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Growth Pattern Analysis of Winter Sown Safflower (*Carthamus tinctorius* L.) Due to Variation of Sowing Time

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ABSTRACT

Safflower, renowned for its versatility in applications such as edible oil production, industrial uses, and potential health benefits, holds significance in global agriculture owing to its temperature tolerance and utility in crop rotation. This study aimed to investigate the impact of different winter season sowing times on diverse growth parameters of safflower. The research, comprising three replications and involving two distinct safflower genotypes (Olas and Linas), examined four distinct sowing times between October 30 and December 14, spaced 15 days apart. Parameters evaluated included Leaf Area Index (LAI), Relative Growth Rate (RGR), Net Assimilation Rate (NAR), Crop Growth Rate (CGR), and Total Dry Matter (TDM). The findings revealed that early sowing time is advantageous across several parameters, particularly in total dry matter accumulation, except the net assimilation rate. Early sown plants exhibited higher values for leaf area index, crop growth rate, dry matter accumulation, and net assimilation rate. Conversely, late-sown plants displayed a higher partial growth rate, influenced by factors such as shorter daylight duration and a lower leaf area index. In consideration of these comprehensive evaluations, the conclusion is drawn that the choice of safflower sowing time should hinge on a meticulous assessment of specific growth parameters of interest. The optimal sowing time should align with the traits under scrutiny, thus maximizing the overall performance and potential yield of the crop.

Keywords: crop growth and development, growth parameters, safflower, sowing.

INTRODUCTION

It is estimated that the impact of global climate change, whose impact is increasing every year, will be felt more in Turkey. Agricultural drought, which is likely to occur due to global climate change, will create challenging effects on feeding the increasing population and increasing and sustaining productivity. Safflower, which is supported by the state to fill the edible oil deficit in Turkey, has been increasingly included in crop rotation recently. Therefore, it becomes more important to have information about the growth pattern of the safflower plant.

Safflower (*Carthamus tinctorius* L.) is a versatile small oilseed crop that can offer various benefits to rain-fed grain-based cropping systems due to its tolerance to cold, drought, salinity, and reduced input needs (Öztürk et al., 2008; Ebrahimi et al., 2017). This annual crop can be grown in arid, semi-arid and rain-fed conditions, thanks to its deep root system and xerophytic characteristics (Johnston et al., 2002; Dordas and Sioulas, 2008). Several studies have shown that safflower can be grown as a winter crop in regions with moderate temperatures or as a spring crop in cooler regions (Koutroubas et al., 2004; Yau, 2007).

Analysing growth patterns not only sheds light on how plants accumulate dry matter but also unveils factors that can influence their productivity. It enables us to determine the distribution and accumulation of dry matter in the vegetative and generative organs, derived from the photosynthetic assimilation process, from emergence to maturation. Conducting studies on these aspects would be highly advantageous, particularly for providing plant breeders with appropriate models of plant growth and development, facilitating the development of high-yielding varieties.

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The plant growth analysis has become increasingly significant, particularly in controlled conditions, as it offers valuable insights into the physiological aspects of plant breeding (Fourcaud et al., 2008). It has been reported that through these analyses, determining the optimal planting time and plant density becomes feasible, leading to enhanced yield and quality when accompanied by timely irrigation and fertilization practices (Abbas et al., 2019). The determination of the optimal sowing time relies on the temperature and humidity conditions specific to the area. Moreover, timely sowing enhances grain retention in the field, leading to increased seed yield and high-quality oil production. Although several research have evaluated the adaptability of the safflower plant in Türkiye and in the world (Steberl et al., 2020; Culpan, 2023; Kamle et al., 2023; Yılmaz et al., 2023), comprehensive research focusing on its growth and development period remains scarce. Furthermore, there is a limited understanding of the physiological growth and development patterns exhibited by safflower plants. So that, this research was conducted to determine the effects of planting time on the growth parameters of the safflower plant, considering the effects of cultivation techniques on the growth parameters of the safflower plant.

MATERIAL AND METHODS

Experimental Area

The study was conducted at the Faculty of Agriculture, Ondokuz Mayıs University, Samsun (41°37.49'N, 35°36'30"E), in winter season of two consecutive growing seasons (2018, 2019). Soil analysis of the experimental area indicated a clayey soil texture, with clay content comprising 47.5% of the soil composition. The pH level of the soil was neutral (pH 7). Moreover, the soil exhibited high levels of phosphorus (293 ppm) and potassium (10.3 ppm), while the organic matter content was relatively low (2.71%).

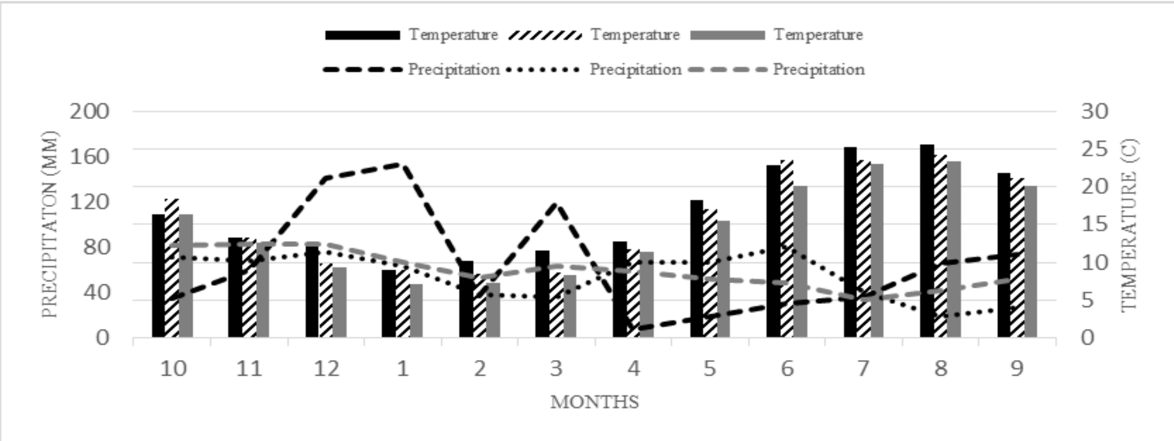


Figure 1. The average monthly temperature and precipitation in Exp I (2017-2018), Exp II (2018-2019) and long-term average (last 55 years)

The monthly temperature average in both experimental years is higher than the average for the long term. In the first year of the experiment, the average temperature in all months except November, December and January was higher than the monthly average temperature in the second year. In addition, the monthly average temperature in May, June and July, during the flowering, seed setting and maturation periods, is higher than the monthly average temperatures in other growth and development periods (Figure 1). The total amount of precipitation in the 2nd year is higher in all other months except December, January, and March. The amount of precipitation in one year in April, May, June and July, which includes the flowering, seed setting and harvest periods, is less than the second year and the average long-term. The amount of precipitation in the 2nd year of the same period is higher than the long-term average (Figure 1).

Plant material

Olas and Linas safflower varieties were used as plant material. For the first year of the experiment, the experimental plots were fertilized with Diammonium phosphate (DAP) fertilizer at a rate of 100 kg ha-1. DAP is a two-nutrient fertilizer. It contains 18% nitrogen (N) and 46% phosphorus (P) as P_2O_5. Since its nitrogen content is in ammonium (NH4) form, it is particularly effective in the first development stages of plants. In the second year, during the stem elongation stage of the safflower plants, ammonium nitrate (33% N) fertilizer was applied. Chemical pesticide containing the active ingredients Cypermethrin and Thiacloprid against broad bean (*Tropinota hirta*), aphid (*Uroleucon Compositae*) and spittlebug diseases was applied at a dose of 400 ml ha-1 during the stem elongation, branching and flowering periods.

Method

The experimental design employed a randomized complete block design with three replications. Each experimental plot consisted of five rows, measuring 3 meters in length, with a row spacing of 40 cm and 10 cm between individual plants. Varieties were assigned to the main plots, while sowing dates (October 30th, November 14th, November 29th, and December 14th) were assigned to the sub-plots.

Plant Sampling and Measurements

To analyze the plant growth pattern, a total of 10 plants were sampled from each block at six distinct stages of the developmental process, (emergence, rosette, stem elongation, branching, flowering, and maturation). The plants were individually dried in paper bags at a temperature of 83°C for 48 hours using an oven. Following the drying process, the dry matter weights were determined by weighing them on a scale with a precision of 0.01 g. The quantitative analysis of plant growth parameters and the calculation models employed in this study were based on previous works by Uzun (1997) and Hunt et al. (2002).

Leaf Area Index (LAI) = LA/SA; Relative Growth Rate (RGR) = 1/W/(dW/dt); Net Assimilation Rate (NAR) = (1/LA) x (dw/dt); Crop Growth Rate (CGR) = (1/SA) x (dw/dt); A: Leaf area; dw: Dry matter increase; dt: Time difference; SA: Ground Area.

Statistical analysis

A homogeneity test was performed on the data collected from observations and measurements. Then, analysis of variance (ANOVA) was conducted using the JMP 16.1 statistical program. Based on the significance of the ANOVA, the groupings between the means were made using the Tukey multiple comparison tests ($\alpha = 0.01$).

RESULTS AND DISCUSSION

Leaf area index (LAI). The variance analysis results indicate a statistically significant impact of the interaction between year and variety on the leaf area index across all development periods. Furthermore, it was observed that the interactions involving sowing date (year x sowing date, variety x sowing date and year x variety x sowing date) also significantly influenced the leaf area index throughout all developmental stages (Table 1).

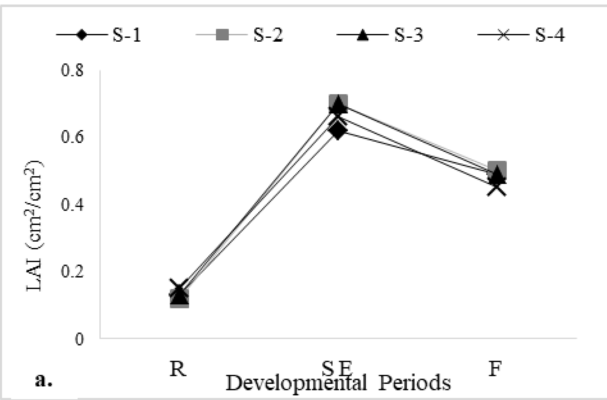
Significant variations in the average leaf area index were observed across developmental stages, with measurements of 0.135, 0.673, and 0.488 cm^2 cm^{-2}. Notably, a comparative analysis between the Linas and Olas cultivars unveiled substantial differences. The leaf area index of the Linas variety (0.138, 0.675, and 0.488 cm^2 cm^{-2}, respectively) was found to be higher than that of the Olas variety (0.128, 0.670, and 0.483 cm^2 cm^{-2}, respectively) during the rosette, stem elongation, and flowering periods (Figure 2).

The analysis revealed a rapid increase in leaf area for both varieties throughout the entire growing season, peaking at the stem elongation phase across all four sowing dates. Subsequently, a decline in leaf area was observed in the subsequent developmental period. Across the rosette, stem elongation, and flowering stages, the first sowing time consistently yielded the highest leaf area index in all three development periods (0.15, 0.69 and 0.52 cm^2 cm^{-2}, respectively) (Figure 2).

The leaf area index serves as a crucial determinant of plant productivity and is widely used for evaluating photosynthetic efficiency, encompassing key factors like light interception and light use efficiency (Hunt, 1982; Baret and Vintilă, 2003 quoted by Petcu et al., 2011). Additionally, assessing the leaf area index is vital due to its role as a reliable indicator of both the plant's photosynthetic capacity and the level of dry matter accumulation. Various studies on safflower plants have reported diverse ranges of leaf area index values. Notably, the rosette period exhibits values between 0.3 and 1.0 cm^2/cm^2, the flowering period ranges from 2.5 to 4.0 cm^2 cm^{-2} (Moatshe et al., 2020), and the stem elongation period is reported to be 0.4 cm^2 cm^{-2} (Attia et al., 2011). The present study aligns with prior safflower investigations, indicating consistency in the measured leaf area index values.

The leaf area index is a trait influenced by ecological factors, exhibiting variations in values across developmental phases due to differences in temperature, sunshine duration, relative humidity, and precipitation levels between years. The quantity of rainfall holds significance during plant development, contributing to the increase in leaf area index by fostering greater leaf number and expanded leaf area. Notably, in the second year of the study, precipitation levels and the leaf area index during the months corresponding to the stem elongation and flowering periods (April and May) were observed to be higher compared to the first year (Table 1).

The plant's genetic structure plays a pivotal role in influencing its growth and development, with environmental conditions establishing the boundaries of this effect. Consequently, when assessing plant development periods, it is crucial to consider both the genetic makeup and environmental factors. In this study, the evaluation of two safflower varieties revealed distinctive patterns: the Linas variety exhibited a higher leaf area index during the rosette stage, whereas the Olas variety demonstrated a higher leaf area index in the stem elongation and flowering stages. This underscores the significance of understanding the interplay between genetic traits and environmental conditions in comprehending plant development dynamics. Previous research, as reported by Hassan et al. (2015), has noted variations in the leaf area index of safflower planted in winter across different periods. In the current study, the planting time was found to have a significant impact on the leaf area index during the rosette, stem elongation, and flowering periods. Notably, early seeding, particularly during the second sowing date, resulted in a substantial increase in the leaf area index. Conversely, delaying the sowing date affected plant growth by constraining the elongation and expansion of leaf cells, leading to a decrease in the leaf area index. Additionally, the lower leaf area index in late-sown plants can be attributed to factors such as reduced sunshine exposure and a lower accumulation of growth degree days.



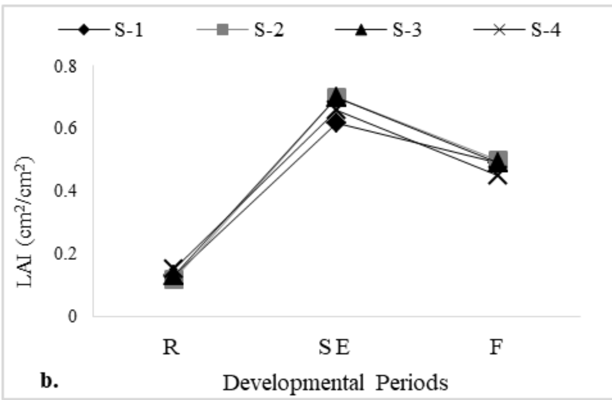


Figure 2. Effects of different sowing dates on LAI of two safflower varieties at different growth stages. (a) Olas, (b) Linas. S-1 = October 30th; S-2 = November 14th; S-3 = November 29th; S-4 = December 14th; R = Rosette; SE = Stem Elongation; F = Flowering.

Relative growth rate (RGR). Significant effects were observed in the relative growth rate across all development periods, except for the flowering period, where the year effect was not statistically significant. Although the variety did not independently influence the relative growth rate in all evaluated periods, the year x variety interaction was found to be statistically significant during the flowering period. Moreover, the impact of the sowing date was significant throughout all developmental periods, with the interaction effect of year x sowing date proving significant in all periods except for the flowering stage. Additionally, the cultivar x sowing date interaction demonstrated significance during the rosette and flowering periods. Notably, the triple interaction of year x cultivar x sowing date was determined to be significant across all developmental periods (Table 1).

A decline in relative growth rate was observed in both safflower varieties from rosette formation to flowering. Specifically, the relative growth rate was 28.0, 14.7 and 7.2 mg $g^{-1}day^{-1}$ in the Olas variety and 27.4, 14.9, and 7.1 mg $g^{-1}day^{-1}$ in the Linas variety during the rosette, stem elongation, and flowering periods. Analyzing the sowing times revealed that the highest relative growth rate occurred on the first sowing date during the rosette and flowering periods (29.7 and 7.9 mg $g^{-1}day^{-1}$, respectively), while it occurred on the fourth sowing date during the stem elongation period (19.5 mg $g^{-1}day^{-1}$) (Figure 3).

In terms of the interaction between variety and sowing time, the highest relative growth rate was observed during specific periods. For the Olas variety, it occurred in the rosette period on the 3rd sowing date (31.6 mg $g^{-1}day^{-1}$), during the stem elongation period on the 4th sowing date (19.3 mg $g^{-1}day^{-1}$), and in the flowering period on the 1st sowing date (8.7 mg $g^{-1}day^{-1}$). In contrast, for the Linas variety, the highest relative growth rate was obtained in the rosette period on the 1st sowing date (31.4 mg $g^{-1}day^{-1}$), during the stem elongation period on the 4th sowing date (19.7 mg $g^{-1}day^{-1}$), and in the flowering period on the 4th sowing date (8.1 mg $g^{-1}day^{-1}$) (Figure 3).

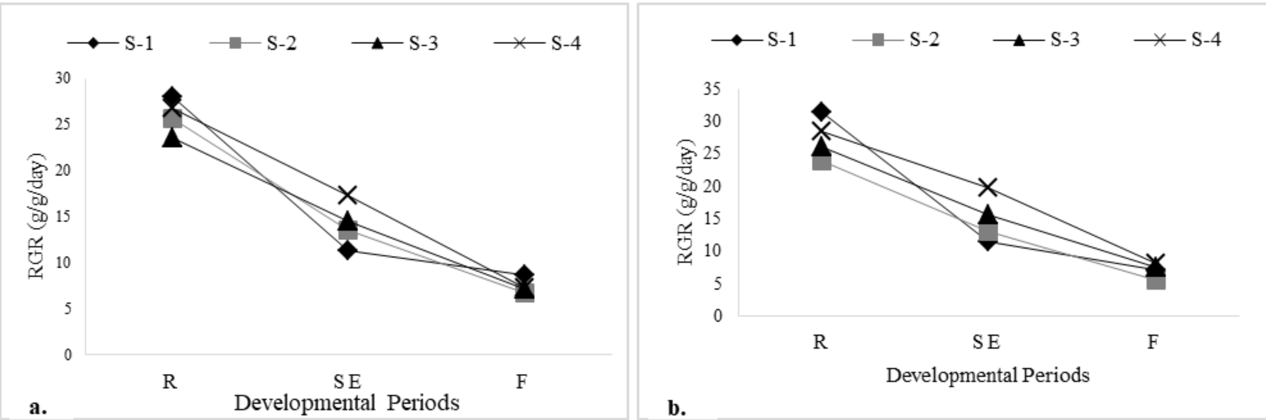


Figure 3. Effects of different sowing dates on RGR of two safflower varieties at different growth stages.
(a) Olas, (b) Linas. S-1 = October 30th; S-2 = November 14th; S-3 = November 29th; S-4 = December 14th; R = Rosette; SE = Stem Elongation; F = Flowering.

The relative growth rate is a significant metric in plant physiology, providing a quantitative measure of a plant's growth by assessing the daily increase in dry matter relative to its initial dry matter accumulation (Uzun, 1997). This rate is comprised of two essential components: physiological and morphological aspects, collectively influencing the plant's carbon economy. The physiological component is reflected in the net assimilation rate, closely tied to net photosynthesis. In contrast, the morphological components include specific leaf areas and the distribution of assimilates (Lambers et al., 1998). Together, these factors contribute to a comprehensive understanding of a plant's growth dynamics and resource utilization.

Research studies on safflower have presented varying patterns in the relative growth rate. For instance, Sahu et al. (2017) observed fluctuations, with values ranging between 25.0-26.0 mg $g^{-1}day^{-1}$ during the 30-60 days following sowing. Beyond 60 days post-sowing, the relative growth rate decreased to 4.0-5.0 mg $g^{-1}day^{-1}$. In a separate investigation, Hivare et al. (2019) documented safflower's relative growth rate at different growth stages. They reported rates of 24.5 mg $g^{-1}day^{-1}$ between 40-60 days, 51.3 mg $g^{-1}day^{-1}$ from 60-80 days, and 12.7 mg/g/day from 80-100 days after sowing. These findings highlight the dynamic nature of safflower growth and the importance of considering multiple factors influencing relative growth rates in different stages of development.

The relative growth rate serves as a trait influenced by various ecological factors. Except for the flowering period, differences in the relative growth rate during all developmental periods were notably affected by variations in temperature, duration of sunshine, relative humidity, and precipitation levels between years. For example, the higher relative growth rates observed in the second year, across all development periods except the stem elongation stage, can be attributed to a more evenly distributed precipitation pattern throughout the plant's growth cycle during that year. In contrast, in the first year, significant rainfall was concentrated primarily in the initial developmental periods (rosette and stem elongation) during December, January, and March, with respective amounts of 141.1, 153.6, and 118.9 mm. The precipitation distribution reveals that the first year had more rainfall during the plant's vegetative phase, whereas the second-year experienced increased precipitation during the plant's generative phase (Figure 1). Different sowing dates had a substantial effect on safflower relative growth rate across all development periods. Plants planted late in the stem elongation period, especially in the fourth planting period, exhibited a high growth rate, and the relative growth rate increased faster during the stem elongation period, coinciding with the rise in spring temperatures.

Net assimilation rate (NAR). Significant year effects were observed throughout all developmental stages, with the cultivar effect playing a pivotal role specifically during stem elongation periods. Moreover, the interaction effect between year and cultivar demonstrated significance during both stem elongation and flowering phases. Regarding the net assimilation rate, it was established that the impacts of sowing date, along with the interaction effect of year and sowing date, were significant across all development periods. Notably, the variety-sowing date interaction significantly influenced the net assimilation rate only in the rosette period. Additionally, the triple interaction of year, variety, and sowing date exhibited a statistically significant impact on the net assimilation rate across all developmental stages (Table 1). Throughout the development stages, a noticeable increase in net assimilation rate was observed, reaching its peak during the flowering period. Specifically, during the rosette, stem elongation, and flowering periods, the net assimilation rate varied between 1.23, 1.55, and 10.39 g m^{-2} day^{-1}, respectively. Notably, the Linas variety demonstrated a higher net assimilation rate compared to the Olas variety during the rosette, stem elongation, and flowering periods, recording values of 1.22, 1.60, and 10.47 g m^{-2} day^{-1}, respectively (Figure 4).

Distinct sowing times revealed varying peaks in net assimilation rates under specific conditions. The rosette period recorded the highest net assimilation rate at the 1st sowing date (1.21 g m^{-2} day^{-1}), while the stem elongation period exhibited the peak at the 4th sowing time (1.97 g m^{-2} day^{-1}). Notably, the flowering period reached its highest net assimilation rate at the 3rd sowing time (11.56 g m^{-2} day^{-1}) (Figure 4). When considering the interplay between variety and sowing time, the rosette period saw the highest net assimilation rate during the 3rd sowing time for the Olas variety (31.6 g m^{-2} day^{-1}) and the 1st sowing time for the Linas variety (31.4 g m^{-2} day^{-1}). In the stem elongation period, the peak occurred at the 4th sowing time for both Olas and Linas varieties, registering rates of 19.3 g m^{-2} day^{-1} and 19.7 g m^{-2} day^{-1}, respectively. Moving to the flowering period, the Olas variety exhibited the highest net assimilation rate at the 1st sowing time (8.7 g m^{-2} day^{-1}), while the Linas variety reached its peak at the 4th sowing time (8.1 g m^{-2} day^{-1}) (Figure 4).

Table 1. Variance analysis table and F values of the LAI, RGR and NAR for the growth periods

Sources of Variation	LAI			RGR			NAR		
	R	SE	F	R	SE	F	R	SE	F
Block	0.36	0.39	1.10	0.38	0.42	0.19	0.15	1.39	0.40
Year(Y)	61.90**	9.96*	319.22**	80.38**	14.19**	2.56	287.82**	397.96**	42.59**
Cultivar(C)	9.05**	0.03	2.09	0.28	0.33	0.27	0.32	22.70**	0.001
YxC	7.24*	5.39*	63.34**	0.11	1.36	8.82*	0.12	10.64**	11.58**
SD	27.36**	160.17**	167.84**	15.16**	104.03**	13.69**	7.04**	150.42**	5.33*
YxSD	151.07**	1318.59**	227.98**	52.86**	19.98**	2.81	78.64**	30.82**	5.19*
CxSD	12.92**	25.87**	113.27**	8.53**	2.25	5.30*	6.72**	1.25	2.17
YxCxSD	7.17**	59.82**	298.02**	9.49**	4.15*	6.92**	4.49*	3.78*	8.97**
CV (%)	9.16	7.22	9.38	1.70	1.27	0.89	6.84	7.30	5.98

*Significant at level 0.05 ($p \leq 0.05$), **Significant at level 0.01 ($p \leq 0.01$), SD = Sowing date, R = Rosette, SE = Stem Elongation; F = Flowering.

The net assimilation rate, a component of plant growth rate, serves as a crucial measure indicating a plant's efficiency in producing new dry matter per unit leaf area. This complex physiological variable is closely tied to the plant's photosynthesis and respiration rates (Uzun, 1997). Additionally, it is considered a measure of the net carbon content and is highly correlated with net photosynthesis (Lambers et al., 1998). Numerous studies have highlighted the significance of the net assimilation rate in plant growth and yield. It has been reported that growth-related variables such as leaf area index, net assimilation rate and leaf chlorophyll content tend to increase in the vegetative growth stage and peak at the flowering stage (Yasari and Patwardhan, 2006). Hassan et al. (2015) also reported that there was a significant positive relationship between the net assimilation rate and seed yield, and that the net assimilation rate increased from the time of sowing, reaching the highest amount on the 105th day, and then decreased until maturity.

The net assimilation rate, a key component of plant growth rate, serves as a critical indicator of a plant's efficiency in generating new dry matter per unit leaf area. This intricate physiological parameter is intricately linked to a plant's photosynthesis and respiration rates, as noted by Uzun (1997). Furthermore, it functions as a gauge of the net carbon content and exhibits a strong correlation with net photosynthesis, as highlighted by Lambers et al. (1998). Numerous studies underscore the significance of the net assimilation rate in influencing plant growth and yield. Research, such as that conducted by Yasari and Patwardhan (2006), reveals that growth-related variables, including leaf area index, net assimilation rate, and leaf chlorophyll content, tend to increase during the vegetative growth stage, reaching their peak at the flowering stage. In a study by Hassan et al. (2015), a noteworthy positive relationship between the net assimilation rate and seed yield was reported. The net assimilation rate exhibited an increasing trend from the time of sowing, reaching its highest value on the 105th day, and subsequently declining until maturity. This emphasizes the dynamic nature of the net assimilation rate throughout the plant's life cycle and its pivotal role in influencing overall growth and productivity. Several researchers have explored the net assimilation rate of safflower, presenting a spectrum of values. Omidi and Sharifmogadas (2010) documented rates ranging from 12.01 to 13.9

g m^{-2} day^{-1}, while Naderi et al. (2005) reported values between 11.6 and 12.8 g m^{-2} day^{-1}. In a study conducted by Hivare et al. (2019), the net assimilation rate exhibited variability, starting at 1.56 g m^{-2} day^{-1} between 40-60 days after sowing and decreasing to 1.27 g m^{-2} day^{-1} between 80-100 days after sowing. Furthermore, the rate was recorded as 1.51-2.06 g m^{-2} day^{-1} at 21 days after sowing, 3.03-4.29 g m^{-2} day^{-1} at 63 days after sowing, 3.37-5.62 g m^{-2} day^{-1} at 105 days after sowing, and 1.18-2.35 g m^{-2} day^{-1} at 147 days after sowing, with a range of 0.41-1.46 g m^{-2} day^{-1} during ripening (Hassan et al., 2015). While the net assimilation rate values obtained in this research align with certain prior studies on safflower, variations from others are also apparent. Moreover, the observed net assimilation rate curve in this study bears resemblance to the curve described by Moatshe et al. (2020) for safflower plants. These findings highlight the nuanced nature of net assimilation rate in safflower, influenced by factors such as growth stage and environmental conditions, contributing to the diversity in reported values across different studies.

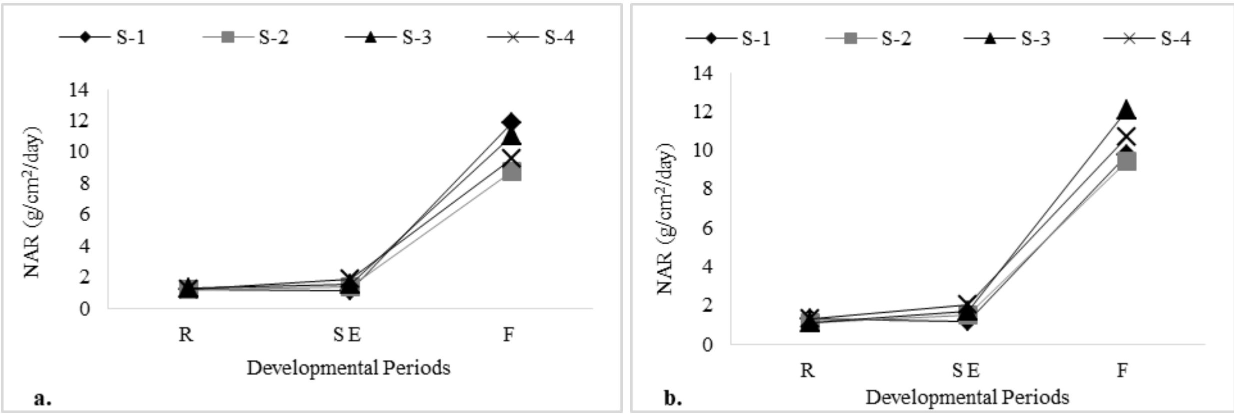


Figure 4. Effects of different sowing times on NAR of two safflower varieties at different growth stages. (a) Olas, (b) Linas. S-1 = October 30th; S-2 = November 14th; S-3 = November 29th; S-4 = December 14th; R = Rosette; SE = Stem Elongation; F = Flowering.

The net assimilation rate emerges as a pivotal trait profoundly impacted by ecological factors, with discernible variations throughout various plant development stages primarily attributed to fluctuations in temperature, sunshine duration, relative humidity, and precipitation levels across different years. Notably, the Linas cultivar displayed an elevated net assimilation rate during the stem elongation period, a trend potentially linked to increased precipitation observed in the second year, particularly during stem elongation phases. Distinctive patterns in the net assimilation rate were also observed in relation to safflower's response to different sowing dates across all growth periods. Early sown plants exhibited higher net assimilation rates in the initial stages, especially during rosette periods, while late-sown safflower plants demonstrated increased rates as growth progressed towards flowering. This suggests a dynamic responsiveness of the net assimilation rate to varying planting times during summer vegetation, with delayed sowing potentially contributing to heightened rates. Plausible explanations include the influence of rising temperatures, accumulated growth degree days, and extended exposure to favourable conditions. Furthermore, the net assimilation rate in safflower is recognized to be significantly influenced by factors such as temperature, radiation, and nutrient availability, as noted by Ahmadi et al. (2014). The association between greater radiation capture and increased assimilation production aligns with findings emphasizing the impact of these factors on the net assimilation rate, as reported by Hassan et al. (2015). This underscores the intricate interplay of environmental variables in shaping the net assimilation rate dynamics in safflower plants.

Crop growth rate (CGR). Prominent findings from the study highlight the substantial influence of the year factor on crop growth rate throughout all developmental stages. The cultivar effect exhibited significance during the rosette, stem elongation, and harvest periods, emphasizing its role in shaping crop growth. Furthermore, the year-cultivar interaction demonstrated significance across all developmental phases, except for the stem elongation period, indicating a dynamic interplay between these factors. The significance of both the sowing date and the interaction effect of year-cultivar-sowing date on crop growth rate was observed across all developmental periods, excluding the harvest period. This underscores the importance of considering the timing of sowing and its interplay with other factors in understanding crop growth dynamics. Additionally, the interaction effect of year x sowing date displayed significance across all developmental periods except for the flowering phase, further highlighting the nuanced relationship between these variables.

Lastly, the cultivar x sowing date interaction emerged as a significant factor in the rosette and harvest periods, underscoring the influence of the specific combination of cultivar and sowing date on crop growth rate during these stages (Table 2). These findings collectively contribute to a comprehensive understanding of the multifaceted factors influencing crop growth across different developmental periods.

The average plant growth rate demonstrated a notable increase across sequential developmental stages, progressing from the rosette to stem elongation, flowering, and finally reaching the harvest periods (0.163, 1.02, 5.10, and 6.43 g m^{-2} day^{-1}, respectively). When considering different varieties, it was discerned that the Linas variety consistently exhibited a higher plant growth rate than the Olas variety during the rosette, stem elongation, and flowering periods (1.67, 1.06, and 5.11 g m^{-2} day^{-1}, respectively). However, during the harvest period, the plant growth rate was 6.24 g m^{-2} day^{-1} for the Linas variety and 6.62 g m^{-2} day^{-1} for the Olas variety (Figure 5). Distinct sowing times revealed varying peak crop growth rates: the first sowing time yielded the highest rate of 0.181 g m^{-2} day^{-1} during the rosette periods, the fourth sowing time demonstrated a peak of 1.22 g m^{-2} day^{-1} during the stem elongation period, and the third sowing time exhibited the highest rate of 5.66 g m^{-2} day^{-1} during the flowering period. The consistent pattern of increasing crop growth rate from the rosette period to harvest was observed across all sowing times for both varieties. At harvest time, the highest plant growth rate was 6.83 g m^{-2} day^{-1} for the Olas variety at the fourth sowing time, while the Linas variety reached 7.1 g m^{-2} day^{-1} at the second sowing time (Figure 3). These findings provide valuable insights into the dynamic patterns of plant growth rates influenced by variety and sowing timing across different developmental stages.

Crop growth rate stands as a pivotal factor influencing grain yield, with reported variations across different studies. For instance, Sahu et al. (2017) noted a plant growth rate of 0.42-0.47 g m^{-2} day^{-1} 30-60 days after sowing, decreasing to 0.21-0.33 g m^{-2} day^{-1} at harvest time. Hasan et al. (2015) reported varied rates, ranging from 1.31-1.58 g m^{-2} day^{-1} at 42 days after sowing to 0.46-1.64 g m^{-2} day^{-1} during the ripening period. In contrast, Omidi and Sharifmogadas (2010) reported a higher crop growth rate during the harvest period, ranging from 23.9-24.2 g m^{-2} day^{-1}.

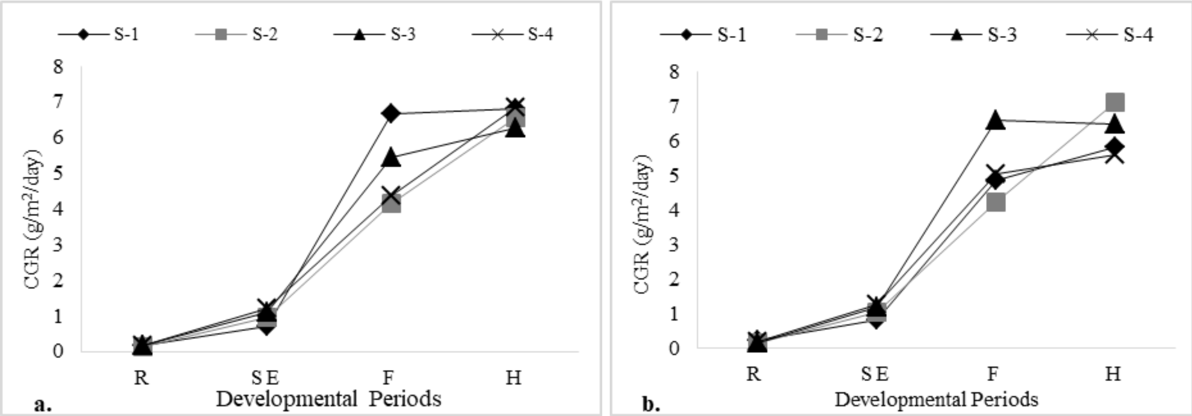


Figure 5. Effects of different sowing times on CGR of two safflower varieties at different growth stages. (a) Olas, (b) Linas. S-1 = October 30th; S-2 = November 14th; S-3 = November 29th; S-4 = December 14th; R = Rosette; SE = Stem Elongation; F = Flowering; H = Harvest.

The intricate dynamics of crop growth rate are significantly influenced by ecological factors. Variations in temperature, duration of sunshine, relative humidity, and precipitation levels between years played a substantial role in shaping crop growth rates across all developmental periods, except during the harvest period. It's noteworthy that both excessively low and high temperatures can have adverse effects on plant growth and development. Conversely, within certain limits, increased light intensity tends to accelerate plant growth (Mohret al., 2012). The second year, characterized by more evenly distributed rainfall throughout the growth cycle, exhibited the highest crop growth rates across all development periods except the stem elongation stage. The distribution of precipitation, with more rainfall during the vegetative phase in the first year and increased precipitation during the generative phase in the second year, likely contributed to this observation (Figure 1). Varietal differences were also observed, with the Linas variety showing a higher crop growth rate during the rosette and stem elongation periods, while the Olas variety excelled during the harvest period. Early sowings, particularly the second sowing date, consistently resulted in higher crop growth rates across all development stages except for the stem elongation period. In contrast, late sowings exhibited lower crop growth rates, influenced by factors such as reduced sunshine duration, lower growth degree day accumulation, and notably, a decreased leaf area index, collectively contributing to diminished crop growth rates. These findings underscore the intricate interplay of environmental and management factors in shaping crop growth rates.

Total dry matter (TDM). The impact of various factors on plant development and dry matter accumulation was explored, revealing significant trends. The year effect demonstrated significance throughout all development periods, emphasizing its consistent influence. The cultivar effect played a crucial role during the rosette and stem elongation periods, underscoring its importance in specific phases of plant growth. Additionally, the interaction effect of year x cultivar exhibited significance in the rosette, flowering, and harvest periods, suggesting a dynamic interplay between these factors.

The effect of sowing date, year x sowing date, and the interaction of year x cultivar x sowing date were all found to be significant across all development periods, highlighting the importance of timing and its interaction with other factors. Notably, the variety x sowing date interaction proved significant in all development periods except the stem elongation period, further emphasizing the nuanced relationship between variety and sowing date (Table 2). Evaluating the total dry matter accumulation across developmental periods revealed varying amounts. The Linas variety exhibited higher total dry matter amounts during the rosette and stem elongation periods compared to the Olas variety. Although not statistically significant, the Olas variety recorded higher total dry matter amounts during the flowering and harvest periods. The highest total dry matter accumulation occurred during the second sowing date, particularly during the stem elongation, flowering, and harvest periods. In the rosette period, the highest total dry matter was obtained during the first sowing date. Consistent patterns were observed in both safflower varieties, with the highest total dry matter formation occurring at the second sowing time in the stem elongation, flowering, and harvest periods, and at the first sowing time in the rosette period (Figure 6). These findings contribute valuable insights into the multifaceted factors influencing dry matter accumulation and plant development in safflower.

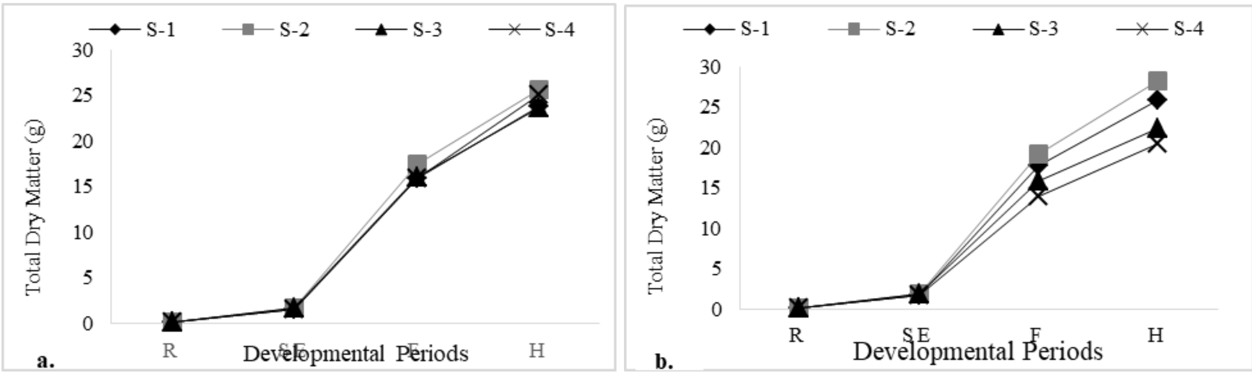


Figure 6. Effects of different sowing times on Total Dry Matter of two safflower varieties at different growth stages. (a) Olas, (b) Linas. S-1 = October 30th; S-2 = November 14th; S-3 = November 29th; S-4 = December 14th; R = Rosette; SE = Stem Elongation; F = Flowering; H = Harvest.

Total dry matter is a critical quantitative trait with direct implications for yield and its components in safflower plant as the other plants. An increase in total dry matter is associated with elevated branch number, capsule number, grain number, and grain weight, contributing to enhanced productivity per unit area. Reported total dry matter amounts in safflower plants range from 630.2 to 965.3 g/cm^2 (Soleymani and Shahrajabian, 2011). During the developmental period at 40, 60, 80, and 100 days after planting, the total dry matter amounts were reported as 5.96, 9.72, 27.10 g, and 34.96 g, respectively (Hivare et al., 2019).

Table 2. Variance analysis table and F values of the CGR and TDM for the growth periods

Sources of Variation	Crop Growth Rate				Total Dry Matter			
	R	SE	F	H	R	SE	F	H
Block	0.15	0.41	0.59	1.22	2.66	0.35	1.51	2.39
Year(Y)	1162.37**	155.23**	67.14**	4.55*	29.43**	19.89**	418.70**	446.10**
Cultivar(C)	24.21**	11.83**	0.001	4.30*	110.55**	8.96*	2.03	0.84
Y x C	17.82**	0.001	6.69*	6.95*	32.40**	0.03	33.65**	14.94**
SD	96.20**	180.88**	5.09*	3.18	35.51**	10.95**	20.17**	17.18**
YxSD	141.76**	180.70**	2.93	7.69**	40.87**	47.30**	15.64**	22.08**
CxSD	25.87**	0.98	1.24	5.06*	16.44**	0.39	26.67**	19.61**
YxCxSD	18.57**	5.64*	6.64**	0.55	3.99*	4.16*	10.58**	4.60*
CV (%)	3.30	9.07	7.52	6.76	7.91	7.31	9.83	8.80

*Significant at level 0.05 (p≤0.05), **Significant at level 0.01 (p≤0.01), SD = Sowing date, R = Rosette, SE = Stem Elongation; F = Flowering, H = Harvest.

The total dry matter amount is significantly influenced by ecological factors, particularly temperature and precipitation. In the second year of the experiment, where precipitation was evenly distributed throughout the plant's development period, a contrast was observed compared to the first year, where precipitation concentrated solely during initial development stages such as emergence, rosette, and stem elongation. Research indicates that the allocation of dry matter between vegetative and generative organs varies significantly among varieties, with early maturing and smaller-sized varieties tending to accumulate more total dry matter in generative organs compared to their late-maturing and larger-sized counterparts (Baydar and Kara, 2010). Moreover, the total dry matter amount is significantly affected by different planting dates across all development periods. Early planting, especially during the second planting time, consistently led to higher total dry matter amounts until the harvest period. The trends observed in the rosette period persisted in later stages of plant development, indicating that delayed planting negatively impacted plant development, causing a swift transition to the generative phase, and decelerating vegetative growth. Consequently, this slowdown affected other plant organs, resulting in a decrease in total dry matter. These findings underscore the intricate interplay of environmental factors and planting practices in influencing total dry matter accumulation in safflower plants.

CONCLUSIONS

Sowing time significantly affected key aspects of safflower plant development. Early sowing, especially on the second sowing date, led to a higher leaf area index, while delays in sowing negatively impacted plant development, resulting in a reduced leaf area index. The crop growth rate was notably influenced by sowing time, with early sown plants displaying increased rates in most development periods. Late-sown crops exhibited lower growth rates due to factors like shorter daylight duration and a lower leaf area index. The relative growth rate varied with sowing time, with late-sown plants in specific periods showing higher growth rates. Net assimilation rate and total dry matter were also significantly impacted by sowing time, with early sown plants generally outperforming in these aspects. Despite the advantages of early sowing, considerations should be trait-specific, as exceptions were noted, particularly in the Net Assimilation Rate during winter vegetation. The recommendation is to tailor safflower sowing decisions based on the specific trait under consideration.

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