the same group. The shortest plant height was recorded in the cv. Ayaz. The number of branches of the cultivars changed between 3.4-4.3. The average number of heads of the cultivars was 4.5. The highest value was taken from the cv. Olas. Thousand seed weights of the cultivars varied between 36.11 g (cv. Remzibey) and 41.60 g (cv. Dinçer). The highest 1000 seed weight was recorded in cv. Dinçer and cv. Linas. The seed yield of six cultivars varied between 86.70 kg da^{-1} (cv. Ayaz) and 178.85 kg da^{-1} (cv. Olas). followed by cv. Dinçer with 173.22 kg da^{-1}. The average oil ratio of cultivars was recorded as 28.58%. The highest oil ratio was detected in Olas (32.92%) and Linas (32.35%) cultivars. Fatty oil ratios of Ayaz, Dinçer and Remzibey cultivars were found to be similar (mean 25.15%) (Table 4).

Table 4. Average values and statistical groupings for seed yield and yield components.

Cultivars	PH[2] (cm)	NB (pcs $plant^{-1}$)	NH (pcs $plant^{-1}$)	TSW (g)	SY (kg da^{-1})	OR (%)
Dinçer	45.37 [A1]	3.8	4.5 [AB]	41.60 [A]	173.22 [AB]	25.25 [C]
Olas	47.30 [A]	4.3	5.4 [A]	38.21 [B]	178.85 [A]	32.92 [A]
Ayaz	37.91 [C]	3.4	4.4 [B]	38.63 [B]	86.70 [D]	25.44 [C]
Balcı	45.78 [A]	3.8	4.5 [AB]	38.92 [B]	132.83 [C]	30.79 [B]
Linas	46.04 [A]	4.0	4.3 [B]	40.76 [A]	161.39 [ABC]	32.35 [A]
Remzibey	41.68 [B]	4.2	4.2 [B]	36.11 [C]	138.38 [BC]	24.77 [C]
Mean	**44.01**	**3.9**	**4.5**	**39.03**	**145.22**	**28.58**
LSD $_{(0.05)}$	3.232	-	0.989	1.582	40.175	1.544
Irrigation Applications						
IA-1	41.77 [B]	3.8 [BC]	3.4 [B]	38.21	93.62 [C]	28.14
IA-2	42.75 [AB]	3.0 [C]	3.6 [B]	38.64	122.17 [BC]	28.77
IA-3	44.70 [AB]	3.8 [BC]	5.2 [A]	39.44	164.54 [A]	28.91
IA-4	44.41 [A]	4.4 [AB]	5.2 [A]	39.40	158.68 [AB]	28.96
IA-5	46.44 [A]	4.7 [A]	5.5 [A]	39.51	187.13 [A]	28.15
Mean	**44.01**	**3.9**	**4.5**	**39.04**	**145.22**	**28.58**
LSD $_{(0.05)}$	2.951	0.840	0.902	-	36.674	-
C	**	ns	*	**	**	**
IA	*	**	**	ns	**	ns

[1] The difference between means indicated by the same letter is statistically insignificant.
*, F-test significant at $P \leq 0.05$; **, F-test significant at $P \leq 0.01$; ns: non-significant; C: Cultivar, IA: Irrigation Applications
[2]**PH:** Plant Height, **NB:** Number of Branches, **NH:** Number of Heads, **TSW:** Thousand Seed Weight, **SY:** Seed Yield, **OR:** Oil Ratio (n=3).
The C x IA interaction was found to be statistically insignificant.

Among the irrigation applications, the highest seed yield was obtained from IA-5, followed by IA-3, IA-4 and IA-2. The lowest yield was obtained from the control application (IA-1) without irrigation. In numerous studies conducted, it has been observed that there is a high change in seed yield obtained from safflower genotypes against irrigation practices (Ghamarnia and Sephri, 2010; Omidi et al., 2012). Similarly, in our study, the effect of irrigation practices on seed yield was found to be statistically significant at the 1% level (Table 4). Drought stress significantly reduces safflower seed yield (Koutroubas and Papakosta, 2010; de Almeida Silva et al., 2023). However, it has been observed that the responses of genotypes in terms of seed yield are different, and some genotypes are not affected by drought conditions (Aeini et al., 2018). In our study, the safflower cultivars used showed differences in their responses to irrigation applications in terms of seed yield (Figure 4).

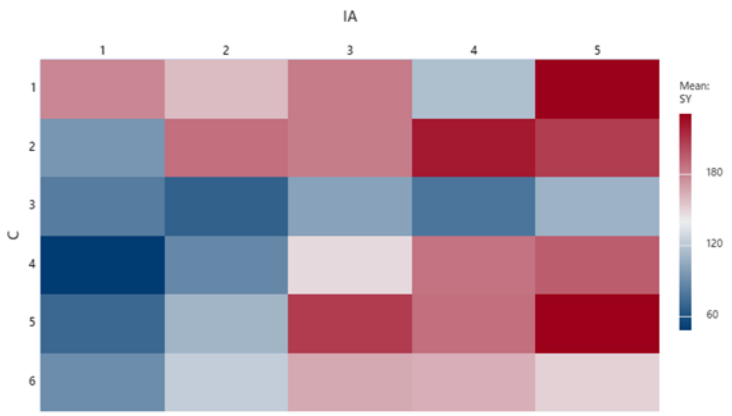

Figure 4. Responses of cultivars to irrigation applications in terms of seed yield.
(Column: Irrigation Applications, Row: Cultivars respectively, Ayaz, Dinçer, Remzibey, Balcı, Olas, Linas)

Safflower genotypes with long plant height create more primary branches, increasing seed yield. However, drought stress causes safflower plant height to shorten (Mosupiemang et al., 2022). Similarly, in our study, among the irrigation applications, the shortest plant height was taken from the control application where irrigation was not performed, and the longest plant height was recorded in IA-4 and IA-5. In safflower, first-order side branches form on the main stem, and second-order side branches form on these branches. Since heads are in both primary and secondary branches, the number of branches in safflower is a character that indirectly determines the number of heads in the plant (Sharif Moghaddasi and Omidi, 2010). Irrigation practices had an impact on the number of branches and the highest number of branches was reached in IA-5, followed by IA-4. The number of branches was the same in IA-1 and IA-3, but the least number of branches was taken from IA-2. The least number of heads was taken from the control application where irrigation was not performed, and the highest number of heads was recorded in IA-5. Although it is known that water scarcity affects all yield elements in safflower cultivation, the number of heads per plant is affected by drought (Nabipour et al., 2007; Tabib Laoghmani et al., 2019). Water scarcity, especially in the initial stages of plant development, further exacerbates this effect (Movahhady-Dehnavy et al., 2009). While water scarcity causes serious decreases in both the number of heads and the number of seeds in the head when it occurs before the flowering period of the plant (Jabbari et al., 2010). It has been reported that irrigation after the flowering period has a positive effect on seed yield and yield elements (Sharrif Moghaddasi and Omidi, 2010). One of the factors that determine the yield in field crop cultivation is the weight of one thousand seeds. For this reason, it is desired that the thousand seed weight of the plants is high (Koç, 2021). On our study, the effect of irrigation applications on the weight of 1000 seeds and seed oil ratio was found to be statistically insignificant (Table 4). However, the lowest thousand seed weight was recorded in IA-1 and IA-2 applications. It is a character that is affected by water stress per thousand seed weight. When irrigation is applied, both the root system and vegetative organs of the plants develop better, and larger seeds are produced (Wang et al., 2020). The seed size of the safflower is related to the climatic conditions experienced during the flowering period (Culpan, 2023). The research reports that drought stress does not have a significant effect on safflower seed oil ratio (Naderi et al., 2015). As can be seen in Table 4, the oil ratio of the safflower cultivars included in the study were found to be similar in all irrigation applications (Figure 5).

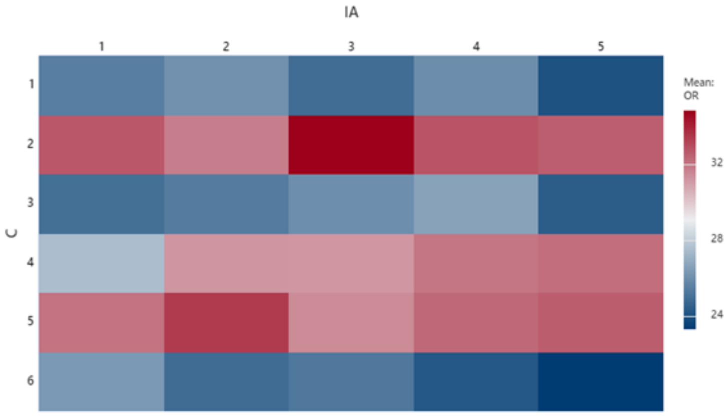

Figure 5. Responses of cultivars to irrigation applications in terms of oil ratio.
(Column: Irrigation Applications, Row: Cultivars respectively, Ayaz, Dinçer, Remzibey, Balcı, Olas, Linas)

The binary relationships between irrigation practices and the examined yield and yield components are presented in Figure 6 and Table 5. A significant positive relationship was found between irrigation applications at different development periods and NB, NH and SY at the 1% level, and with PH at the 5% level. When the binary relationships between seed yield and other yield elements evaluated in the study were examined, a very strong ($P \leq 0.01$) positive relationship was determined between PH and NB, NH, TSW, SY and OR, and between NB and NH, TSW and SY. In addition, a positive significant relationship of the 5% level was recorded between TSW and SY (Table 5) (Papageorgiou, 2022). A very strong relationship was found between irrigation practices and plant height, number of heads, thousand seed weight and seed yield. The traits examined with irrigation treatments formed two groups (A and B). The oil ratio was in a separate group (B) (Figure 7). In a study conducted by Yau (2006), the oil ratio of safflower plants that were not irrigated and whose water needs were met by natural rainfall was 30%, while this rate was determined to be 31% in irrigated conditions, and it was stated that irrigation had no effect on the oil ratio. This situation is like our results.

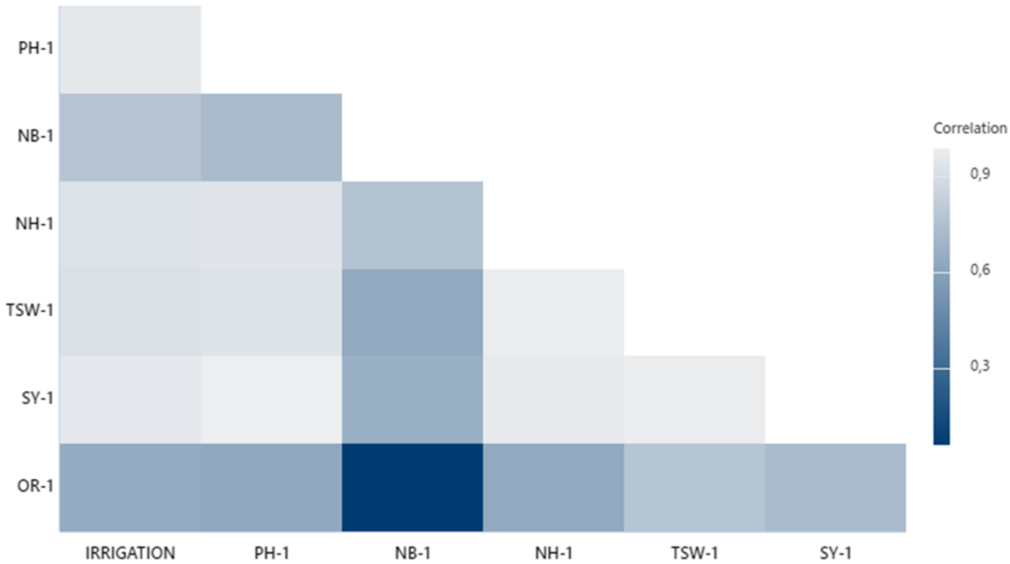

Figure 6. Bilateral relationships between irrigation applications and the examined yield and yield components.

Table 5. Correlation between irrigation applications, yield and yield components

	IA[1]	PH	NB	NH	TSW	SY	OR
IA	1.000						
PH	0.254*	1.000					
NB	0.511**	0.749**	1.000				
NH	0.459**	0.652**	0.917**	1.000			
TSW	0.175	0.343**	0.318**	0.277**	1.000		
SY	0.401**	0.714**	0.668**	0.593**	0.486**	1.000	
OR	-0.005	0.294**	0.166	0.049	0.020	0.109	1.000

*Significant at $P \leq 0.05$; **Significant at $P \leq 0.01$

[1]C: Cultivar, IA: Irrigation Applications, PH: Plant Height, NB: Number of Branches, NH: Number of Heads, TSW: Thousand Seed Weight, SY: Seed Yield, OR: Oil Ratio

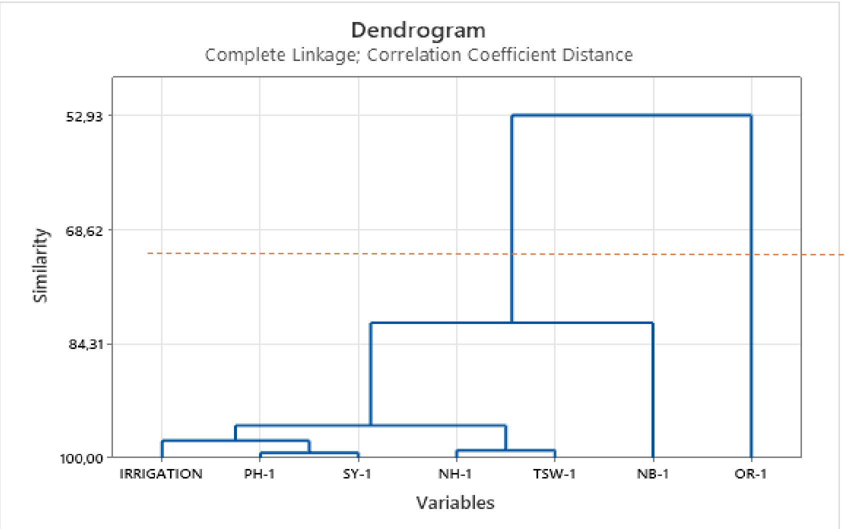

Figure 7. Dendrogram of the relationships between irrigation applications and the traits investigated.

4. Conclusion

The results suggest that irrigation during stem elongation and post-flowering stages can significantly enhance safflower yield and its components. Further studies are needed to optimize irrigation quantities under varying environmental conditions for sustainable safflower production. Specifically, determining the precise irrigation levels, frequencies, and timing to maximize water use efficiency without compromising yield is crucial. This research can serve as a baseline for developing region-specific irrigation management practices, particularly in arid and semi-arid climates where water resources are limited. Additionally, long-term studies incorporating diverse safflower genotypes and soil types could provide more robust recommendations for sustainable safflower production systems.

Declaration of Author Contributions

The authors declare that they have contributed equally to the article. All authors declare that they have seen/read and approved the final version of the article ready for publication.

Declaration of Conflicts of Interest

All authors declare that there is no conflict of interest related to this article.

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