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Research Article

Omega-3 in Dragon's head (*Lallemantia iberica* (MB) Fischer & Meyer) as effected by irrigation regimes and sowing date

Saeideh Maleki Farahani [1*], Maryam Mirdoraghi [1], Alireza Rezazadeh [2]

[1] Shahed University, Department of Crop Production and Plant Breeding, College of Agriculture, Shahed University, Tehran, Iran
[2] Shahed University, Department of Crop Protection, College of Agriculture, Shahed University, Tehran, Iran
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Abstract

In order to evaluate the effect of irrigation regimes and sowing dates on linolenic acid (Omega-3) content in dragon's head (*Lallemantia iberica*), an experiment was conducted factorial as a randomized complete block design in three replications in the research farm of Shahed University on crop year 2021–2022 in the research farm of Shahed University. The experimental treatments included: Irrigation regimes at three levels: I_{20}: Irrigation after 20% depletion of soil available water (SAW); I_{40}: An irrigation after 40% depletion of SAW; and IS_{20}: Irrigation at sowing and before flowering based on 20% depletion of SAW. The second factor was the sowing dates of autumn (November 15) and spring (March 15). The interaction effect of autumn sowing date and irrigation regime I20 produced the greatest seed yield (680.1 $kg.ha^{-1}$), harvest index (0.28), chlorophyll b content (0.457 $mg.g^{-1}$ Fw), seed number per plant (469.0), and branch number per plant (9.83). Also, the amount of linolenic acid was greater under the treatment of sowing date and irrigation regime I20, with values of 64.07% and 64.33%, respectively. A water shortage in the soil also decreased linolenic acid content under deficit irrigation treatments (IS_{20} and I_{40}) although in I_{40} it was not statistically different from I_{20}. Totally, it was clearly determined that the low temperature of autumn increased Omega-3 in the Dragon's head.

Keywords: Linolenic acid, Low irrigation, Photosynthetic pigments, Rainfed, Spring sowing

Abbreviations: SAW: Soil available water depletion; I_{20}: Complete irrigation or control; I_{40}: Low irrigation; I_{S20}: Supplementary irrigation.

Introduction

The agricultural industry is one of the most vulnerable parts of human society to climate change due to its dependence on weather and climate, and even slight changes in the regional and global climate can have a great impact on agriculture (Gudarzi, 2019). One of the consequences of climate change is its effect on plants' needs for water and, as a result, the need for irrigation in different places. This need for irrigation can be significant on a large scale in an area, especially in hot and dry areas. By affecting the water supply of the region, this phenomenon can make the management of agricultural production and the planning of water resources extremely difficult (Gudarzi, 2019). Considering the geographical location of Iran, its location in the dry climate belt of the world, and the lack of precipitation, it must be acknowledged that the occurrence of water crises is one of the main climatic characteristics of Iran (Kiani Salmi and Amini, 2018). Due to the fact that drought stress is one of the most significant non-living stresses, it is expected to limit plant growth, production, and survival in many regions of the world, and due to climate change, its intensity and spread are increasing. (Pirnajmedin and Majidi, 2022). Studies have shown that one of the most important reasons for yield reduction is drought and water stress, along with changes in rainfall and temperature trends (Pirjalili and Omidi, 2017). One of the factors that reduces photosynthesis speed under drought stress is the reduction of chlorophyll content. This is due to plant stomata closing or damage to the photosynthetic apparatus. (Sharifi Soltani *et al.*, 2022).

In recent decades, emphasis on development using environmental capabilities has been one of the most important components of the country's development planning (Mitchell, 2018). Environmental capabilities include many components, and the ability to grow and develop economic crops that are compatible with the region, such as the cultivation of oilseeds in arid and semi-arid regions of the country, is considered one of these components (Rostami Ahmadvandi *et al.*, 2020). Oilseeds are currently one of the most important crops

*Corresponding Author, Email: maleki@shahed.ac.ir

after cereals and constitute the second largest food reserve in the world (Tavassoli *et al.*, 2021).

Dragon's head, with the scientific name *Lallemantia iberica*, is an annual and herbaceous plant of the Mentha family that is cultivated in different parts of Europe, the Middle East, and especially Iran (Abdollahi and Maleki Farahani, 2019). The dragon's head plant has characteristics including: High competitiveness with weeds, high resistance to pests and diseases, low expectations in terms of nutrients, a short growth period, high adaptability to different climates, resistance to drought and salinity, and adaptability to autumn and spring sowing in rainfed conditions with the least care. This plant contains secondary metabolites, and its seeds are rich in mucilage, polysaccharides, fiber, oil, and protein (Omidi *et al.,* 2018). Currently, this plant is cultivated for seed production, oil extraction, and mucilage (Javanmard *et al.,* 2021). In addition, it has more than 30% dry oil with antioxidant properties (Amanzadeh *et al.*, 2011). The low availability of water in Iran and the unique capabilities of the dragon's head plant to adapt to Iran's climate emphasize the need to conduct comprehensive research on this plant from different perspectives (Rostami Ahmadvandi and Faghihi, 2021). The optimal sowing date of a plant is one of the important factors that should be considered in the cultivation pattern of each region. One of the best strategies to adapt to climate change is to determine the optimal sowing time in order to avoid increasing water consumption and reducing yield. This strategy can be implemented by determining the sowing date based on the pattern of temperature changes and rainfall in the future (Gudarzi, 2019).

Considering that the effects of climate change, including drought stress and temperature increases, increase the risk of producing agricultural products in drought conditions. Obviously, in order to reduce the effects of climate change, such as temperature increases and drought stress, it is necessary to implement agricultural management solutions, such as irrigation regimes, to achieve optimal yield and a suitable sowing date, so that increasing water use and decreasing yield can be avoided by adjusting the sowing date. Therefore, the present study was conducted with the aim of evaluating the effect of irrigation regimes and sowing dates on the content of linolenic acid (Omega-3) in a dragon's head (*Lallemantia iberica*).

Materials and methods

In order to evaluate the influence of irrigation regimes and sowing dates on the content of linolenic acid in dragon's head (*Lallemantia iberica*), an experiment was conducted in the form of a randomized complete block design in three replications at the research farm of the Agricultural College of Shahed University, Tehran, Iran (35 E, 55 N, altitude: 1026 m above sea level, and the average annual rainfall is 216 mm) in 2020-2021. Average temperatures and precipitation during the growing period are given in Figure 1. The experimental treatments include: The first factor, irrigation systems at three levels: 1) supplementary irrigation (irrigation in two stages, including the planting and pre-flowering stages) is based on 20% SAW (reduction of available soil water); 2) complete irrigation or control (irrigation based on 20 % SAW); and 3) low irrigation (irrigation based on 40 % SAW) is the second factor of autumn (November 15) and spring (March 15) sowing dates. To determine the physical and chemical properties of the soil, before starting the experiment, samples were randomly taken from several points of the soil at the test site at two depths of 0–15 and 15–30 cm using agar, and soil properties, including soil pH and EC, cation exchange capacity (Chapman, 1965), total soil nitrogen content by the Kjeldal method, usable phosphorus by sodium bicarbonate extraction (Olsen, 1954), usable potassium by the Helmeke and Sparks method (Helmeke and Sparks, 1996), and organic matter percentage (Nelson and Sommers, 1996), were measured (Table 1). The dimensions of the plots were set at 2 m (width) × 5 m (length). The final density of dragon's heads in the plots was considered to be 40 plants per m^2, with 25 cm intra row and 10 cm inter row respectively. During irrigation, furrow irrigation was used, and the ends of the plots were completely closed in order to prevent water from escaping. To prevent water leakage, a distance of 1 m between the main plots and repetitions was considered.

Seed yield and yield components were determined at the end of the growing season after the autumn field (June 25) and spring field (July 1) were fully mature. To determine the yield components, 10 plants were harvested from each plot, and the number of branches per plant, plant height, achene number per inflorescence, achene number per plant, number of inflorescence per plant, seed number per achene, number of seeds per inflorescence, number of seeds per plant, seed weight per plant, and 1000 - grains weight were measured. To determine the seed yield, biological yield, and harvest index, the final harvest of the crop was done manually after removing the marginal rows from a surface of 1 m^2. Afterward, the sample was placed in an oven at 65 degrees Celsius for 48 hours, weighed, and the biological yield and harvest index were calculated. The seed yield was calculated based on the weight of isolated seeds.

Photosynthetic pigments: To measure chlorophyll *a* and *b* concentrations, 10 mL of acetone (80%) was used to decompose fresh leaves (1 g). For the first step, the sample was centrifuged for five minutes at a speed of 5000–10,000 rpm. After that, the supernatant was transferred, and this procedure continued until the residue became colorless. The following formula was used to determine the chlorophyll concentration: (Arnon, 1949).

$$\text{Chl } a\ (\text{mg g}^{-1}\text{ FW}) = (12.7(\text{A } 663.6) - 2.69(\text{A } 646.6)) \times \text{V}/1000 \times \text{W}$$

$$\text{Chl } b\ (\text{mg g}^{-1}\text{ FW}) = (22.9(\text{A } 646) - 4.68(\text{A } 663.6)) \times \text{V}/1000 \times \text{W}$$

$$\text{Car}\ (\text{mg g}^{-1}\text{ FW}) = (1000\text{A } 470 - 1.8 \text{ Chl a} - 85.02 \text{ Chl b})/1.98$$

In these formulas, A, Chl a, Chl b, Car, V, and W

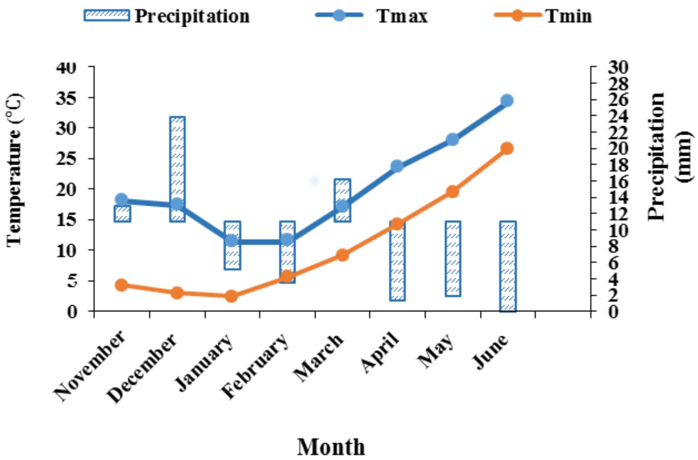

Figure 1. Average temperature and rainfall in the crop year 2021-2022

Table 1. Physical and chemical characteristics of soil at 0-30 cm depth

N (%)	K	p	Electrical conductivity	Clay	Silt	Sand	Soil texture	Depth (cm)
	(mg kg^{-1})		dS/m		%			
0.14	8788	41	5.21	12	54	34	Loamy lay	0-30

are, respectively, the optical absorption of the samples, the concentration of chlorophyll *a*, the concentration of chlorophyll *b*, the concentration of carotenoid, the final volume of acetone consumed, and the weight of fresh tissue. The sum of chlorophylls *a* and *b* were used to calculate the total chlorophyll content.

Fatty acids: By methylating fixed oil into fatty acids and using gas chromatography (GC), the fatty acid content of seeds was found. Oil samples were weighed and then treated with 3 mL of heptane solution and 2 mL of sodium hydroxide solution (0.01 M) with a shaker at 10,000 rpm for 15 s in a 5 mL screw-top test tube. Finally, a microliter syringe was used to inject 1 µl of the FAME sample into the gas chromatograph. The analysis of the fatty acid methyl esters was performed using an Agilent 7890A GC (Agilent Technologies, Inc. 2010) fitted with a flame ionization detector (FID) and a BPX capillary (part number 054980) column (50 m, 0.22 mm internal diameter, 0.2 µm film, nitrogen was the carrier gas with a head pressure of 4.136 bar, Agilent Technologies, Inc. 2010). For the first 10 minutes, the column's initial temperature was held at 165 °C and then set to rise by 1.5 degrees Celsius every minute from 165 to 200 °C. Temperatures were set to 250 C for the injector and 280 C for the detector, respectively (Barthet *et al.*, 2002).

Data analysis and calculations related to simple Pearson correlation coefficients between traits were performed with SAS (ver 9.4) and SPSS (ver 23) software, respectively, and the average of treatments was compared by LSD test at a statistical level of 5%. The graphs were drawn using Excel software.

Results and discussion

The results of the variance analysis table of the effect of irrigation regimes and sowing date on the studied traits showed that the effect of irrigation regimes on the number of seeds per plant, 1000 seed weight, seed yield, biological yield, total chlorophyll, and chlorophyll *b* were significant at the level of 1% (P≤0.01) and the traits of number of branches per plant, harvest index, chlorophyll *a*, achene number per inflorescence, carotenoid, and linolenic acid were significant (P≤0.05) (Table 2). Also, the results of this table showed that the effect of sowing date on plant height traits, achene number per inflorescence, achene number per plant, number of inflorescence per plant, seed weight per plant, seed yield, biological yield, chlorophyll *b*, and linolenic acid in the level 1% (P≤0.01) and on the traits of number of seed per inflorescence, number of seed per plant, total chlorophyll, and carotenoids were significant at the level of 5% (P≤0.05). However, the interaction effect of irrigation regimes and sowing date on the traits of the number of seeds per plant, seed weight per plant, seed yield, biological yield, harvest index, and chlorophyll *b* was significant at the 1% level (P≤0.01) and on the traits of the number of branches per plant and achene number per inflorescence, it was significant at the 5% level (P≤0.05) (Table 2).

Branch number per plant: Branching in plants is strongly influenced by environmental conditions, especially soil physical properties or drought stress; therefore, environmental conditions can change the contribution of branches to the final yield (Amiri dehahmadi *et al.*, 2020). The results show that, compared to the I40 irrigation regime with an average of 6.5 and the IS20 irrigation regime with an average of 5.5, the number of branches per plant under the interaction of the autumn sowing date and the I20 irrigation regime with an average of 9.83 has increased by 33.8% and 44.0%, respectively (Table 3). Also, the number of branches per plant in the autumn sowing

Table 2. Variance analysis of the effect of irrigation regimes and sowing date on yield and yield components and physiological traits of Dragon's head

S.O.V	DF	Mean squares								
		Branch number per plant	Plant height	Achenenumber of per inflorescence	Achene number of per plant	Inflorescence number of per plant	Seed number per achene	Seed number per inflorescence	Seed number of per plant	Seed weight per plant
Block (A)	2	0.097	109.2	0.003	3513.4	181.6	0.65	39.3	221.8	0.004
Irrigation regime (B)	2	11.76*	57.8^{ns}	7.34*	36.0^{ns}	123.1^{ns}	1.87^{ns}	11.3^{ns}	15006.0**	0.17^{ns}
(A)×(B)	4	0.84	83.7	0.54	489.2	32.1	1.14	12.6	447.7	0.02
(C)	1	1.38^{ns}	1081.1**	9.24**	39218.6**	2201.1**	0.26^{ns}	104.6*	163096.6**	3.48**
(B)× (C)	2	5.59*	112.8^{ns}	0.21^{ns}	6004.1^{ns}	59.28^{ns}	0.85^{ns}	14.5^{ns}	4096.2**	0.38**
(A)× (C)	2	0.84	9.12	0.611	2648.1	145.3	0.77	0.90	226.4	0.007
Error	4	0.43	27.62	0.241	1586.4	39.3	0.16	7.89	418.0	0.01
CV (%)		10.54	12.84	8.63	24.06	20.23	14.91	20.04	6.84	8.12

ns, * and **: no significant difference and significant at 5% and 1%, respectivel

Continue of table 2.

S.O.V	DF	Mean squares								
		1000-seeds weight	Seed yield	Yield biological	Harvest index	Chl T	Chl a	Chl b	Carotenoid	Linolenic acid
Block (A)	2	0.006	44.5	10847.24	0.001	0.004	0.011	0.0004	38.93	1.78
Irrigation regime (B)	2	2.34**	358270.2**	5267585.49**	0.005**	0.223**	0.025*	0.158**	65.77*	8.0*
(A)×(B)	4	0.11	842.0	46417.50	0.00008	0.006	0.003	0.0001	5.29	1.05
(C)	1	0.0003^{ns}	206448.1**	3382083.97**	0.00007^{ns}	0.026*	0.0061^{ns}	0.021**	33.87*	44.43**
(B)× (C)	2	0.05^{ns}	40415.9**	999604.17**	0.002**	0.001^{ns}	0.0067^{ns}	0.016**	0.185^{ns}	0.681^{ns}
(A)× (C)	2	0.21	42.0	3154.53	0.00005	0.001^{ns}	0.0067	0.0006	1.49	2.66
Error	4	0.03	477.0	11044.84	0.0003	0.0025	0.0036	0.00009	3.88	1.28
CV (%)		4.98	5.39	5.64	8.18	5.73	9.77	3.56	10.95	1.80

ns, * and **: no significant difference and significant at 5% and 1%, respectivel

Table 3. The mean comparison of the interaction of irrigation regimes and sowing date on yield and yield components and physiological traits of Dragon's head

Irrigation regime		Branch number per plant	Seed number per plant	Seed weight per plant (g)	Chl b (mg.g^{-1} Fw)	Harvest index.(%)	Biological yield (kg ha^{-1})	Seed yield (kg ha^{-1})
I_{20}	Autumn	9.83^{a}	469.0^{a}	2.08^{a}	0.457^{a}	0.285^{a}	2817.3^{a}	680.1^{a}
	Spring	5.83^{c}	218.5^{d}	0.68^{d}	0.444^{a}	0.239^{b}	2733.0^{a}	644.7^{a}
I_{40}	Autumn	6.5^{b}	385.3^{b}	1.74^{b}	0.258^{b}	0.241^{ab}	2762.0^{a}	553.7^{b}
	Spring	5.63^{c}	229.5^{d}	0.88^{d}	0.249^{b}	0.232^{b}	1049.0^{c}	195.7^{d}
I_{S20}	Autumn	5.5^{c}	327.2^{c}	1.24^{c}	0.225^{b}	0.181^{c}	1305.3^{b}	301.0^{c}
	Spring	3.73^{d}	162.5^{e}	0.86^{d}	0.031^{c}	0.223^{bc}	501.4^{d}	51.83^{e}

The means have a common letter of no significant difference with LSD test at 5% level

under the I_{20} irrigation regime with an average of 9.83 compared to the number of branches per plant in the spring sowing under the irrigation regimes of I_{20} with an average of 5.83, I_{40} with an average of 5.63, and I_{S20} with an average of 3.73 increased by 40.6, 42.7, and 3.73 percent, respectively (Table 3). During the growing period, stress adversely affected the number of branches per plant, reducing it to at least 5.5 branches per plant. The decrease in the number of branches in a plant under drought stress indicates the plant's resistance to reducing the amount of transpiration and tolerance of stress by reducing the height, a diameter of the stem, and number of secondary branches (Asghari *et al.,* 2014). Ghasemian Ardestani *et al*. (2019) stated that drought stress at the time of seed filling in the plant leads to a decrease in the yield of canola seeds by reducing the number of branches in the plant. He also stated that the number of branches in the plant increased by 44% on October 15 compared to March. In addition, in this experiment, the number of branches per plant in the spring sowing under the I_{40} irrigation regime did not have a statistically significant difference with the same attribute in the autumn sowing under the I_{S20} irrigation regime, which shows that autumn sowing can be used to reduce the amount of water consumed compared to spring sowing.

Plant height: The results of the effect of the simple sowing date on plant height showed this trait with an average of 48.66 cm (autumn sowing) has an increase of 31.8% compared to plant height with an average of 33.16 cm (spring sowing) (Figure 2A). The sowing date affects the height and growth of the plant through changes in weather factors such as temperature, day length, and soil moisture during the growth period. The length of the growth period in autumn provides enough time to use temperature, light, and moisture and increases the production of photosynthetic materials, which ultimately increases growth (Zareei Siahbidi *et al.*, 2021).

Achene number per inflorescence: The results of the effect of the simple irrigation regimes on the achene number per inflorescence showed that this trait under the I_{20} irrigation regime with an average of 6.68 compared to the I_{40} irrigation regime with an average of 5.90 and the I_{S20} with an average of 4.50 led to an 11.6 and 32.6% increase in the achene number per inflorescence, respectively (Figure 3A). Also, the results of the effect of the simple sowing date on the achene number per inflorescence showed that this trait with an average of 6.41 (autumn sowing) has an increase of 22.4% compared to the achene number per inflorescence with an average of 97.4 (spring sowing) (Figure 2B). Which was consistent with the results of Abdollahi and Maleki Farahani (Abdollahi and Maleki Farahani, 2019).

Achene number per plant: The comparison results of the simple effect of sowing dates on the achene number per plant showed that this trait, with an average of 212.19 (autumn sowing), has an increase of 43.9% compared to the achene number per plant, with an average of 118.83 (spring sowing) (Figure 2C).

Inflorescence number per plant: The results of the effect of the simple sowing date on the inflorescence number per plant showed that this trait, with an average of 42.59 (autumn sowing), has an increase of 53.2% compared to the inflorescence number per plant, with an average of 19.93 (spring sowing) (Figure 2D).

Seed number per inflorescence: The results of the effect of the simple sowing date on the seed number per inflorescence showed that this trait, with an average of 16.43 (autumn sowing), has an increase of 29.3% compared to the seed number per inflorescence with an average of 11.61 (spring sowing) (Figure 2E).

Seed number per plant: The results show that, compared to the I40 irrigation regime with an average of 385.3 and the IS20 irrigation regime with an average of 372.2, the number of seeds per plant under the interaction of the autumn sowing date and the I20 irrigation regime with an average of 469.0 has increased by 17.8% and 20.6%, respectively (Table 3). Also, the number of seeds per plant in autumn cultivation under the I20 irrigation regime with an average of 469.0 compared to the number of seeds per plant in spring cultivation under the I20 irrigation regime with an average of 218.5, the I40 irrigation regime with an average of 229.5%, and the IS20 irrigation regime with an average of 162.735, respectively 53.4%, showed an increase of 51.06% and 65.3%. The amount of seeds produced by each plant increases as irrigation water increases, whereas a decrease in irrigation water and a sudden increase in temperature cause premature aging of plant leaves. It seems that inoculation and the number of seeds per plant decrease during late sowing, which is related to unfavorable weather conditions and high temperatures. In addition, a shorter photoperiod and a shorter vegetative growth period may result in less seed production per plant.

Seeds weight: The results show that, compared to the I40 irrigation regime with an average of 1.74 and the IS20 irrigation regime with an average of 1.24, the weight of seeds per plant under the interaction of the autumn sowing date and the I20 irrigation regime with an average of 2.08 has increased by 16.3% and 40.3%, respectively (Table 3). Also, the seed weight per plant in the autumn sowing under the I_{20} irrigation regime with an average of 2.08 compared to the seed weight per plant in the spring sowing under the I_{20} irrigation regime with an average of 0.68, the I_{40} with an average of 0.88, and the I_{S20} with an average of 0.86 increased by 67.3, 57.6, and 58.6 percent, respectively. According to the observations of Rezvani moghadam and Sadeghi samarjan (2007), the reduction of water availability, which shortens the pollination period and thus reduces the number of seeds per plant, is one of the effective factors in reducing seed weight per plant. The sowing date plays an important role in increasing the yield of plants. Choosing the right planting date is one of the most important ways to achieve a high yield from crops. Early sowing dates in plants increase the durability of the leaf surface and water absorption during the critical periods between the appearance of flower buds and flowering, increase the number of seeds per unit area without reducing their weight, and lead to an increase in yield (Farnia and Moradi, 2015).

1000-seed weight: According to the results (Figure 3E), the average 1000-grain Weight in the I20 irrigation regime (4.49 g) increased by 11.3 and 7.30% compared to the I40 irrigation regime (4.16 g) and the IS20 irrigation regime (3.28 gr). Lack of water often leads to the closing of the stomata, the reduction of the number of leaves, the reduction of the produced photosynthetic materials, and the consumption of organic compounds to regulate the osmotic pressure and reduce the weight of thousands of seeds. For this reason, stress factors during plant growth, such as drought, usually reduce the amount of photosynthetic resources allocated to seeds, resulting in fewer and smaller seeds (Wang *et al.*, 2016).

Seed yield: The results show that, compared to the I40 irrigation regime with an average of 553.7 $kg.ha^{-1}$ and the IS20 irrigation regime with an average of 301.0 $kg.ha^{-1}$, the seed yield under the interaction of the autumn sowing date and the I20 irrigation regime with an average of 680.1 $kg.ha^{-1}$ has increased by 18.55% and 55.7%, respectively (Table 3). Also, the seed yield

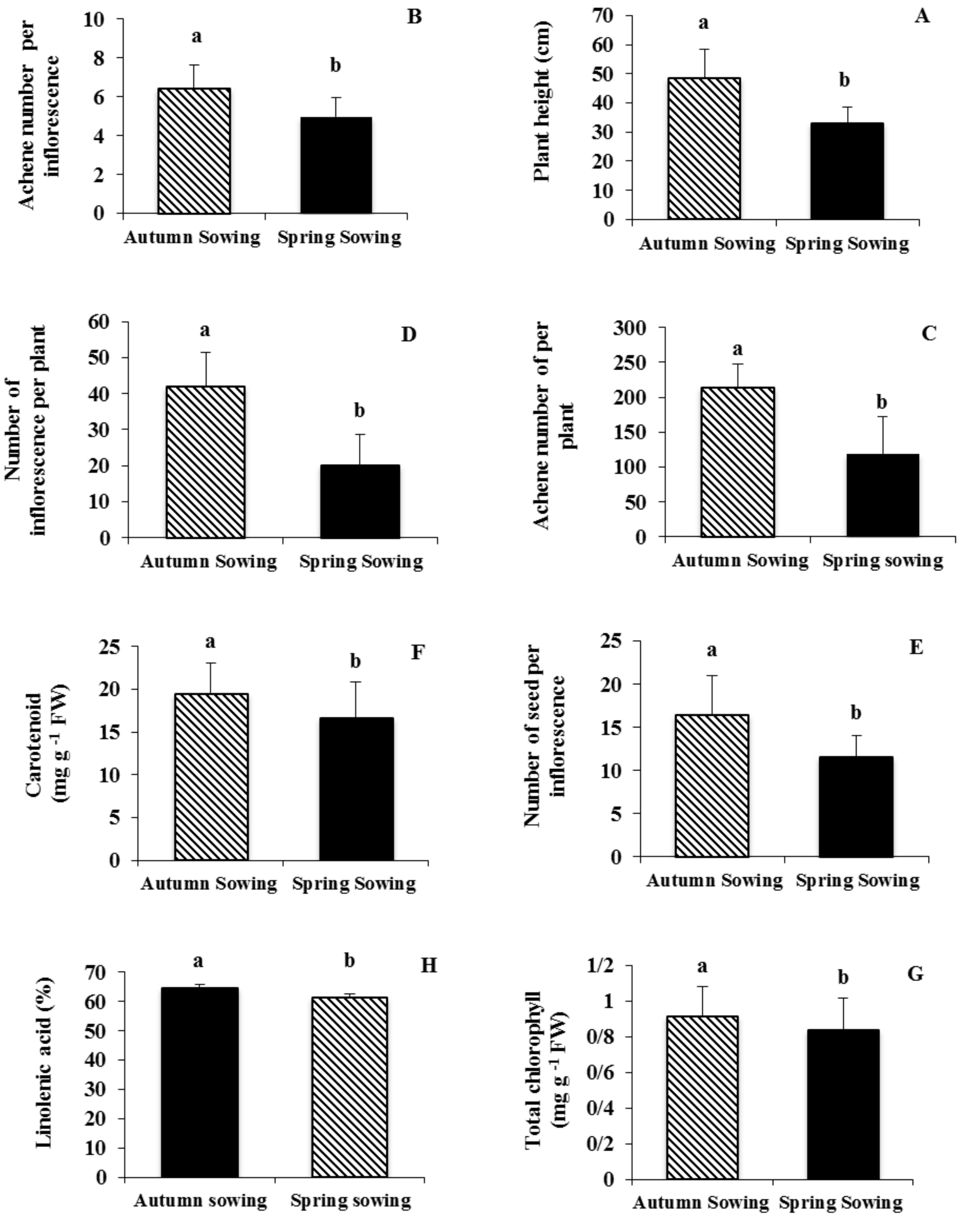

Figure 2. The simple effect of sowing date on plant height (A), achene number of per inflorescence (B), achene number of per plant (C), number of inflorescence per plant (D), number of seed per inflorescence (E), carotenoid (F), total chlorophyll (G) and Linolenic acid (H). The means have a common letter of no significant difference with LSD test at 5% level

in the autumn sowing under the I_{20} irrigation regime with an average of 680.1 compared to the seed yield in the spring sowing under the I_{20} irrigation regime with an average of 644.7, the I_{40} with an average of 195.7, and the I_{S20} with an average of 51.83 $kg.ha^{-1}$ increased by 5.2, 71.2, and 92.3 percent, respectively. In addition, the seed yield under the I_{20} irrigation regime (autumn sowing) and the seed yield under the I_{20} irrigation regime (spring sowing) did not show a statistically significant difference with each other, which indicates that the I_{20} irrigation regime (spring sowing) can, due to the decrease of autumn rains, the absence of a

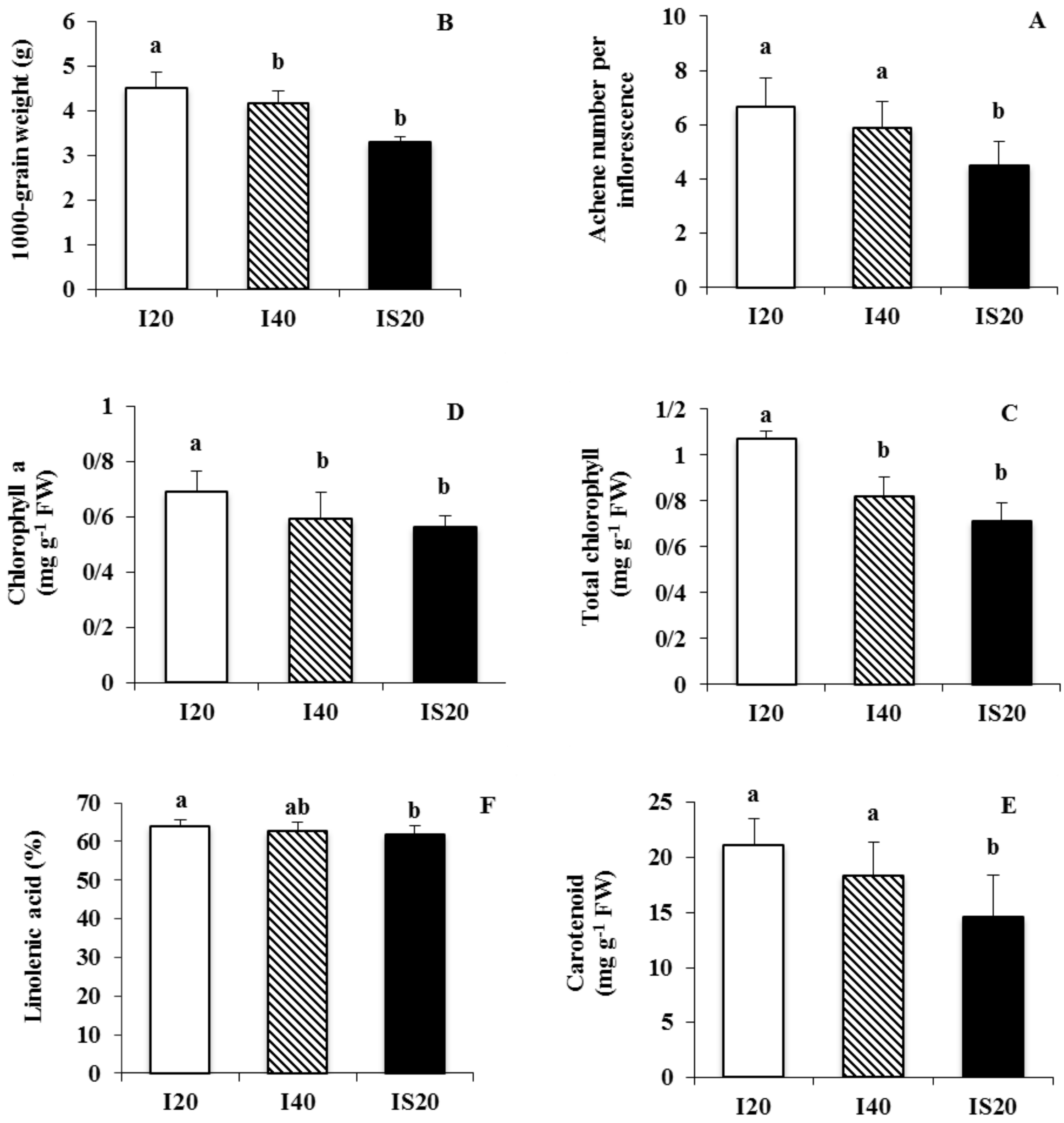

Figure 3. The simple effect of Irrigation regimes on Achene number of per inflorescence (A), 1000 grain weight (B), Total chlorophyll (C), chlorophyll *a* (D), carotenoid (E), and linolenic acid (F). The means have a common letter of no significant difference with LSD test at 5% level

statistically significant difference between autumn and spring sowing, and the reduction of the length of the growth period in spring, be used to achieve the desired yield faster (Table 3). In addition, the seed yield under the I_{20} irrigation regime (autumn sowing) and the seed yield under the I_{20} irrigation regime (spring sowing) did not show a statistically significant difference with each other, which indicates that the I_{20} irrigation regime (spring sowing) can, due to the decrease in autumn rains, the absence of a statistically significant difference between autumn and spring sowing, and the reduction of the length of the growth period in spring, be used to achieve the desired yield faster (Table 3). The effect of moisture stress on the reproductive stages of the plant is related to the reduction of flower fertility and the reduction of the transfer of synthesized materials to the destination (seeds), which ultimately leads to a decrease in the weight of one thousand seeds and the production of seeds per unit area (Gharechaei *et al.*, 2019).

Biological yield: The results show that, compared to the I40 irrigation regime with an average of 2762.0 kg.ha^{-1} and the IS20 irrigation regime with an average of 1305.3 kg.ha^{-1}, the biological yield under the interaction of the autumn sowing date and the I20 irrigation regime with an average of 2817.73 kg.ha^{-1} has increased by 1.9% and 53.6%, respectively (Table 3). Also, the biological yield in the autumn sowing under the I_{20} irrigation regime with an average of 2817.73 kg.ha^{-1} compared to the seed yield in the spring sowing under the I_{20} irrigation regimes with an average of

2733.0, the I_{40} with an average of 1049.05, and the I_{S20} with an average of 501.40 kg.ha^{-1} increased by 3, 62.7 and 82.2 percent, respectively. Accumulation of solutes under low water conditions leads to reduction or inhibition of aerial part growth because the synthesis of compatible solutes and their accumulation consume a significant amount of energy (Lisar *et al.,* 2012). In the Naservafaei *et al*. experiment, the decrease in water availability for the plant led to a decrease in photosynthetic pigments and, as a result, a decrease in photosynthesis and dry matter in the dragon's head (Naservafaei *et al.,* 2021). This issue was completely noticeable in plant growth and yield and in the components of seed yield as constituent components of the biological yield of the plant. By delaying the planting date, the amount of dry matter will decrease when faced with heat stress at the end of the season. This problem reduces the production of dry matter by reducing the length of growth periods due to high temperatures.

Harvest index: The results show that, compared to the I40 irrigation regime with an average of 0.241% and the IS20 irrigation regime with an average of 0.181%, the harvest index under the interaction of the autumn sowing date and the I20 irrigation regime with an average of 0.285% has increased by 15.4% and 36.4%, respectively (Table 3). Also, the harvest index in the autumn sowing under the I_{20} irrigation regime with an average of 0.285 % compared to the harvest index in the spring sowing under the I_{20} irrigation regime with an average of 0.239 the I_{40} with an average of 0.232 and the I_{S20} with an average of 0.223 % increased by 16.1, 18.5 and 21.7%, respectively. Karimi Jalilehvandi *et al*. stated that the changes in day length and relative temperature of the plant make the plant a suitable opportunity to grow and are a reason for the increase in harvest index, a thousand seed weight, and seed yield in autumn sowing compared to spring sowing (Karimi Jalilehvandi *et al.,* 2020). Considering that the lack of moisture in the stages of seed formation causes a decrease in the production of photosynthesis to fill the seeds, the harvest index decreases (Amiri *et al.,* 2020).

Photosynthetic pigments: Another physiological trait affected by drought stress is the chlorophyll and carotenoid content of leaves. Some plants maintain their amount of chlorophyll during drought stress, and in others, the amount of chlorophyll decreases (Afshar Mohamadian *et al.,* 2019).

Chlorophyll *a* According to the results (Figure 3E), the average Chlorophyll *a* concentration in the I20 irrigation regime (0.688 mg.g^{-1} Fw) increased by 13.8 and 18.02% compared to the I40 irrigation regime (0.593 mg.g^{-1} Fw) and the IS20 irrigation regime (0.564 mg.g^{-1} Fw).

Chlorophyll *b* The results show that, compared to the I40 irrigation regime with an average of 0.258 mg.g^{-1} Fw and the IS20 irrigation regime with an average of 0.258 mg.g^{-1} Fw, the chlorophyll b under the interaction of the autumn sowing date and the I20 irrigation regime with an average of 0.457 mg.g^{-1} Fw has increased by 15.4% and 36.4%, respectively (Table 3). Also, the Chlorophyll *b* in the autumn sowing under the I_{20} irrigation regime with an average of 0.457 mg.g^{-1} Fw compared to the Chlorophyll *b* in the spring sowing under the I_{20} irrigation regime with an average of 0.444 mg.g^{-1} Fw the I_{40} with an average of 0.249 mg.g^{-1} Fw and the I_{S20} with an average of 0.031 mg.g^{-1} Fw increased by 2.8, 45.5, and 93.2 %, respectively. Chlorophyll *b* under the I_{40} irrigation regime (autumn and spring sowing) and chlorophyll *b* under the I_{S20} irrigation regime (autumn sowing) did not show a statistically significant difference with each other (Table 3).

Total chlorophyll: According to the results (Figure 2G), there was an 8.3% increase in the total Chlorophyll levels in the autumn sowing (mean of 0.913 mg.g^{-1} Fw) compared to the spring sowing (mean of 0.837 mg.g^{-1} Fw). Also, the average carotenoid concentration in the I20 irrigation regime (1.07 mg.g^{-1} Fw) increased by 22.7 and 33.6% compared to the I40 irrigation regime (0.827 mg/g FW) and the IS20 irrigation regime (0.710 mg.g^{-1} Fw) (Figure 3C).

Carotenoid: According to the results (Figure 2F), there was a 14.1% increase in the carotenoid levels in the autumn sowing (mean of 19.37 mg.g^{-1} Fw) compared to the spring sowing (mean of 16.63 mg.g^{-1} Fw). Also, the average carotenoid concentration in the I20 irrigation regime (21.13 mg.g^{-1} Fw) increased by 13.2 and 31.2% compared to the I40 irrigation regime (18.33 mg.g^{-1} Fw) and the IS20 irrigation regime (14.53 mg.g^{-1} Fw) (Figure 3E). According to the report by Naservafaei *et al*. the concentration of photosynthetic pigments (a, b, total, and carotenoids) in the leaves of dragon's head plants decreased with the decrease in the amount of water available to the plant (Naservafaei *et al.,* 2021). Since the interaction of chlorophylls with chloroplast proteins decreases during drought stress, the decrease in chlorophyll concentration may be due to the degradation of chlorophylls (Attarzadeh *et al.,* 2020). In the conditions of drought stress, the chlorophyll concentration decreases with the damage to the chloroplasts by active oxygen species; apparently, in the conditions of mild stress, the decrease in the amount of photosynthesis of the plant is caused by the closing of the stomata, but in the conditions of severe stress, this closing of the stomata increases the mesophyll resistance, and the effect of the tension on the thylakoid membrane is intensified (Mustafavi and Jalilian, 2019). Due to exposure to high temperatures and a delay in sowing, the growth rate of the plant increases and the length of the phenological stages decreases. Due to exposure to high temperatures and a delay in sowing, the growth rate of the plant increases and the length of the phenological stages decreases. As a result, it prevents the growth of different plant parts and reduces the production of photosynthetic materials (Ahmadi and Maleki Farahani, 2021). Carotenoids absorb high energies from short waves in drought-stress conditions.

Table 4. Correlation coefficients of studied traits

	Branch number per plant (1)	Plant Height (cm) (2)	Achene number per inflorescence (3)	Achene number per plant (4)	Inflorescence number per plant (5)	Seed number per achene (6)	Seed number per inflorescence (7)	Seed number per plant (8)	Seed weight per plant (g) (9)	1000-grain Weight (g) (10)	Seed yield (kg ha-1) (11)	Biological Yield (kg ha-1) (12)	Harvest index (%) (13)	Total chloroph ll (mg g $^{-1}$ FW) (14)	Chlorophyll *a* (mg g $^{-1}$ FW) (15)	Chlorophyll *b* (mg g $^{-1}$ FW) (16)	Cartenoid (mg g $^{-1}$ FW) (17)	Linolenic acid (%) (18)
1	1																	
2	0.315^{ns}	1																
3	0.781^{ns}	0.616^{ns}	1															
4	0.382^{ns}	0.801^{ns}	0.618^{ns}	1														
5	0.310^{ns}	0.736^{ns}	0.777^{ns}	0.743^{ns}	1													
6	0.819*	0.447^{ns}	0.787^{ns}	0.168^{ns}	0.374^{ns}	1												
7	0.621^{ns}	0.688^{ns}	0.784^{ns}	0.928**	0.799^{ns}	0.364^{ns}	1											
8	0.509^{ns}	0.783^{ns}	0.869*	0.887*	0.935**	0.441^{ns}	0.931**	1										
9	0.547^{ns}	0.832*	0.798^{ns}	0.966**	0.813*	0.400^{ns}	0.956**	0.957**	1									
10	0.641^{ns}	0.035^{ns}	0.752^{ns}	0.006^{ns}	0.329^{ns}	0.736^{ns}	0.248^{ns}	0.386^{ns}	0.247^{ns}	1								
11	0.753^{ns}	0.438^{ns}	0.900*	0.312^{ns}	0.688^{ns}	0.868*	0.571^{ns}	0.668^{ns}	0.527^{ns}	0.775^{ns}	1							
12	0.760^{ns}	0.521^{ns}	0.908*	0.327^{ns}	0.666^{ns}	0.923**	0.550^{ns}	0.665^{ns}	0.548^{ns}	0.766^{ns}	0.986**	1						
13	0.922**	0.185^{ns}	0.737^{ns}	0.360^{ns}	0.195^{ns}	0.688^{ns}	0.552^{ns}	0.460^{ns}	0.517^{ns}	0.721^{ns}	0.597^{ns}	0.607^{ns}	1					
14	0.836*	0.177^{ns}	0.844*	0.207^{ns}	0.511^{ns}	0.804^{ns}	0.528^{ns}	0.548^{ns}	0.421^{ns}	0.849*	0.940**	0.896*	0.742^{ns}	1				
15	0.979**	0.356^{ns}	0.828*	0.403^{ns}	0.442^{ns}	0.834*	0.669^{ns}	0.581^{ns}	0.574^{ns}	0.648^{ns}	0.848*	0.838*	0.848*	0.900*	1			
16	0.625^{ns}	0.105^{ns}	0.800^{ns}	0.131^{ns}	0.581^{ns}	0.676^{ns}	0.433^{ns}	0.543^{ns}	0.344^{ns}	0.887*	-0.906*	0.845*	0.576^{ns}	0.946**	0.718^{ns}	1		
17	0.589^{ns}	-0.379^{ns}	0.409^{ns}	-0.363^{ns}	-0.141^{ns}	0.594^{ns}	-0.084^{ns}	-0.058^{ns}	-0.149^{ns}	0.869*	0.523^{ns}	0.500^{ns}	0.683^{ns}	0.715^{ns}	0.549^{ns}	0.695^{ns}	1	
18	0.575^{ns}	0.754^{ns}	0.891*	0.702^{ns}	0.943**	0.631^{ns}	0.830*	0.921**	0.822*	0.458^{ns}	0.856*	0.847*	0.405^{ns}	0.702^{ns}	0.693^{ns}	0.684^{ns}	0.049^{ns}	1

ns, * and **: no significant difference and significant at 5% and 1%, respectively

They convert singlet oxygen to triplet oxygen and then act as antioxidants by capturing the oxygen radicals produced. Mild water deficiency causes an increase in the amount of carotenoids, while severe water deficiency causes a decrease in the amount of carotenoids (Naservafaei *et al.,* 2021). In addition, the results of this research showed that carotenoid levels increased and decreased under the I_{40} irrigation regime compared to the I_{S20} and I_{20} regimes, respectively. Considering that carotenoids play an important role in modulating the effects of drought stress in plant organs (Azimi, 2020), the increase of carotenoids under the I_{40} irrigation regime compared to the I_{S20} irrigation regime indicates their tolerance to drought stress.

Fatty acid: There is a long history of dragon's head cultivation in the semi-arid and arid regions of Iran. (Mohammadghasemi *et al*., 2021). Among the fatty acids present in the oil are unsaturated acids (e.g., oleic, linoleic, and linolenic acids) and saturated acids (e.g., palmitic and stearic acids) (Zamani *et al.,* 2022). There are many uses for dragon's head oil, which is due to its high linolenic acid content. Although its low yield discourages farmers from cultivating it, its high linolenic acid content makes up for it (Amanzadeh *et al.*, 2011).

In the present study, the results of the effect of the simple sowing date showed that with the increase in the length of the growing period (autumn sowing), the fatty acid linolenic acid had an average of 64.39% compared to linolenic acid in the conditions of decreasing the length of the growing period (spring sowing) with an average of 25. 61%, increased by 4.8% (Figure 2H). The researchers found that the highest linolenic acid content was 65.362% in dragon's head plant under winter sowing and the lowest was 54.651% in spring sowing (Mohammadghasemi *et al.,* 2021). However, more detailed investigations showed that the date of sowing usually plays a role in increasing linolenic acid, but the effect of irrigation regimes was more effective on fatty acids due to climatic changes and water shortages. Therefore, linolenic acid increased by 2.3% and 3.5%, respectively, under irrigation regime I20 with an average of 64.07% compared to I40 with an average of 62.59 and IS20 with an average of 61.8% (Figure 3F). The amount of linolenic acid in the I_{40} irrigation regime did not show a statistically significant difference with the I_{20} and I_{S20} irrigation regimes. This result indicates that due to the increase in temperature, decrease in rainfall, and lack of water, the I_{40} irrigation regime can be used as the most favorable irrigation regime under climate change conditions for the productivity of linolenic acid, the most essential fatty acid in dragon's head. Paravar *et al*. stated that with the increase of irrigation intervals from I30 to I90, the content of the fatty acid linolenic acid (LNA) decreased (Paravar *et al.,* 2021). The cytosol organelle in cells is responsible for the synthesis of the fatty acid linolenic acid. So, when there isn't enough water or there's a drought, the transfer of fatty acids from one organelle to another has an effect on fatty acids (Paravar *et al.,* 2021).

Correlation coefficient: One of the indicators for evaluating the degree of relationship between traits is determining correlation coefficients. The results of the correlation between studied traits and seed yield showed that seed yield was correlated with biological yield ($r = 0.986^{**}$), total chlorophyll ($r = 0.940^{**}$), chlorophyll *b* ($r = 0.906^{*}$), number of achene in the inflorescence ($r = 0.900^{*}$), number of seeds in the achene ($r = 0.868^{*}$), linolenic acid ($r = 0.856^{*}$), and chlorophyll *a* ($r = 0.848^{*}$) and has a positive and significant correlation (Table 4). One of the important factors in the growth and development of plants is the rate of photosynthesis. Since leaves have a high chlorophyll content, they are more effective at absorbing light and facilitating photosynthesis. As a result, both seed yield and photosynthesis increase (Fazeli *et al.,* 2015). Vaezi Rad *et al*. also showed that there is a positive correlation between the amount of chlorophyll and seed yield (Vaezi *et al.,* 2009). Based on the results of previous studies, linolenic acid can be considered one of the important factors for increasing seed yield in high-yielding rapeseed cultivars. Because linolenic acid is necessary to increase the photosynthetic activity of rapeseed and the development of pollen grains (Mostafavi-Rad *et al.,* 2013).

Conclusion

Due to climate changes, including temperature increases and rainfall decreases, low irrigation regime planning is one of the most important tools for optimizing water consumption to achieve optimal performance in arid and semi-arid regions of Iran .The results of the present study showed that the irrigation regime of I_{20} in autumn and spring improved all studied traits. In addition, the increase in all traits was more evident in the autumn sowing. Also, seed yield under the I_{20} irrigation regime (autumn sowing) and seed yield under the I_{20} irrigation regime (spring sowing) did not show a statistically significant difference with each other, which indicates that the I_{20} irrigation regime (spring sowing) can reduce rainfall due to the autumn sowing, and the lack of a statistically significant difference between autumn and spring sowing and reducing the length of the growth period in spring should be used to achieve the desired yield faster. However, due to the importance of investigating irrigation regimes in the current conditions of Iran, which is facing climate changes such as drought, increasing temperature, decreasing rainfall, and ultimately water shortage, and on the other hand, maintaining unsaturated fatty acids such as linolenic acid in dragon's head oilseed under climate changes in the future, in autumn sowing conditions, it can be concluded that the I40 low irrigation regime is the optimal irrigation regime following the I20 regime. Due to the increased drought stress, all studied traits decreased under both the I40 and IS20 irrigation regimens; however, the decrease was less under the I40 irrigation regime. In addition, the I_{40} irrigation regime is optimally effective in reducing water consumption by increasing the length of the growth period and subsequently increasing the efficiency of resource use, which led to an increase in all studied traits after the full I_{20} irrigation regime. In addition to this, given the increase in the content of linolenic acid in the conditions of autumn cultivation and the I_{40} irrigation regime and the lack of statistically significant differences with the I_{20} and I_{S20} irrigation regimes, respectively, it can be concluded that the I_{40} irrigation regime is used to improve linolenic acid in conditions of water shortage and non-water shortage to save water consumption. Therefore, in addition to recommending that farmers grow dragon's heads as a drought-tolerant plant under the I_{40} low irrigation regime and an earlier sowing date in arid and semi-arid regions of Iran, more studies should be conducted to confirm the mentioned cases.

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