horticulturae

MDPI

Article

How Climate Variability Affects Safflower (*Carthamus tinctorius* L.) Yield, Oil, and Fatty Acids in Response to Sowing Dates

Muhammad Sajid [1], Hassan Munir [1], Saeed Rauf [2], Iqra Ibtahaj [3], Bilal Ahamad Paray [4], Anna Kiełtyka-Dadasiewicz [5,*], Aleksandra Głowacka [5] and Mohamed A. A. Ahmed [6]

1 Department of Agronomy, University of Agriculture Faisalabad, Faisalabad 38040, Pakistan; saajid@uaf.edu.pk (M.S.); hmbajwa@uaf.edu.pk (H.M.)
2 Department of Plant Breeding & Genetics, College of Agriculture, University of Sargodha, Sargodha 40100, Pakistan; saeedbreeder@hotmail.com
3 Department of Botany, University of Agriculture Faisalabad, Faisalabad 38040, Pakistan; iqraibtahaj@gmail.com
4 Department of Zoology, College of Science, King Saud University, P.O. Box 2455, Riyadh 11451, Saudi Arabia; bparay@ksu.edu.sa
5 Department of Plant Cultivation Technology and Commodity Sciences, University of Life Sciences in Lublin, 13 Akademicka Street, 20-950 Lublin, Poland; leksandra.glowacka@up.lublin.pl
6 Plant Production Department (Horticulture—Medicinal and Aromatic Plants), Faculty of Agriculture (Saba Basha), Alexandria University, Alexandria 21531, Egypt; drmohamedmarey19@alexu.edu.eg
* Correspondence: anna.kieltyka-dadasiewicz@up.lublin.pl

Abstract: Climate variability is a major challenge concerning food security; therefore, there is a need for pragmatic solutions to improve agricultural production. Henceforth, this study was planned to optimize the planting time of exotic safflowers under the prevailing conditions in Faisalabad, Pakistan. A study was executed by employing a split-plot design with six safflower accessions and five sowing dates ranging from 31 October 2019 to 31 December 2019. The results of the experimental safflower accession PI-198990 produced significant seed yields (2432 kg ha^{-1}, 2772 kg ha^{-1} and 2366 kg ha^{-1}) when sown on 30 November 2019, 15 December 2019, and 31 December 2019, respectively. On the other hand, on 31 October 2019 and 30 November 2019, sown safflower accessions PI-208677 and PI-250187 were the best performers, respectively. However, a higher achene oil percentage (31.5% and 30.8%) was noted in accessions PI-250187 and PI-314650 when sown on 31 December 2019 and 15 December 2019, respectively. The highest oleic acid content (22.92% and 22.83%) was determined in accession PI-314650 when planted on 30 November 2019 and 15 December 2019, respectively, whereas a higher linoleic acid content was observed on 31 October 2019 and 30 November 2019. Stability analysis showed that safflower accession PI-210834 was the most stable under all sowing environments, followed by PI-314650. Correlation analysis showed that oil percentage showed a negative correlation with phenological traits and growing degree days, and oil yield showed a strong positive relationship with heads, seed yield, biological yield, thousand seed weight, and harvest index.

Keywords: fatty acid; safflower accessions; sowing dates; seed yield; oil; stability

check for updates

Citation: Sajid, M.; Munir, H.; Rauf, S.; Ibtahaj, I.; Paray, B.A.; Kiełtyka-Dadasiewicz, A.; Głowacka, A.; Ahmed, M.A.A. How Climate Variability Affects Safflower (*Carthamus tinctorius* L.) Yield, Oil, and Fatty Acids in Response to Sowing Dates. *Horticulturae* **2024**, *10*, 539. https://doi.org/10.3390/horticulturae10060539

Academic Editor: Costanza Ceccanti

Received: 17 April 2024
Revised: 15 May 2024
Accepted: 18 May 2024
Published: 22 May 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Safflower (*Carthamus tinctorius* L.) is an oilseed plant of the Asteraceae family. It is cultivated for its flowers which have numerous medical uses [1]; however, safflower is currently mainly grown for its high-quality seed oil [2]. Moreover, it can be cultivated for animal feedstock and biodiesel production [3], as a food colorant [4], and as a good-quality forage crop [5]. The total global production of safflower seeds was 590,869 tons, while 81,299 tons (13.8 percent of global production) were produced in Europe [6]. Selecting an

appropriate sowing time is an important factor for attaining high yield and an important part of the production package that increases their seed yield and income.

Climate variability has a significant impact on safflower yield, oil, and fatty acids, particularly in relation to sowing dates. Climate change (CC) induced by global warming is significantly changing the seasons and crop growth patterns. CC may challenge global crop production by inducing stress conditions during the key development phase of the plant. A sudden rise in temperature may induce pollen sterility, modify the growing degree days, and accelerate crop maturity or early senescence. Therefore, there is a continuous need to revise the production plan of the crop species to obtain the highest benefits in terms of yield and economic return.

Safflower yield has also been known to be affected by CC. A sudden rise in temperature or freezing conditions will challenge optimum crop production and may affect crop growth and photosynthate production [7,8]. However, depending on soil moisture availability, sowing can be done from late September to mid-November. The optimum sowing conditions typically include a soil temperature of around 15–20° and well-drained soil with good moisture retention, as well as a pH range of 6.0–7.5. Safflower is sensitive to waterlogging, so avoiding waterlogged conditions is crucial. Suboptimal conditions could include soil temperatures outside of the ideal range, poor soil drainage leading to waterlogging, or acidic or alkaline soil conditions.

In this regard, the sowing date determines the climatic conditions that safflower seeds will be exposed to during their growth, which can affect their yield and fatty acid composition. For example, sowing safflower seeds during the fall or winter months can result in higher grain and oil yields due to the climatic conditions that are more favorable for safflower growth during these seasons [7,8]. Delaying the planting time shortened the germination and flowering period due to changes in temperature to reduce dry matter accumulation. Thousand seed weight, number of seeds per capitulum, and seed yield were more affected than crop biomass [9]. The late planting of spring safflower results in a lower seed yield in semi-arid and high-elevation Mediterranean environments, and delayed flowering does not allow it to escape from terminal drought and heat stress [10]. An early planting time combined with an early flowering cultivar would be required to achieve a high seed yield in areas with lower rainfall [11]. Moreover, the optimum planting time produced the maximum safflower seed yield (2000 kg ha^{-1}) [12]. Moreover, it was identified that delaying sowing by 9–18 days reduced seed yield by 510–850 kg ha^{-1}. Tahmasebizadeh [13] showed that the planting time significantly influenced the number of capitula in safflower plants and [14] reported that planting time has a significant impact on safflower growth and seed yield. Koutroubas [15] stated that the sowing date is a critical factor for maximizing safflower seed yield, and that identifying the right sowing time is the most critical factor for enhancing safflower productivity.

The fatty acid composition of safflower oil is primarily made up of unsaturated linoleic (C18:2) and oleic (C18:1) fatty acids with a low proportion of saturated fatty acids [16]. The process of fatty acid synthesis in plants starts with the conversion of acetyl-CoA into malonyl-CoA, which is used as a building block for fatty acid synthesis. Moreover, this procedure is catalyzed by the enzyme acetyl-CoA carboxylase (ACC) [17–19]. Afterward, malonyl-CoA is extended with the help of enzymatic reactions, particularly fatty acid synthase and fatty acid elongase, eventually resulting in various fatty acid chains [17–19]. In addition, when fatty acids are produced, they are brought together into triacylglycerol synthesis (TAGs) through the enzymes glycerol-3phosphate acyltransferase (GPAT), lysophosphatidic acid acyltransferase (LPAAT), and diacylglycerol acyltransferase (DGAT). This process involves the condensation of glycerol-3-phosphate with a fatty acid to produce diacylglycerol, which is then further acylated with another fatty acid [17–19].

However, the proportion of these fatty acids can vary depending on the cultivar and sowing date. However, safflower oil from seeds sown in the spring may have a higher proportion of linoleic acid than safflower oil from seeds sown in the fall or winter [7,8]. The environmental conditions during the growing season can also affect safflower yield

and fatty acid composition. Particularly, temperature can have a significant impact on safflower yield and oil content. High temperatures during the flowering stage can reduce safflower yield and oil content, while low temperatures during the seed development stage can increase safflower oil content [16,20]. The effects of sowing dates on safflower yield and fatty acid composition are complex and can vary depending on the cultivar, environmental conditions, and cultural practices. Therefore, further research is needed to optimize sowing practices for safflowers to enhance the yield and nutritional composition of new accessions. The type of cultivar, environmental conditions, and cultural practices can all affect safflower yield and fatty acid composition. Keeping in view the above-mentioned facts, this study was set up to optimize the sowing time of safflowers in Faisalabad, Pakistan to recommend better sowing times to farmer communities in order to avoid yield-limiting factors in the future.

2. Materials and Methods

The field experiment was conducted during 2019–2020 to optimize the sowing time of safflower candidate lines under different planting times. The study was organized by using a split-plot design by keeping the sowing time in the main plot and safflower accessions (obtained from United States Department of Agriculture-Agricultural Research Service) in the subplots, and by having three replications. Soil parameters, environmental conditions, planting materials, and the crop husbandry package for the selected site is given in Figure 1.

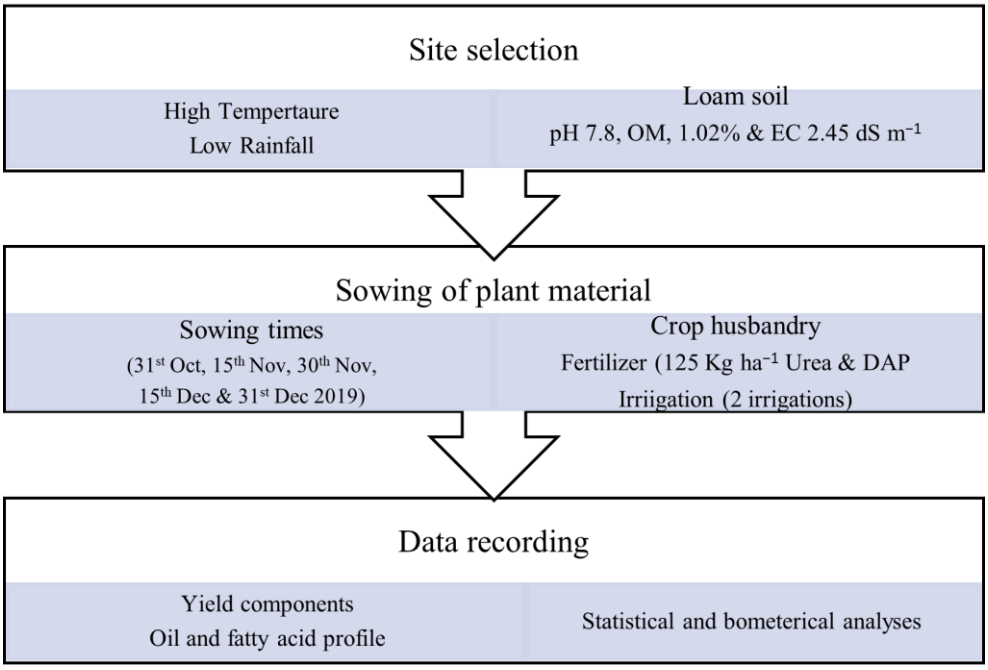

Figure 1. Soil parameters, environmental conditions, planting materials, and the crop husbandry package for the selected site.

2.1. Site Selection and Crop Growth Conditions

All accessions were grown at a single site, i.e., in Faisalabad, Pakistan (31.2537° N, 73.0438° E, and altitude 184.4 m). Faisalabad is an industrialized urban area situated in the central Punjab mixed-cropping zone. Faisalabad's climate is semi-arid and characterized by very high temperatures in summer where peak temperatures often exceed >45 °C, threatening crop production due to poor grain filling and anthesis of summer crops.

Accessions were sown in rows, with row-to-row distances of 45 cm and plant-to-plant distances of 15 cm, respectively. Pre-emergence herbicide (Dualgold) with S-metolachlor ($C_{15}H_{22}ClNO_2$) as an active ingredient was applied at a dosage of 1976 mL ha^{-1} after 10 h of planting. However, a full dose and a half dose of 125 kg ha^{-1} diammonium

phosphate (DAP) and urea, respectively, were used at sowing time, whereas the remaining urea was given at first irrigation (40 DAS) and second irrigation (at flowering). Soil analysis and weather variables were recorded during the study period (Table 1; Figure 2). Phenological traits, growing degree days, agronomic traits, and oil traits were noted thorough standard methodology.

Table 1. Soil and weather variables.

Variables	Value	Unit
* Sample depth	0–30	Cm
Soil type	Loam	-
Soil saturation	33.0	%
EC	2.45	dS m^{-1}
pH	7.8	-
Organic matter	1.02	%
Nitrogen	0.27	%
Phosphorus	9.7	mg kg^{-1}
Potassium	167.0	mg kg^{-1}
** Relative humidity	77.41	%
Rainfall	159.80	mm
Max. temperature	39.00	°C
Min. temperature	3.00	°C
Av. vegetative phase photoperiod	6.00	h
Av. maturity phase photoperiod	8.75	h

* Soil data were obtained by randomly sampling the soil at the depths of 15 and 30 cm, respectively, and ** environmental physical parameters were obtained from the meteorological observatory (Davis Vantage Pro2 Weather Station) installed near the experimentation site.

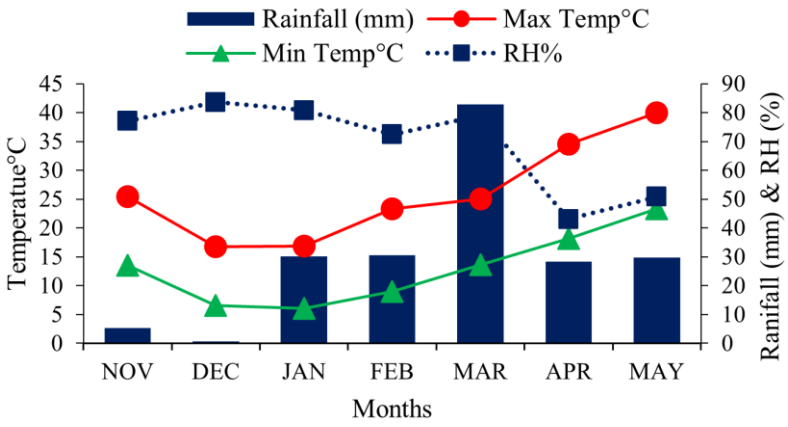

Figure 2. Maximum and minimum temperatures, rainfall, and relative humidity data of the safflowers during the experiment.

2.2. Determination of Plant Traits

2.2.1. Collection of Phenological and Agronomic Traits

Phenological traits were measured from the time of sowing to the time of harvesting of targeted sowing dates of safflower accessions. Moreover, plant height, the number of branches and capitulum, and the number of seeds and capitulum were measured by taking 10 plants from each experimental unit. Achene and biological yield data were collected from an area of 1 m^2 and then converted into kg ha^{-1}. However, the harvest index was calculated using the formula of economic yield over biological yield.

2.2.2. Growing Degree Days Calculation

For the calculation of growing degrees days (GDD), temperature, humidity, rainfall, and photoperiod data were obtained from the agrometeorological observatory installed 50 m from the trial site. The agrometeorological (Davis Vantage Pro2 Weather Station)

observatory automatically delivers the data to the Agromet-Bulletin Agricultural Meteorology Cell Department of Agronomy, University of Agriculture Faisalabad Pakistan. Growing degree days were calculated from sowing to harvesting time with the help of the following formula.

$$GDD = \frac{T_{Max} - T_{Min}}{2} - T_{base} \quad (1)$$

Here;

T_{Max} = Maximum temperature on X Day
T_{Min} = Minimum temperature on X Day
T_{base} = Base temperature (3 °C) at which growth and degree days accumulation is possible

2.3. Determination of Oil Content

The Soxhlet apparatus was used for seed oil extraction. First, a 10 g clean seed sample at 12% seed moisture was crushed in a grinder and then loaded onto the apparatus for 24 h, employing n-hexane as a solvent. The reduced sample weight was weighed on an analytical weighing balance to calculate achene oil percentage through the following equation as prescribed by [21].

$$\text{Achene oil Content}(\%) = \frac{\text{Initial sample weight} - \text{Final sample weight}}{\text{Intial sample weight}} \quad (2)$$

2.4. Seed Fatty Acids Determination

For fatty acid (oleic and linoleic acid) determination, the extracted oil from selected samples was used and put into an Eppendorf tube. The collected oil (50 µL) was methylated by employing 4 mL KOH and left for 1 h at normal temperature. Methylated fatty acids were separated using n-hexane, and fatty acid contents were assessed by employing gas chromatography (M-3900, Varian, Palo Alto, CA, USA). Fatty acid determination was performed by applying a fused capillary column of flame as an ionizing detector at 3.5 mL min^{-1}, using nitrogen as the gas carrier. The injector and detector were sustained at 260 °C, whereas the column oven was set at 222 °C. Esterified fatty acids were infused and the fatty acid was verified by comparing their peak retention time to standards.

2.5. Statistical Analyses

Data were analyzed using the Fisher analysis of variance technique (ANOVA) and the treatment mean was differentiated by deploying the LSD test at α 0.05 [22]. Treatment means were presented by employing a paired comparison plot technique using OriginPro-2021 SR0 software. The data had a normal distribution following the "Shapiro–Wilk" test; therefore, correlation analysis was performed using a two-tailed *t*-test (df−2). Online STABILITYSOFT analysis [23] was used to assess the stability of safflower accessions. Safflower accessions were classified according to their stability by Shukla's stability variance σ^2_i [24], regression coefficient *bi [25], deviation from regression S^2d_i [26], Wricke's ecovalence W_i^2 [27], and Kang's ranking KR [28].

3. Results

As far as the data were concerned, it is evident from Table S1 (given as Supplementary Data) that the mean sum of squares for all traits showed significant variations for sowing dates, safflower accessions, and their interaction.

3.1. Description of Phenological Traits and Degree Days

Explaining the phenological traits, on the 31 October 2019 and 15 November 2019 sowing dates, the maximum days were taken for flowering in the PI-198990 and PI-314650 accessions and the least days were used by PI-199907 and PI-208677, respectively. However, on 30 November 2019, 15 December 2019, and 31 December 2019, the highest days were counted in accessions PI-250187 and PI-314650, and the lowest days were utilized for

flowering in the PI-250187 and PI-208677 accessions, respectively (Figure 3). However, looking at the data regarding days to maturity, the highest number of days was seen in accessions PI-314650 and PI-198990 when sown on 31 October 2019 and 15 November 2019, respectively, whereas the minimum number of days were observed in PI-250187 under both sowing times. Accessions PI-198990 and PI-250187 had the most days for maturity and the least days were recorded in accession PI-199907 when exposed to 30 November 2019 and 15 December 2019 planting times. However, on 31 December 2019, accession PI-208677 took more days to mature and the minimum number of days was seen in accession PI-199907 (Figure 3). Similarly, a greater number of growing degree days were counted when safflower was grown on 31 October 2019 and 15 November 2019, whereas the lowest count was reflected from the 31 December 2019 sowing date (Figure 3).

3.2. Description of Agronomic Traits

With respect to plant height, the tallest plants were identified from accessions PI-210834 and PI-250187; however, the shortest heights were seen in the PI-199907 and PI-20867 accessions, planted on 31 October 2019 and 15 November 2019, respectively (Figure 3). In addition, on the 30 November 2019 and 15 December 2019 planting dates, accessions PI-198990 and PI-314650 were marked as having the tallest heights, respectively, whereas the lowest plant height was measured in safflower accession PI-199907 under both sowing times. Accession PI-314650 had the tallest plants but the lowest plant length was observed in PI-199907 when sown on 31 December 2019. As per the depiction in Figure 3, a higher number of branches were counted in accessions PI-210834 and PI-250187 when planting was performed on 31 October 2019 and 15 November 2019, respectively, and the least number of branches were declared from PI-314650 under both sowing dates. Accession PI-198990 displayed the leading branch count, and the lowest number of branches were documented from PI-314650 under the 30 November 2019 and 15 December 2019 sowing conditions. On the 31 December 2019 sowing date, accession PI-199907 had the highest number of branches, whereas the lowest number of branches counted was in accession PI-314650.

Data regarding capitulum per plant showed that the maximum was from accession PI-250187 but the lowest capitulum was collected from PI-314650, sown on 31 October 2019 and 15 November 2019 (Figure 3). Sown on 30 November 2019, accession PI-250187 had a greater number of capitula, whereas the minimum capitula count was gathered from accession PI-314650. Similarly, the PI-250187 accession was identified as possessing the highest number of capitula and the least value was recorded in accession PI-314650, sown on 15 December 2019. PI-199907 had the highest capitula count per plant and safflower accession PI-314650 (sown on 31 December 2019) had the lowest (Figure 3).

For the 31 October 2019 and 15 November 2019 plantation dates, safflower accession PI-314650 had the leading number of seeds per capitulum, and the least number of seeds were counted from PI-199907. Sowing on 30 November 2019 significantly reflected the highest number of seeds from accession PI-314650, results that are recorded with parity in accession PI-198990, and the worst-performing accession was PI-199907. However, on the 15 December 2019 sowing date, safflower accession PI-208677 displayed the maximum seeds in comparison to other accessions. On the 31 December 2019 sowing date, accession PI-210834 had the highest seed count, which with similar to the seed count from PI-250187, and the minimum value was obtained from PI-208677 (Figure 3).

Thousand achene weight was significantly affected by sowing times and the leading achene weight was accumulated from accession PI-210834 when sown on 31 October 2019 and 15 November 2019. However, when planted on 30 November 2019, safflower accessions PI-210834 and PI-198990 possessed the highest thousand achene weight, whereas, when planted on 15 December 2019, accession PI-210834 exhibited the highest achene mass in comparison to other safflower accessions (Figure 3).

Achene yield showed significant variation in response to varying sowing times and, on 31 October 2019, safflower accession PI-198990 resulted in the maximum yield as compared to other accessions (Figure 4). On 15 November 2019, safflower accession PI-210834 had

the highest yield and the least yield was obtained from accession PI-199907. Moreover, when sown on 30 November 2019, accession PI-198990 displayed the leading achene yield and the least yield was obtained from PI-314650. In addition, on 15 December 2019 and 31 December 2019, safflower accession PI-198990 had the highest yield, whereas the minimum yield belonged to PI-199907.

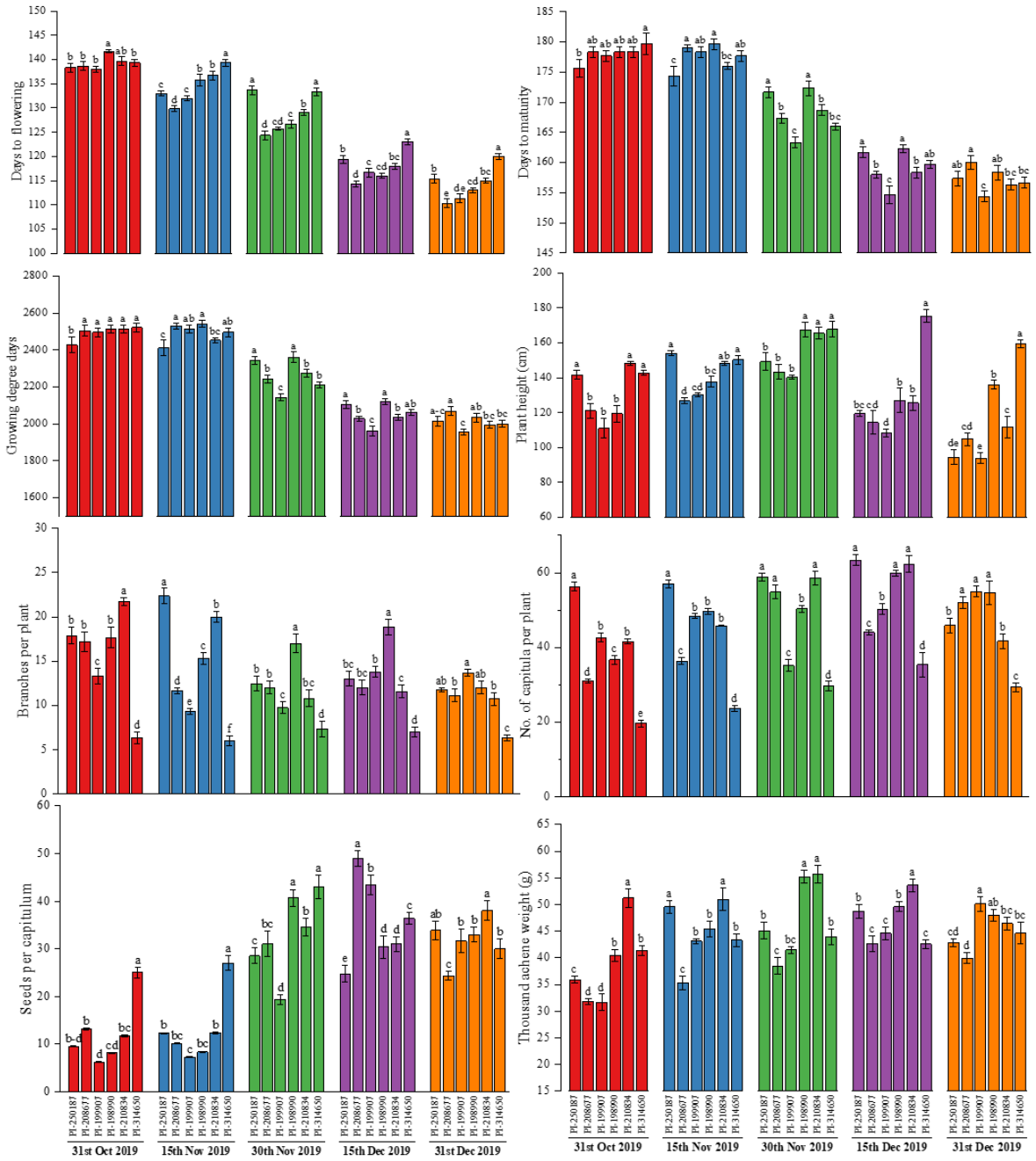

Figure 3. Effect of different sowing dates on the studied traits of safflower accessions. Lowercase letters above the bars show significant ($p \leq 0.05$) means, and similar letters denote insignificance at $p \geq 0.05$. This was computed using LSD tests. Error bars show variation among the experimental units of respective treatments.

The biological yield was significantly influenced by different safflower planting times. When planted on 31 October 2019 and 15 November 2019, the highest biomass was gathered from safflower accessions PI-198990 and PI-210834, respectively, whereas the least biomass was accumulated from PI-199907 in response to the prescribed sowing dates. Planted on

30 November 2019, accession PI-210834 accumulated more biomass, whereas the poorest performer was PI-314650. However, accessions PI-210834 and PI-198990 were identified as the leading biomass accumulators in comparison to other tested accessions when plantation was performed on 15 December 2019 (Figure 4). On 31 December 2019, safflower planting favored accession PI-250187 regarding maximum biological yield, followed by PI-208677, with the lowest biological yield coming from accession PI-199907.

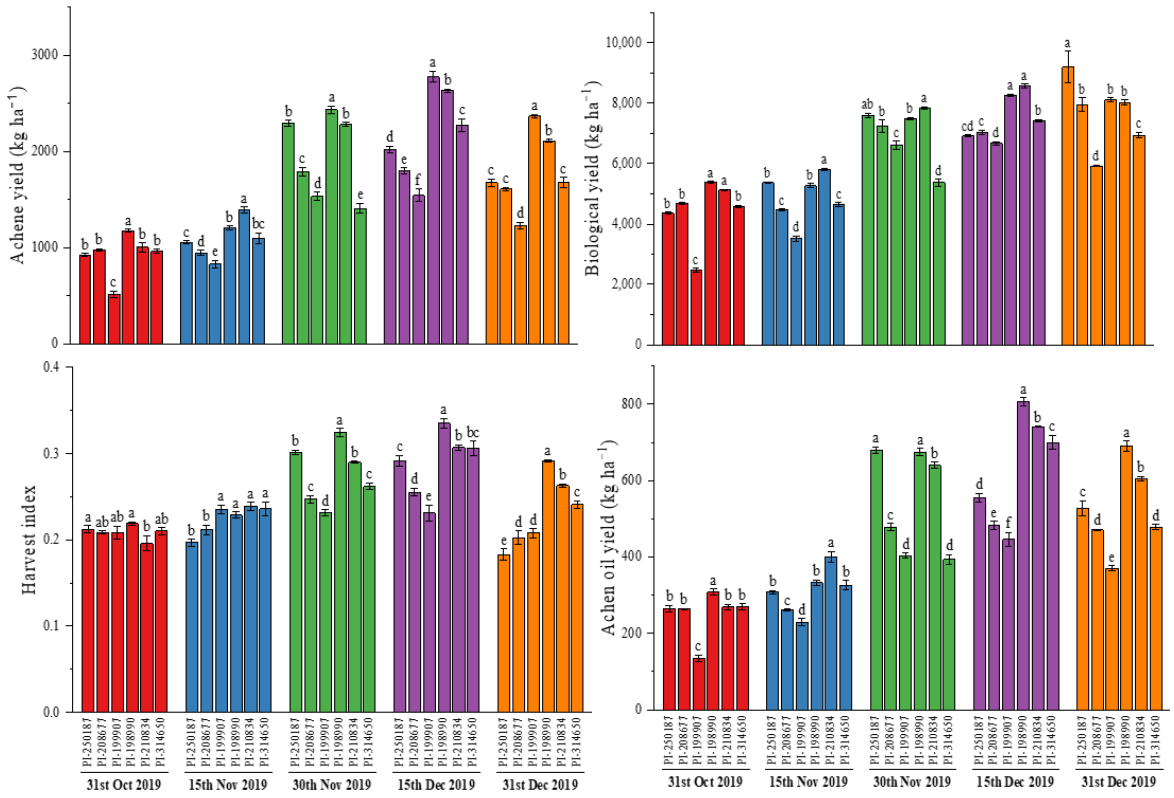

Figure 4. Effect of different sowing dates on the studied traits of safflower accessions. Lowercase letters above the bars show significant ($p \leq 0.05$) means. Similar letters denote insignificance at $p \geq 0.05$ probability, as computed using LSD tests. Error bars show the variation among the experimental units of respective treatments.

The harvest index was significantly increased in accessions PI-198990 and PI-208677 when sown on 31 October 2019. However, on 15 November 2019, sowing was effective for PI-210834 and PI-314650, whereas the lowest value was observed in accession PI-250187. Moreover, when sown on 30 November 2019, safflower accession PI-198990 had the leading harvest index and the lowest value resulted from PI-199907. Plantings on 15 December 2019 and 31 December 2019 showed accession PI-198990 had the highest harvest index, whereas the minimum value was assessed in safflower accessions PI-199907 and PI-250187, respectively (Figure 4).

Regarding oil yield, on 31 October 2019, accession PI-198990 had the best performance, whereas the lowest oil yield was collected from accession PI-199907 (Figure 4). On the 15 November 2019 and 30 November 2019 sowing dates, accessions PI-210834 and PI-250187 had greater oil yields, respectively, whereas the lowest oil yield was obtained from accession PI-199907. Accession PI-198990 was identified as having a greater oil yield when safflowers were planted on 15 December 2019 and 31 December 2019, whereas the worst oil yield came from PI-199907.

3.3. Description of Oil Content and Fatty Acid Profile

Sown on 31 October 2019, safflower accession PI-250187 resulted in the maximum oil content, which was similar in value to that of PI-314650, and the lowest oil content was extracted from accession PI-199907 (Table 2). Safflower accessions PI-314650, PI-250187,

and PI-210834 had the highest oil content when plantation was performed on 15 November 2019. However, safflower cultivation on 30 November 2019 and 15 December 2019 led to significantly greater oil percentages in accessions PI-250187 and PI-314650, and the worst-performing accessions were PI-199907 and PI-208677, respectively. Cultivated on 31 December 2019, accession PI-250187 had the highest oil percentage, followed by PI-199907, and the lowest accumulator of oil content was accession PI-314650.

Table 2. Effect of different sowing dates on achene oil, linoleic acid, and oleic acid contents of safflower accessions. Lowercase letters above the bars show significant ($p \leq 0.05$) means and similar letters denote insignificance at $p \geq 0.05$, as computed using LSD tests. Error bars show the variation among the experimental units of respective treatments.

Accessions	Achen Oil Content (%)				
	Sowing Dates				
	31 October 2019	15 November 2019	30 November 2019	15 December 2019	31 December 2019
PI-250187	28.57 ^{a}	29.23 ^{a}	29.67 ^{a}	27.54 ^{cd}	31.51 ^{a}
PI-208677	27.00 ^{bc}	27.63 ^{b}	26.70 ^{cd}	26.84 ^{d}	29.27 ^{bc}
PI-199907	25.90 ^{d}	27.73 ^{b}	26.34 ^{d}	28.95 ^{b}	30.10 ^{b}
PI-198990	26.10 ^{cd}	27.67 ^{b}	27.75 ^{bc}	29.11 ^{b}	29.15 ^{bc}
PI-210834	26.80 ^{cd}	28.84 ^{a}	28.08 ^{b}	28.14 ^{bc}	28.65 ^{c}
PI-314650	28.00 ^{ab}	29.70 ^{a}	27.93 ^{b}	30.80 ^{a}	28.61 ^{c}
	Linoleic acid C 18:2 (%)				
PI-250187	74.57 ^{a}	69.73 ^{ab}	72.57 ^{ab}	70.38 ^{a}	67.88 ^{a}
PI-208677	74.20 ^{a}	69.85 ^{ab}	72.48 $^{a–c}$	67.88 ^{b}	68.76 ^{a}
PI-199907	71.03 ^{c}	69.72 ^{ab}	73.93 ^{a}	67.88 ^{b}	67.88 ^{a}
PI-198990	71.10 ^{bc}	71.47 ^{a}	70.60 ^{c}	68.76 ^{ab}	67.00 ^{ab}
PI-210834	73.03 ^{ab}	69.41 ^{b}	71.40 ^{bc}	67.88 ^{b}	67.88 ^{a}
PI-314650	70.17 ^{c}	70.32 ^{ab}	66.63 ^{d}	65.17 ^{c}	65.07 ^{b}
	Oleic acid C 18:1 (%)				
PI-250187	13.37 ^{c}	18.27 ^{ab}	15.43 ^{cd}	17.62 ^{c}	20.12 ^{b}
PI-208677	13.80 ^{c}	18.15 ^{ab}	15.52 $^{b-d}$	20.12 ^{b}	19.24 ^{b}
PI-199907	16.97 ^{a}	18.28 ^{ab}	14.07 ^{d}	20.12 ^{b}	20.12 ^{b}
PI-198990	16.77 ^{ab}	16.53 ^{b}	17.40 ^{b}	19.24 ^{bc}	21.00 ^{ab}
PI-210834	14.97 ^{bc}	18.59 ^{a}	16.60 ^{bc}	20.12 ^{b}	20.12 ^{b}
PI-314650	17.83 ^{a}	17.68 ^{ab}	21.37 ^{a}	22.83 ^{a}	22.93 ^{a}

On 31 October 2019, the highest linoleic acid content was determined from accessions P-250187 and PI-208677; however, the lowest concentration was determined in accession PI-314650 (Table 2). Sown on 15 November 2019, accession PI-198990 had the greatest linoleic acid value recorded at parity with the results of the remaining safflower accessions, although the lowest value was recorded in PI-210834. Moreover, on the 30 November 2019 and 15 December 2019 planting dates, linoleic acid was significantly influenced in accessions PI-199907 and PI-250187, respectively, whereas the lowest linoleic acid value was determined in PI-314650. Sown on 31 December 2019, safflower accession PI-208677 showed the highest level of linoleic acid, which is similar to the findings from the remaining accessions. The lowest level of linoleic acid was measured from PI-314650.

Similarly, on the 31 October 2019 planting date, safflower accessions PI-314650 and PI-199907 resulted in the highest concentrations of oleic acid. The lowest level was measured in PI-250187. Sown on 15 November 2019, accession PI-210834 had the highest oleic acid concentration, similar to the levels from the remaining accessions, while the lowest amount was assessed in accession PI-198990. However, PI-314650 had the highest oleic acid concentration when sown on 30 November 2019, 15 December 2019, and 31 December 2019, whereas the lower-performing safflower accessions were PI-199907, PI-250187, and PI-208677, respectively (Table 2).

3.4. Correlation Analysis

Pearson correlation association was estimated among the studied traits shown in Table 3. Growing degree days (GDD) had strong positive correlations with days to flowering (DF) and days to maturity (DM) in this study. Number of heads negatively correlated with DF and number of branches (Bran). Number of seeds per head showed negative correlations with DF, DM, GDD, and Bran. However, biological yield ha^{-1} (BYH) showed positive correlations with Bran, number of heads, and seed yield ha^{-1} (SYH), thus showing that these traits had positively contributed to biological yield. Thousand seed weight (TSW) also had positive relationships with heads, seeds, SYH, and BYH, showing that greater head size and BYH led to higher TSW in safflower accessions. Achene oil content had negative correlations with DF, DM, and GDD. Thus, we found an inverse relationship between DF, DM, and GDD with the achene oil content of safflower accessions. In addition, OA displayed a significant negative correlation with DF, DM, GDD, Bran., number of seeds, and oil content. It showed that the higher the DF, DM, and GDD, the more reduced the OA concentration of safflower accessions. Oil yield had positive relationships with seeds per head, SYH, BYH, TSW, and harvest index (HI). Consequently, these traits positively contributed to oil yield. Moreover, LA had negative associations with DF, DM, GDD, Bran., seeds, and oil content, suggesting that these traits had negatively contributed to LA content. However, linoleic acid also exhibited a negative relationship with OA content, thus showing that safflower accessions with higher OA contents had lower linoleic contents. Similarly, Bran, SYH, BYH, TSW, and HI were identified as having non-significant relationships with DF, DM, and GDD.

3.5. Stability Analysis

Stability analysis is important for various fields and in the context of plant breeding and agriculture, it is important for yield perdition, genotype–environment interactions (different crop varieties may respond to environmental changes. This analysis helps to quantify the genotype–environment interactions which allow breeders to develop varieties that perform consistently well across a range of environments), resource optimization, sustainable agriculture, and market demand. The stability of the selected safflower accessions was determined across the five sowing dates (Table 4). Multiple stability variances were calculated which are embedded in the text below. Safflower accession PI-198990 had the highest average yield over the five sowing dates, followed by PI-210834. Some stability attributes were targeted to choose stable safflower accessions across the five sowing dates. Accessions with the lowest ecovalence (W_i^2) values had more stability across the sowing regimes. With regard to W_i^2, accession PI-199907 displayed the lowest value and was marked as stable. Moreover, accessions with the lowest Shukla variance (σ^2_i) showed more stability, and PI-199907 had the lowest value and was marked as stable. Moreover, deviations from the regression (S^2d_i) coefficient should be non-significant ($p \geq 0.05$). As per our evaluation, accession PI-210834 has a co-efficient of regression that was near to unity, with insignificant deviation from regression. Safflower accession PI-198990 diverged from the regression slope and had high bi; consequently, this accession is recommended to be planted in a high-yielding environment. However, PI-208677 displayed a lower value than unity, thus it is fit for a stressful and low-yielding environment. The Kang ranking system assigns lower ranking values to accessions with stronger stability and good yield potential, making those accessions more desirable in terms of seed yield. PI-210834 had ranked lower, consequently, it has more stability and a considerable seed yield. However, safflower accessions PI-199907 and PI-198990 had acceptable yields; nonetheless, it may be less stable as compared to the above-mentioned accessions and is ranked higher.

To summarize the above results of the stability analyses, accession PI-210834 was a stable genotype across all five set of sowing dates with acceptable yields. This accession may be further recommended for production as an environment-proof variety under medium-to-late sowing conditions. In order to follow a high-production package, accession PI1-988990 may be further recommended for cultivation under optimum sowing conditions with high input conditions.

Table 3. Pearson correlation analysis of growth, yield, and oil traits, i.e., days to flowering (DF), growing degree days (GDD), days to harvest maturity (DM), plant height (PH), branches plan-1, capitulum per plant (CPP), seeds per capitulum (SPC), thousand achene weight (TAW), achene yield (AY), biological yield (BY), harvest index (HI), achene oil content (AOC), achene oil yield (AOY), linoleic acid (LA), and oleic acid (OA).

	DF	**DM**	**GDD**	**PH**	**Bran**	**Heads**	**Seeds**	**SYH**	**BYH**	**TSW**	**HI**	**Oil**	**OY**	**OA**
DM	0.921 **	1												
GDD	0.919 **	0.999	1											
PH	0.431 *	0.307	0.295	1										
Bran	0.228	0.307	0.310	−0.107	1									
Heads	−0.469 **	−0.337	−0.340	−0.092	0.380 *	1								
Seeds	−0.647 **	−0.744 **	−0.748 **	0.055	−0.418 *	0.273	1							
SYH	−0.134	−0.169	−0.181	0.217	0.205	0.336	0.280	1						
BYH	0.104	0.169	0.167	0.319	0.512 **	0.629 **	0.008	0.445 *	1					
TSW	−0.278	−0.286	−0.285	0.284	0.191	0.577 **	0.372 *	0.455 *	0.668 **	1				
HI	−0.201	−0.299	−0.312	−0.014	−0.197	−0.210	0.349	0.634 **	−0.337	−0.070	1			
Oil	−0.407 *	−0.429 *	−0.429 *	−0.013	−0.175	0.199	0.363 *	0.195	−0.097	0.275	0.251	1		
OY	−0.137	−0.143	−0.153	0.255	0.187	0.388 *	0.259	0.967 **	0.490 **	0.450 *	0.564 **	0.234	1	
OA	−0.602 **	−0.643 **	−0.634 **	−0.039	−0.425 *	0.032	0.567 **	−0.063	−0.160	0.274	0.053	0.513 **	−0.047	1
LA	0.600 **	0.642 **	0.633 **	0.040	0.423 *	−0.031	−0.565 **	0.065	0.158	−0.273	−0.050	−0.512 **	0.049	−1.000 **

Here; * $p \leq 0.05$ ** $p \leq 0.013.5$.

Table 4. Stability performance of safflower accessions across five sowing dates.

Genotypes	**Yield**	$\mathbf{W_i^2}$	$\boldsymbol{\sigma^2_i}$	$\mathbf{s^2d_i}$	$\mathbf{b_i}$	**CVi**	**KR**
PI-250187	1593	147643	44720	20982	1.0	37	7
PI-208677	1425	90952	23461	3784	0.8	30	8
PI-199907	1130	80607	19582	4864	0.8	40	8
PI-198990	1991	184334	58479	5113	1.4	37	6
PI-210834	1883	77077	18258	3289	1.2	35	3
PI-314650	1483	271058	91001	34297	0.8	35	10

4. Discussion

A sowing date experiment was executed to select the optimum planting time for safflower germplasms under semi-arid and terminal heat stress conditions. This enables the selection of optimum sowing dates and better agronomic management decisions aimed at maximizing yield under the current global climate. Selection of the best optimum sowing dates provides the best environmental conditions to complete growth cycle and to obtain profitable yields of field crops including the safflower [29]. This trial evaluated several sowing times for safflowers under differential environmental conditions, i.e., growing degree days, and thus the evaluated accessions were exposed to a range of environmental conditions. Earlier studies including BLUP analyses indicated that photo-thermal conditions had a significant impact on the growth condition of field crops. For instance, climatic and edaphic factors led to significant variations in plant height among safflower accessions sown on different day and in varying locations [30]. Early and late planting resulted in a reduction in plant height which was attributed to terminal heat stress over the growing season as agreed by [31]. Generally, safflower plant height under November planting conditions led to higher measurements, proving that November has more favorable climatic conditions as compared to other sowing times. In safflower, the number of heads plant-1 is a significant yield contributor trait and this feature is influenced by the number of flowers per plant. Planting safflowers at different sowing times substantially impacted the number of heads per plant. Fluctuating temperatures negatively affect pollen formation, fertilization, and synchronization of the reproductive parts of the flower [32]. Consequently, temperature strongly influences pollen formation, resulting in a reduction in fruit setting and capitula [33]. The production potential of safflower heads per plant was influenced by growing time and the genetic potential of test accessions in safflower, as reported by [34]. It was observed that unfavorable planting time considerably affected the yield components, particularly the number of heads, seed size, and seed yield, in a diminishing manner. In the present investigation, the number of heads per plant was positively correlated with seed yield. However, in this study, the highest number of seeds per head was collected in safflowers planted on 15 December 2019. This may be due to the avoidance of the reproductive growth phase due to biotic and abiotic stresses such as chilling and frost stress during January. Late sowing may initiate earlier flowering, leading to a higher harvest index and better mobilization of photosynthates to develop a higher number of capitula [35]. Poor vegetative growth induced by low temperatures and frost stress caused a significant loss of leaves, which may reduce or slow photosynthate translocation to the reproductive parts and may reduce the number of florets and number of seeds per head [36]. Safflower thousand weight depended on sowing time and the genetic potential of the respective genotypes. Both factors significantly interacted with seed weight. Moderately higher temperatures enhanced safflower growth, development, and seed yield prior to a late planting time. Moreover, reductions in seed weight in this study were countered by a considerable increase in the number of heads per plant. High temperatures during flower setting may have had a negative influence on cell size, cotyledon development, and seed filling, leading to a lighter seed weight per plant [37]. Being planted under semi-arid conditions in Pakistan where there was insufficient rainfall, particularly during the critical reproductive phase, resulted in significantly reduced seed yields. Hence, in low rainfall areas, supplemental irrigation is required to enhance seed yields [38]. Heads per plant, seeds per capitulum, and 1000 achene weight are major yield-contributing traits with a positive relationship with the enhancement of safflower yields. Reductions in safflower yields during comparisons of the second planting with the first, third, fourth, and fifth planting times are apparently associated with unfavorable warm weather conditions during the seed setting period of 15 November 2019. Ref [39] reported that canola yields decreased by 58% when exposed to high-temperature stress in the reproductive phase that delayed the flowering period. A further 77% reduction was observed when stress was prolonged till the pod filling phase. The results of this study exposed that the significant increase in safflower yield was due to

the strong positive correlations of harvest index, thousand seed weight, heads per plant, and seeds per head with seed yield.

The lowest biological yield occurred at a later planting time which could be attributed to high temperatures hastening development, reducing the duration, and decreasing the biological yield per day from planting to harvest, as confirmed by [40]. In contrast, the first and last (1 October 2019 and 31 December 2019) planting dates resulted in lower biological yields than the other planting dates. Early and late planting hampered flowering and head formation and its occurrence during flowering and head development led to head abortion, resulting in more biomass production. However, in this study, early and late sowing caused a substantial reduction in biological yield, as supported by [41].

In safflowers, differences in fatty acid profile have been reported due to environmental and genotype characteristics [42]. Temperature and soil moisture were important factors affecting the oleic acid and linoleic acid yield under prevailing conditions. Safflower planting under different sowing dates leads to exposure to different climatic conditions. Accordingly, sowing times such as late planting significantly contributed to oleic acid yields as compared to early planting. Due to high temperatures at the terminal phase of safflower planting, considerable impact was seen regarding increased oleic acid yield at the expense of linoleic acid [43]. Moreover, terminal heat stress resulted in a higher proportion of oleic acid as compared to linoleic acid due to the activity of the desaturase enzyme that converts linoleic acid into oleic acid, as opined by [44].

Pearson correlation discussion showed that the correlation between the number of days, seeds per head, and the various traits of safflowers focuses on the relationships between different factors that influence seed yield and quality. Negative correlation was seen between the number of seeds per head and days to flowering (DF), days to maturity (DM), and growing degree days (GDD) as these traits may be inversely related to seed production [45]. It could be due to the fact that these parameters are associated with plant growth and development, which can influence the number of seeds that are produced. However, the correlation of biological yield with branches, heads, and seed yield is a direct indicator of the plant's photosynthetic efficiency. It indicates that a greater biological yield leads to an increased seed yield and contributes more dry matter for potential fodder use [46]. In addition, studies have described the negative relationship between the oleic acid and linoleic acid contents of safflower seeds sown under different sowing dates. Safflower seeds which were sown during different planting times showed that safflower accessions with a higher oleic acid content exhibited a lower linoleic acid content, highlighting the negative correlation between these two fatty acids due to high-temperature desiccation [42].

Stability analysis exposed various factors to introduce the safflower's adaptability in response to canopy geometry and resilience to abiotic stress, particularly the efficient use of nutrients and water. Accessions with more stability and yield were considered to be successful cultivars instead of unstable [47]. Generally, the 15 December 2019 sowing date had the highest yield contributor by employing safflower accession PI-198990. Stability refers to the closeness of the mean performance of the accession when evaluated over a range of environments. An accession with a higher stability index was considered as environmental proof. Some stability parameters such a W_i^2, σ^2_i, S^2d_i, and KR were assessed to select stable safflower accessions across the five sowing dates. As per [27], according to ecovalence (W_i^2), PI-199907 showed the lowest value and may be considered stable. Accessions with the lowest values of the Shukla variance (σ^2_i) were marked as stable [24]. PI-199907 reflected the lowest value and was appraised as stable, followed by PI-210834. Eberhart and Russell [26] assessed the co-efficient of regression (S^2d_i) to rank accessions for stability and accessions with a regression slope near to unity may be ranked as stable. However, as per our assessment, safflower accession PI-201834 had a co-efficient regression not far from the unity value with non-significant deviation and similar findings were assessed by [48]. Accession PI-198990 had significant variance from the regression slope and exhibited a high bi, hence it was found to be more adaptable to high-yield environments. The Kang ranking [28] showed that lower-ranking accessions

had more stable genotypes, hence yielded more seeds for safflower accessions. Thus, they are considered desirable. Accession PI-210834 is ranked lower per the results of this subject study; thus, it may have good stability and an acceptable yield, which was also confirmed by [30] in a similar fashion. Accessions with high stability may be the least affected by the environment. Accessions such as PI199907 were stable and may be considered the least affected by the environment. On the other hand, accession PI-210834 had better stability and yield and may be grown in optimum to suboptimum conditions with better yield performance [30,49] Accessions with poor stability such as PI198990 may be selected for high-production environments only under optimum sowing dates.

5. Conclusions

In conclusion, safflower accessions were evaluated across five sowing dates in Faisalabad, Pakistan. Surprisingly, safflower accessions with the highest genetic potential for seed yield were planted on 30 November 2019 and 15 December 2019. These were considered to be medium sowing dates and can be grown in the future. In addition, accession PI-210834 had good stability and better yield and thus may be recommended for cultivation under optimum and sub-optimum sowing dates. Accession stability and yield performance have practical implications for farmers and breeders seeking to improve safflower production under varying environmental conditions. PI-198990 had poor stability and may be recommended only for optimum growth conditions. This information is valuable for breeders and farmers who need to consider the specific growing conditions required for each accession to achieve optimal yields. Moreover, PI-199907 was also highly stable and may be considered as 'environmentally resilient' with a better buffering capacity against environmental fluctuations, which is crucial for ensuring food security with respect to climate change.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/horticulturae10060539/s1.

Author Contributions: M.S. and H.M.: Writing—original draft preparation, Conceptualization, Data curation, Investigation, M.A.A.A. and B.A.P.: Methodology, H.M.: Project administration, Resources, Supervision, H.M., A.K.-D., A.G., S.R., I.I. and B.A.P.: Validation, Writing—review and editing. S.R., I.I. and B.A.P.: Formal analysis. All authors have read and agreed to the published version of the manuscript.

Funding: Supported by Researchers Supporting Project Number (RSP2024R144), King Saud University, Riyadh, Saudi Arabia.

Data Availability Statement: Data are contained within the article.

Acknowledgments: This study was supported by Higher Education Commission vide project number R&D/2016/NRPU/6814 and is part of the Ph.D. thesis of the principal author. The authors would also like to extend their sincere appreciation to the Researchers Supporting Project Number (RSP2024R144), King Saud University, Riyadh, Saudi Arabia.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Golkar, P. Breeding improvements in safflower (*Carthamus tinctorius* L.): A review. *Aust. J. Crop Sci.* **2014**, *8*, 1079–1085.
2. Dajue, L.; Mündel, H.H. Safflower. In *Carthamus tinctorius L. Promoting the Conservation and Use of Underutilized and Neglected Crops*; Institute of Plant Genetics and Crop Plant Research, Gatersleben/International Plant Genetic Resources Institute: Rome, Italy, 1996.
3. Yesilyurt, M.K.; Cesur, C.; Aslan, V.; Yilbasi, Z. The production of biodiesel from safflower (*Carthamus tinctorius* L.) oil as a potential feedstock and its usage in compression ignition engine: A comprehensive review. *Renew. Sust. Energ. Rev.* **2020**, *119*, 109574. [CrossRef]
4. Steberl, K.; Hartung, J.; Graeff-honninger, S. Impact of cultivar, harvest date and threshing prameter settings on floret and carthamidin yield of safflower. *Agronomy* **2020**, *10*, 1272. [CrossRef]
5. Bar-Tal, A.; Landau, S.; Li-xin, Z.; Markovitz, T.; Keinan, M.; Dvash, L.; Brener, S.; Weinberg, Z.G. Fodder quality of safflower across an irrigation gradient and with varied nitrogen rates. *Agron. J.* **2008**, *100*, 1499–1505. [CrossRef]

6. FAOSTAT. FAOSTAT Database. 2021. Available online: http://www.fao.org/faostat/en/#home (accessed on 1 January 2018).
7. Cerrotta, A.; Lindstrom, L.I.; Echenique, V. Selection tools for oil content and fatty acid composition in safflower (*Carthamus tinctorius* L.). *Breed. Sci.* **2020**, *70*, 558–566. [CrossRef] [PubMed]
8. Emongor, V. Safflower (*Carthamus tinctorius* L.) the underutilized and neglected crop: A review. *Asian J. Plant Sci.* **2010**, *9*, 299–306. [CrossRef]
9. Heydarizadeh, P.; Sabzalian, M.R.; Khajehpour, M.R. Effect of temperature and day length on vegetative growth and yield of safflower genotypes. *J. Water Soil Sci.* **2008**, *12*, 365–376.
10. Yau, S.K. Winter versus spring sowing of rain-fed safflower in a semi-arid, high-elevation Mediterranean environment. *Eur. J. Agron.* **2007**, *26*, 249–256. [CrossRef]
11. Si, P.; Walton, G.H. Determinants of oil concentration and seed yield in canola and Indian mustard in the lower rainfall areas of Western Australia. *Aust. J. Agric. Res.* **2004**, *55*, 367–377. [CrossRef]
12. Juknevicius, S.; Pekarskas, J. Influence of safflower (*Carthamus tinctorius* L.) sowing time on seed yield, chemical composition, yield structure, growth and development. *Agriculture* **2002**, *4*, 50–59.
13. Tahmasebizadeh, H.; Khodabandeh, N.; Madani, L.; Farahani, A. Surveying the analysis of spring safflower growth and its effect on the performance in Weathers conditions of Arak. *New Find. Agric.* **2008**, *3*, 136–154.
14. Omidi, A.H.; Sharifmogadas, M.R. Evaluation of Iranian safflower cultivars reaction to different sowing dates and plant densities. *World Appl. Sci. J.* **2010**, *8*, 953–958.
15. Koutroubas, S.D.; Papakosta, D.K.; Doitsinis, A. Phenotypic variation in physiological determinants of yield in spring sown safflower under Mediterranean conditions. *Field Crops Res.* **2009**, *112*, 99–204. [CrossRef]
16. Abou Chehade, L.; Angelini, L.G.; Tavarini, S. Genotype and seasonal variation affect yield and oil quality of safflower (*Carthamus tinctorius* L.) under Mediterranean conditions. *Agronomy* **2022**, *12*, 122. [CrossRef]
17. Taylor, D.C.; Smith, M.A.; Fobert, P.; Mietkiewaska, E.; Weselake, R.J. Metabolic engineering of higher plants to produce bio-industrial oils. *Compr. Biotechnol.* **2011**, *4*, 67–85.
18. Yue, A.Q.; Sun, X.P.; Li, R.Z. Metabolic engineering of edible plant oils. *Zhi Wu Sheng Li Yu Fen Zi Sheng Wu Xue Xue Bao = J. Plant Physiol. Mol. Biol.* **2007**, *33*, 489–498.
19. Vanhercke, T.; Wood, C.C.; Stymne, S.; Singh, S.P.; Green, A.G. Metabolic engineering of plant oils and waxes for use as industrial feedstocks. *Plant Biotechnol. J.* **2013**, *11*, 197–210. [CrossRef]
20. Safdari-Monfared, N.; Noor-Mohammadi, G.; Shirani Rad, A.H.; Majidi Hervan, E. Effect of sowing date and glycinebetaine on seed yield, oil content, and fatty acids in rapeseed cultivars. *J. Agric. Sci. Technol.* **2019**, *21*, 1495–1506.
21. Velioglu, S.D.; Temiz, H.T.; Ercioglu, E.; Velioglu, H.M.; Topcu, A.; Boyaci, I.H. Use of Raman spectroscopy for determining erucic acid content in canola oil. *Food Chem.* **2017**, *22*, 87–90. [CrossRef]
22. Steel, R.G.D.; Torrie, J.H.; Dickey, D.A. *Principles and Procedures of Statistics, A Biometrical Approach*, 3rd ed.; McGraw-Hill Book Company, Inc.: New York, NY, USA; Toronto, ON, Canada; London, UK, 1997; pp. 352–358.
23. Pour-Aboughadareh, A.; Yousefian, M.; Moradkhani, H.; Poczai, P.; Siddique, K.H. STABILITYSOFT: A new online program to calculate parametric and non-parametric stability statistics for crop traits. *Appl. Plant Sci.* **2019**, *7*, 01211. [CrossRef]
24. Shukla, G.K. Some statistical aspects of partitioning genotype environmental components of variability. *Heredity* **1972**, *29*, 237–245. [CrossRef]
25. Finlay, K.W.; Wilkinson, G.N. The analysis of adaptation in a plant-breeding programme. *Aust. J. Agric. Res.* **1963**, *14*, 742–754. [CrossRef]
26. Eberhart, S.T.; Russell, W.A. Stability parameters for comparing varieties 1. *Crop Sci.* **1966**, *6*, 36–40. [CrossRef]
27. Wricke, G. Uber eine Methode zur Erfassung der okologischen Streubreite in Feldverzuchen. *Z. Pflanzenzuchtg.* **1962**, *47*, 92–96.
28. Kang, M.S. A rank-sum method for selecting high-yielding, stable corn genotypes. *Cereal Res. Commun.* **1988**, *16*, 113–115.
29. Caliskan, S.; Caliskan, M.E. Row and plant spacing effects on the yield and yield components of safflower in a mediterranean-type environment. *Turk. J. Field Crops* **2018**, *23*, 85–92. [CrossRef]
30. Sajid, M.; Munir, H.; Khaliq, A.; Murtazza, G. Estimation of Yield Potential, Oil Content and Fatty Acid Composition of Safflower in Different Ecological Zones. *J. Agric. Food* **2021**, *2*, 88–107.
31. Temirbekova, S.; Afanasyeva, Y.; Metlina, G.; Vasilchenko, S.; Kalashnikova, E. New safflower oil crops in Russia: Agronomy and Adaptability. In *Regenerative Agriculture*; Springer: Berlin/Heidelberg, Germany, 2021; pp. 261–272.
32. La Bella, S.; Tuttolomondo, T.; Lazzeri, L.; Matteo, R.; Leto, C.; Licata, M. An agronomic evaluation of new safflower (*Carthamus tinctorius* L.) germplasm for seed and oil yields under Mediterranean climate conditions. *Agronomy* **2019**, *9*, 468. [CrossRef]
33. Hall, A.E. Breeding for adaptation to drought and heat in cowpea. *Eur. J. Agron.* **2004**, *21*, 447–454. [CrossRef]
34. Jamshidmoghaddam, M.; Alizadeh, K. Study on effect of planting time on seed yield, oil content and some agronomic traits of safflower (*Carthamus tinctorius* L.) genotypes under moderate cold and cold dryland condition. *Iran. J. Dryland Agric.* **2018**, *6*, 229–245.
35. Jafari, B.; Mohsenabadi, G.; Sabouri, A. Estimation of cardinal temperatures and determination of the effects of tempera-ture and osmotic potential on safflower (*Carthamus tinctorius* L.) germination. *Environ. Stress. Crop Sci.* **2018**, *11*, 1073–1087.
36. Rauf, S. Breeding sunflower (*Helianthus annuus* L.) for drought tolerance. *Commun. Biometry Crop Sci.* **2008**, *3*, 29–44.
37. Ozturk, F. Response of sowing time on the seed yield traits, yield and quality of safflower genotypes in southestern Anatolia of Turkey. *Fresenius Environ. Bull.* **2019**, *28*, 2141–2152.

38. Bortolheiro, F.P.; Silva, M.A. Physiological response and productivity of safflower lines under water deficit and rehydration. *An. Acad. Bras. Cienc.* **2017**, *89*, 3051–3066. [CrossRef] [PubMed]
39. Khan, M.; Rauf, S.; Munir, H.; Kausar, M.; Hussain, M.M.; Ashraf, E. Evaluation of sunflower (*Helianthus annuus* L.) single cross hybrids under heat stress condition. *Arch. Agron. Soil. Sci.* **2017**, *63*, 525–535. [CrossRef]
40. Garsid, A. Sowing time effects on the development, yield and oil of flaxseed in semiarid tropical. *Aust. J. Prod. Agric.* **2004**, *23*, 607–612.
41. Franchini, M.C.; Flemmer, A.C.; Lindstrom, L.I.; Carrin, M.E.; Constenla, D.; Johnson, R.C. How sowing date affects development and performance of safflower through climate variables. *Crop Sci.* **2021**, *61*, 2775–2786. [CrossRef]
42. Oz, M. Relationship between sowing time, variety, and quality in safflower. *J. Chem.* **2016**, *2016*, 9835641. [CrossRef]
43. Sajid, M.; Munir, H.; Khaliq AMurtaza, G. Unveiling safflower yield, oil content, water use efficiency, and membrane stability under differential irrigation regimes. *Arab. J. Geosci.* **2023**, *16*, 249. [CrossRef]
44. Tonnis, B.; Wang, M.L.; Li, X.; Wang, J.; Puppala, N.; Tallury, S.; Yu, J. Peanut FAD2 genotype and growing location interactions significantly affect the level of oleic acid in seeds. *J. Am. Oil Chem. Soc.* **2020**, *97*, 1001–1010. [CrossRef]
45. Barla, A.K.; Kote, G.M.; Deshmukh, D.D. Effect of sowing dates on yield and yield attributes of safflower genotypes. *Int. J. Curr. Microbiol. Appl. Sci.* **2020**, *9*, 361–366. [CrossRef]
46. Golkar, P.; Rahmatabadi, N.; Maibody, S.A.M.M. Improvement of yield and yield stability in safflower using multivariate, parametric and non-parametric methods under different irrigation treatments and planting date. *Acta Agric. Slov.* **2020**, *115*, 315–327. [CrossRef]
47. Hasan, M.J.; Kulsum, M.U.; Sarker, U.; Matin, M.Q.I.; Shahin, N.H.; Kabir, M.S.; Marc, R.A. Assessment of GGE, AMMI, regression, and its deviation model to identify stable rice hybrids in Bangladesh. *Plants* **2022**, *11*, 2336. [CrossRef] [PubMed]
48. Cheng, M.; Fu, X.; Kang, J. Compressibility of different pore and fracture structures and its relationship with heterogeneity and minerals in low-rank coal reservoirs: An experimental study based on nuclear magnetic resonance and micro-CT. *Energ. Fuel* **2020**, *34*, 10894–10903. [CrossRef]
49. Hussain, M.M.; Rauf, S.; Noor, M.; Bibi, A.; Ortiz, R.; Dahlberg, J. Evaluation of Introgressed Lines of Sunflower (*Helianthus annuus* L.) under Contrasting Water Treatments. *Agriculture* **2023**, *13*, 1250. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.