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Entry by Tester Biplot Analysis of Sulfur and Nitrogen on Oil Characteristics of Safflower

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ABSTRACT

The influences of various sulfur and nitrogen fertilizers were evaluated on safflower agronomic traits and fatty acid profile. The fertilizer treatments were sulfur as S1 (no usage), S2 (25 kg ha^{-1} sulfur from sulfur phosphate, SP), S3 (50 kg ha^{-1} sulfur from SP), S4 (25 kg ha^{-1} sulfur from elemental sulfur, ES), S5 (50 kg ha^{-1} sulfur from ES), S6 (25 kg ha^{-1} sulfur from zinc sulfate, ZS), S7 (50 kg ha^{-1} sulfur from ZS) as well as nitrogen usage as N0, N40 and N80 (0, 40 and 80 kg ha^{-1} nitrogen) in form of urea which were tested in Baneh, Iran at 2021. The entry by tester (treatment by trait) biplot which explained 73% of the variability indicated that the N80-S7 was the best treatment for obtaining higher values for most traits like yield and oil performance as well as some fatty acids like linolenic acid. Some other unsaturated fatty acids like oleic, linoleic and arachidic acids were increased under N0-S5 treatment. Also, fatty acid profile-related traits, oil and protein properties were positively related similar to the positive correlations among agronomic traits. According to the distinction and typical abilities, N80-S7 followed by N80-S4 were detected. Based on the discriminative ability of trait, stearic acid, oil, harvest index and capitulum per plant had high discriminating ability. The current investigation underscores the positive impact of sulfur and N on safflower characteristics and emphasizes the joint application to enhance safflower performance in upland semi-arid regions regarding the best treatment as N80-S7 (80 N and 50 kg ha^{-1} sulfur from ZS, respectively).

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1. Introduction

Oilseeds are the second important source of enteric foods in mankind and livestock nutrition and among the oilseed crops, safflower has a lot in terms of seed oil quality and medicinal properties. Safflower is one of the old-world crops with a history of about 4000 years in the world and it is also a crop with wide adaptability in different regions (Sharma *et al.*, 2022). Safflower (*Carthamus tinctorius*) is an ancient crop, with a history spanning approximately 4000 years, and is known for its wide adaptability to various regions. (Sharma *et al.*, 2022). Safflower is grown in nearly 18 countries, with a global cultivated area of 1.12 million hectares and an average seed production of 948 kg ha^{-1} in 2022. In Iran, the safflower cultivation area is 36500 hectares, with an average yield of 1325 kg ha^{-1}. Other high-yielding countries include Mexico (2000 kg ha^{-1}), Tajikistan (1600 kg ha^{-1}), China (1500 kg ha^{-1}), and the United States (1400 kg ha^{-1}) (FAOSTAT, 2022). Safflower is known for its valuable traits, including compatibility with arid and semi-arid climates, high oil quality, and tolerance to non-living pests. It also has both spring and autumn varieties. Its superior oil quality and greater tolerance to adverse environmental conditions, such as drought and salinity, have made it the subject of numerous research studies (Anas *et al.*, 2020). In arid and semi-arid areas, soil organic content serves as a natural nitrogen source for plants, but water stress hinders nitrogen absorption. After moisture stress, nitrogen deficiency becomes the primary factor limiting yield productivity. Since nitrogen is essential for crop growth and development, careful management of its use throughout the plant's growth cycle is crucial (Mosupiemang *et al.*, 2022). Nitrogen is a vital element

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for plants, found in proteins, nucleic acids, and chlorophyll. Providing an adequate amount of nitrogen and ensuring its availability during key phenological stages of plant growth can enhance crop yield (Brar and Vashist, 2020). Therefore, it is important to remember that the excessive use of nitrogenous fertilizers in plants reduces the availability of carbohydrates for oil synthesis while increasing protein synthesis.

Sulfur is an essential nutrient for all living organisms and is commonly used to lower soil pH. It is especially beneficial in arid and semi-arid environments, where it improves the properties of sodium and saline-sodium soils and enhances the absorption of nutrients like zinc, iron, and phosphorus. In most field crops, the ideal nitrogen-to-sulfur ratio is around 10:15, while for oil crops, this ratio should be less than 10 to achieve high yields and improve quality (Sintim *et al*., 2015). Sulfur is essential for protein and enzyme production, as it contributes to the formation of the amino acids; methionine and cysteine. It also plays a key role in synthesizing chlorophyll, vitamins such as thiamine and biotin, glutamine, and coenzyme A. Additionally, sulfur enhances plant resistance to diseases, drought, and cold, and helps prevent the accumulation of nitrates in plant tissues (Künstler *et al.*, 2020). The application of sulfur boosts dry matter production and enhances yield components of safflower, such as increasing the number of capitula per unit area (Sefaoğlu, 2021). Given the importance of safflower as an oilseed crop, along with the calcareous and highly acidic soils in Iran that reduce nutrient availability, the need to apply sulfur is evident. This will help increase oil production in the plant and improve soil conditions.

The interaction between elements, particularly nitrogen and sulfur, is crucial for the growth and performance of field crops, especially safflower. These elements play a key role in the plant's life cycle, with their interaction being essential for maintaining a sulfur balance. Kulczycki (2021) reported a positive interaction between nitrogen and sulfur sulfate, which enhanced grain yield, oil percentage, and nutrient absorption. Due to the high solubility of nitrogenous fertilizers and limited root development at planting, precise experiments are needed to determine the optimal fertilizer amounts for different crops, ensuring efficient use and reducing chemical fertilizer consumption. Given this, the application and balance of nitrogen and sulfur are crucial for optimizing crop performance under the mentioned conditions. Therefore, this research was conducted to examine the effect of sulfur fertilizer application at different nitrogen levels on safflower.

2. Materials and methods

2.1. Trial

The research was conducted in a split-plot design based on a randomized complete block scheme with three replicates in Baneh, Iran, during the 2021 growing season, which received 150 mm of rainfall. The main factor was sulfur, with the following treatments: S1 (no sulfur), S2 (25 kg ha^{-1} sulfur from phosphate sulfate, SP), S3 (50 kg ha^{-1} sulfur from SP), S4 (25 kg ha^{-1} sulfur from elemental sulfur fertilizer, ES), S5 (50 kg ha^{-1} sulfur from ES), S6 (25 kg ha^{-1} sulfur from zinc sulfate, ZS), and S7 (50 kg ha^{-1} sulfur from ZS). The sub-factor was nitrogen application, with treatments N0, N40, and N80 (no nitrogen, 40 kg ha^{-1}, and 80 kg ha^{-1} nitrogen from urea, respectively). Sulfur treatments were applied before sowing, while nitrogen treatments were applied at sowing, stem elongation, and capitulum presence stages. Variety ZY-S (from China) was planted by hand in April at a depth of 3 cm and spaced 10 cm apart. Irrigation was carried out after sowing, and weeding was done manually.

Harvesting was done at maturity, and ten randomly selected plant samples from each experimental unit were used to measure the following parameters: plant height (PH), capitulum diameter (CD), capitula per plant (CP), seeds per plant (SP), and seed yield (SY). The harvest index (HI) was calculated as the ratio of SY to biomass. Random samples from each unit were used to measure thousand seed weight (TSW). Chlorophyll content (CHL) was recorded using a SPAD-02 Plus chlorophyll meter (Konica Minolta Optics, Japan). Oil extraction was performed by mixing seed samples with hexane at a 1:5 ratio, and stirring for 24 hours. For the methyl ester process, 50 ml of the mixture was poured into a tube, adding 1 ml of hexane and shaken with 100 µL of methoxide methanolic sodium (Ortega *et al.*, 2004). The hexane layer was removed, and sodium sulfate was used to eliminate moisture. To prepare for gas chromatography (Agilent 6890N, USA), 1 µL of the hexane phase was collected. The sample was injected into an FFAP-TC capillary column with an FID detector, using nitrogen as the carrier gas, to analyze the fatty acid profile, including oleic acid (18:1, OLE), stearic acid (18:0, STE), palmitic acid (16:0, PAL), linoleic acid (18:2, LINL), linolenic acid (18:3, LINN), and arachidic acid (20:0, ARA). Additionally, oil percentage (OIL), ash percentage (ASH), and protein content (PRO) were measured.

2.2. Statistical analysis

The data were analyzed using the entry-by-tester biplot model via GGEbiplot, which provides a graphical representation of the interaction structure of the measured traits (testers) across the treatments (entries) (Equation 1).

$$\frac{Y_{ij} - \overline{Y_j}}{SD_j} = \sum_{n=1}^{2} \Phi_n \Psi_{in} \Omega_{jn} + R_{ij} \quad (1)$$

Y_{ij} is the mean of each treatment or entry i for each trait or tester j, $\overline{Y_j}$ is the mean of entries for tester j, SD_j is the standard deviation of tester j for entries, Φ_n is the eigenvalue for PC n, Ψ_{in} and Ω_{jn} are values for entry i and tester j on PC n, R_{ij} is the error term of the fitted equation related to treatment i for trait j (Yan, 2019). Additionally, to achieve symmetrical scales for testers and entries, the eigenvalue is corrected through vector absorption, ensuring a normalized presentation of testers and entries.

3. Results and discussion

The first and second principal components (PCs) accounted for 73% of the variability (Fig. 1), with the first PC contributing 51% and the second PC contributing 22% to the explained variance. This variability in the entry-by-tester interaction highlights the significant role of both additive and crossover interactions, which cause the treatment ranks to change across traits. These results align with findings in sunflower research (Sabaghnia and Janmohammadi, 2023), emphasizing the challenge of selecting the best treatments without considering the entry-by-tester interaction. Therefore, the biplot method is recommended as a useful and effective statistical tool for treatment selection.

It has been reported that the biplot model effectively explores treatments and traits. Fig. 1 visually demonstrates the response of nitrogen and sulfur fertilizers, highlighting which treatments performed better for target traits. Most traits, including agronomic ones like plant height (PH), capitulum diameter (CD), capitula per plant (CP), seeds per plant (SP), seed yield (SY), harvest index (HI), and thousand seed weight (TSW), as well as fatty acid profiles like stearic acid (STE) and linolenic acid (LINN), oil percentage (OIL), and protein content (PRO), were grouped in the N80-S7 section. Palmitic acid (16:0, PAL) was distinct, with N40-S7 as the best treatment. Additionally, N0-S5 was the most effective treatment for achieving high levels of oleic acid (OLE), linoleic acid (LINL), and arachidic acid (ARA). N40-S1 showed high ash percentage (ASH), while N80-S1 (80 kg ha^{-1} nitrogen with no sulfur) resulted in high chlorophyll content (CHL). However, the N0-S1 treatment (no nitrogen or sulfur) was not the best for the measured traits (Fig. 1).

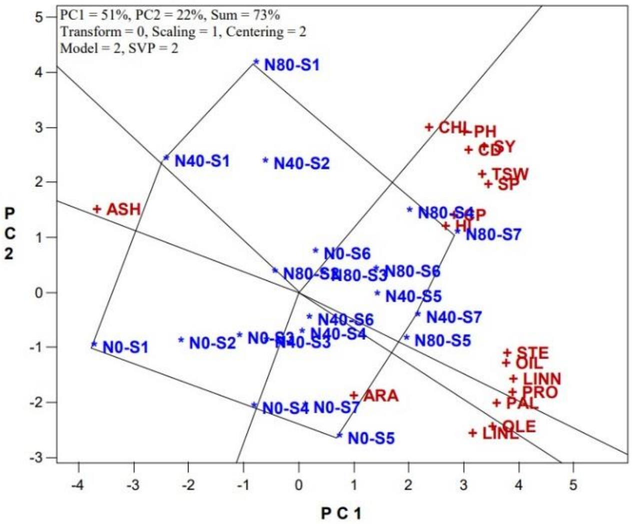

Figure 1. Which fertilizer treatment wins which trait of safflower? Treatments are seven sulfur levels as: S1 (no usage), S2 (25 kg ha^{-1} sulfur from sulfur phosphate), S3 (50 kg ha^{-1} sulfur from sulfur phosphate), S4 (25 kg ha^{-1} sulfur from elemental sulfur), S5 (50 kg ha^{-1} sulfur from elemental sulfur), S6 (25 kg ha^{-1} sulfur from zinc sulfate), S7 (50 kg ha^{-1} zinc sulfate), and three nitrogen levels as N0 (0 kg ha^{-1}), N40 (40 kg ha^{-1}) and N80 (80 kg ha^{-1}). Traits are: PAL, palmitic acid 16:0; STE, stearic acid 18:0; OLE, oleic acid 18:1; LINL, linoleic acid 18:2; ARA, arachidic acid 20:0; LINN linolenic acid 18:3; OIL, oil percent; ASH, ash percent; PH, plant height; CD, capitulum diameter; CP, capitula per plant; SP, seeds per plant; SY, seed yield; HI, harvest index; TSW, thousand seeds weight; and CHL, chlorophyll content.

The yield performance of safflower is primarily influenced by components such as capitula per plant, seeds per plant, and thousand seed weight, as well as unsaturated linolenic acid and lower levels of the harmful saturated stearic acid, with the application of 80 kg ha^{-1} nitrogen and 50 kg ha^{-1} sulfur from ZS. It has been established that linoleic acid is a key oil component of safflower, and the most favorable cultivars exhibit both high-yield performance and high linoleic acid content (Erbaş *et al.*, 2024). The entry-by-tester biplot provided valuable insights into the response of safflower traits under various fertilizer treatments, helping to identify the best treatment. Based on these findings, for practical recommendations, farmers in semi-arid regions can consider applying higher rates of nitrogen and sulfur for improved safflower production.

The correlation among testers (Fig. 2) illustrates the relationships between safflower traits, with the cosine of the traits' lines toward the center indicating the strength of these relationships. Traits are positively associated with angles smaller than 90°, negatively correlated with angles larger than 90°, and are unrelated at a 90° angle. Longer trait vectors indicate significant relationships, while shorter vectors suggest no significance, and traits positioned at the center show no significant relation with others. Fig. 2 illustrates that the fatty acid profile, oil, and protein are positively related, as indicated by the small acute angles between them. Additionally, agronomic traits (PH, CD, CP, SP, SY, HI, and TSW) and CHL show positive associations with acute angles. In contrast, there is a negative relationship between ASH and the fatty acid profile, as shown by the obtuse angles. The relationship between ASH and agronomic traits is nearly zero, as represented by their 90° angle, as well as the relationship between the fatty acid profile and agronomic traits. The predictions from the entry-by-tester interaction biplot model for trait relationships align closely with the numerical correlations (Table 1), though some minor inconsistencies were noted, likely due to the model's 73% variation explanation, rather than 100%. It was found that safflower oil contains a high proportion of unsaturated fatty acids (oleic, linoleic, and linolenic) and lower levels of the less beneficial saturated acid (stearic), making it a desirable source of healthy oil that may positively impact cholesterol levels (Amirkhiz *et al.*, 2021).

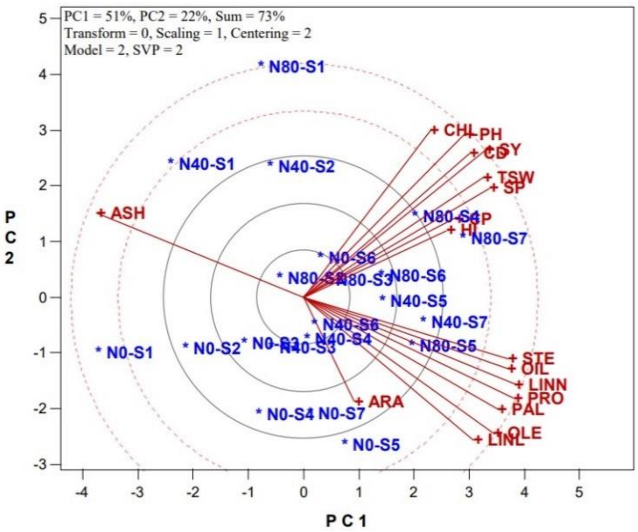

Figure 2. Graphic presentation of interrelationships among measured traits of safflower. Traits are: PAL, palmitic acid 16:0; STE, stearic acid 18:0; OLE, oleic acid 18:1; LINL, linoleic acid 18:2; ARA, arachidic acid 20:0; LINN linolenic acid 18:3; OIL, oil percent; ASH, ash percent; PH, plant height; CD, capitulum diameter; CP, capitula per plant; SP, seeds per plant; SY, seed yield; HI, harvest index; TSW, thousand seeds weight; and CHL, chlorophyll content.

Table 1. Pearson's coefficient of correlations among measured traits of safflower

	PH	CHL	CP	CD	TSW	SP	SY	HI	Ash	Oil	Pro	Pal	Ste	Ole	Linl	Ara
CHL	0.93															
CP	0.42	0.33														
CD	0.92	0.88	0.46													
TSW	0.72	0.69	0.64	0.75												
SP	0.70	0.56	0.57	0.64	0.74											
SY	0.84	0.66	0.62	0.76	0.77	0.87										
HI	0.46	0.19	0.63	0.34	0.38	0.64	0.74									
Ash	-0.33	-0.20	-0.46	-0.33	-0.48	-0.42	-0.40	-0.41								
Oil	0.37	0.23	0.34	0.43	0.44	0.47	0.42	0.45	-0.70							
Pro	0.26	0.14	0.37	0.35	0.46	0.47	0.38	0.38	-0.82	0.80						
Pal	0.21	0.06	0.38	0.27	0.30	0.43	0.33	0.31	-0.78	0.78	0.86					
Ste	0.34	0.25	0.41	0.31	0.54	0.62	0.45	0.35	-0.84	0.63	0.75	0.73				
Ole	0.16	0.07	0.24	0.22	0.30	0.38	0.20	0.19	-0.79	0.83	0.86	0.90	0.82			
Linl	0.15	0.06	0.12	0.19	0.22	0.21	0.20	0.17	-0.77	0.65	0.81	0.75	0.72	0.78		
Ara	-0.04	-0.05	-0.07	0.02	-0.08	-0.09	-0.09	0.05	-0.28	0.28	0.30	0.18	0.14	0.24	0.46	
Linn	0.37	0.29	0.45	0.43	0.42	0.39	0.38	0.37	-0.80	0.86	0.85	0.77	0.70	0.84	0.80	0.39

Critical correlation values, degrees of freedom=19 and P<0.01 are 0.43 and 0.55, respectively. Traits are: PAL, palmitic acid 16:0; STE, stearic acid 18:0; OLE, oleic acid 18:1; LINL, linoleic acid 18:2; ARA, arachidic acid 20:0; LINN linonenic acid 18:3; OIL, oil percent; ash percent (ASH); PH, plant height; CD, capitulum diameter; CP, capitula per plant; SP, seeds per plant; SY, seed yield (SY); HI, harvest index; TSW, thousand seeds weight; and CHL, chlorophyll content.

The potential of a treatment to distinguish traits and its ability to represent the main characteristics of a treatment can be assessed using an ideal treatment position, known as the "perfect position" (Fig. 3).

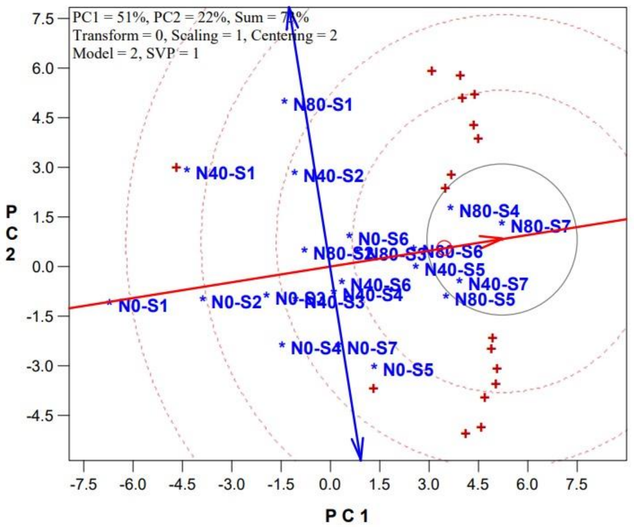

Figure 3. Ranking fertilizer treatments based on measured traits of safflower. Treatments are seven sulfur levels as: S1 (no usage), S2 (25 kg ha^{-1} sulfur from sulfur phosphate), S3 (50 kg ha^{-1} sulfur from sulfur phosphate), S4 (25 kg ha^{-1} sulfur from elemental sulfur), S5 (50 kg ha^{-1} sulfur from elemental sulfur), S6 (25 kg ha^{-1} sulfur from zinc sulfate), S7 (50 kg ha-1 zinc sulfate), and three nitrogen levels as N0 (0 kg ha^{-1}), N40 (40 kg ha^{-1}) and N80 (80 kg ha^{-1}).

The best treatments are those closest to this position, while those farther away are less effective. In this study, N80-S7, followed by N80-S4, are considered ideal because they are closest to the perfect position. In contrast, N0-S1 (no nitrogen and no sulfur), followed by N0-S2 (no nitrogen and 25 kg ha^{-1} sulfur from SP), and N40-S1 (40 kg ha^{-1} nitrogen and 25 kg ha^{-1} sulfur from SP), are far from this ideal position and are therefore the least desirable treatments in terms of distinguishing traits and typical performance. Ideal treatments can be considered as ideotypes, showing high performance in most traits. However, challenges arise when trait associations are not always significant. This is particularly important in safflower production, where seed yield, fatty acid profile, and other agronomic traits are crucial for achieving high-yield performance. However, the use of multivariate statistical models with visual output is crucial for identifying the ideotype treatment in safflower. Ultimately, the best treatment was identified as N80-S7, indicating that the application of high nitrogen and sulfur from zinc sulfate sources is effective for achieving optimal results. This supports the findings of several researchers, who have shown that higher nitrogen and sulfur absorption, along with improved yield performance, is achieved through the application of higher nitrogen levels (Dawar *et al.*, 2022). It appears that high sulfur usage can enhance nitrogen absorption, thereby increasing fertilizer use efficiency by improving the chemical conditions of the soil (Ashraf *et al.*, 2016).

The discriminative ability of a trait is determined by its standard deviation, with higher ability being associated with traits closer to the "perfect trait" position (Fig. 4). Thus, the most favorable traits are located near this position, while those farther away are less ideal. In this study, traits like STE, OIL, HI, and CP exhibited high discriminative ability. However, the discriminative ability for all other traits, except ASH, was higher than the average, meaning they could still discriminate differences among the applied treatments (Fig. 4).

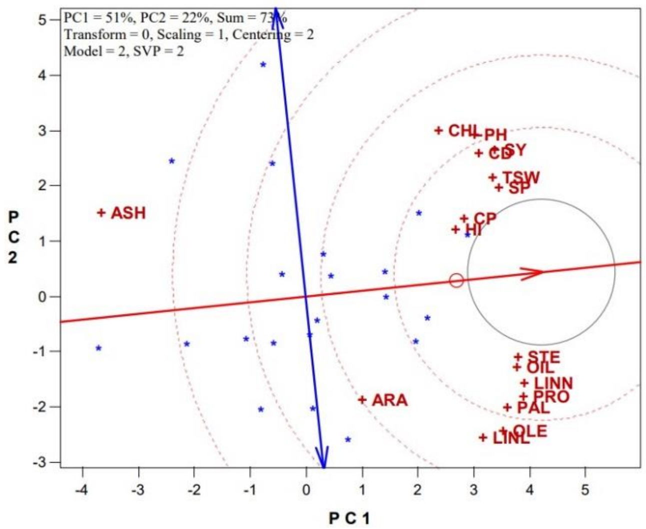

Figure 4. Ranking of traits according to discriminating and representativeness abilities. Traits are: PAL, palmitic acid 16:0; STE, stearic acid 18:0; OLE, oleic acid 18:1; LINL, linoleic acid 18:2; ARA, arachidic acid 20:0; LINN linolenic acid 18:3; OIL, oil percent; ASH, ash percent; PH, plant height; CD, capitulum diameter; CP, capitula per plant; SP, seeds per plant; SY, seed yield; HI, harvest index; TSW, thousand seeds weight; and CHL, chlorophyll content.

The typical ability of a trait, which reflects how well it represents the figurative characteristics of a treatment, is determined by its angle with the horizontal axis, representing the mean of all traits. A smaller angle indicates greater typical ability. Consequently, the more favorable traits (STE, OIL, HI, and CP) had smaller angles with the axis, indicating higher typical ability. In contrast, traits like CHL, ARA, and LINL had larger angles and therefore lower typical ability (Fig. 4). Similarly, previous research has shown that traits such as capitula, oil percentage, and harvest index have high discriminative ability in safflower (Ghanbari *et al.*, 2022), while other studies suggest that seed yield and capitulum traits also exhibit significant discriminating ability in safflower (Ebrahimi *et al.*, 2023).

The effects of fertilizer treatments on yield performance are shown in Fig. 5, where the yield axis is indicated by a line, and an arrow represents its direction. Among the treatments, N80-S7, followed by N80-S4 (80 kg ha^{-1} nitrogen and 25 kg ha^{-1} sulfur from elemental sulfur), and N80-S1 (80 kg ha^{-1} nitrogen with no sulfur), were the most favorable for yield performance. In contrast, N0-S1 (no nitrogen or sulfur), N0-S2 (no nitrogen and 25 kg ha^{-1} sulfur from phosphate sulfate), and N0-S4 (no nitrogen and 25 kg ha^{-1} sulfur from elemental sulfur) were the least favorable treatments for yield (Fig. 5).

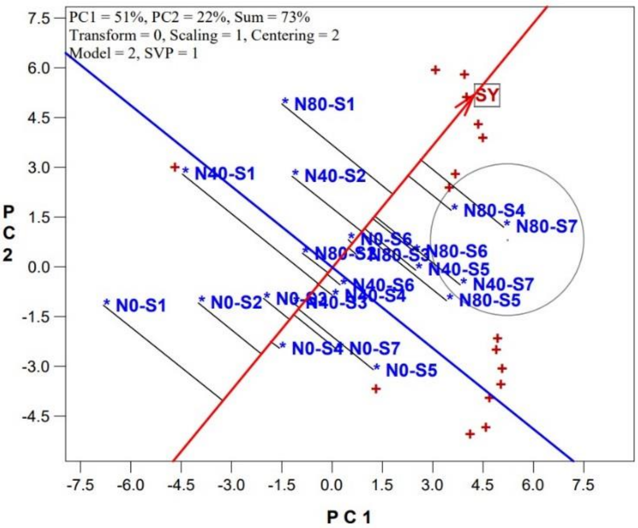

Figure 5. The performance of/at seed yield (SY) across various fertilizer treatments. Treatments are seven sulfur levels as: S1 (no usage), S2 (25 kg ha^{-1} sulfur from sulfur phosphate), S3 (50 kg ha^{-1} sulfur from sulfur phosphate), S4 (25 kg ha^{-1} sulfur from elemental sulfur), S5 (50 kg ha^{-1} sulfur from elemental sulfur), S6 (25 kg ha^{-1} sulfur from zinc sulfate), S7 (50 kg ha-1 zinc sulfate), and three nitrogen levels as N0 (0 kg ha^{-1}), N40 (40 kg ha^{-1}) and N80 (80 kg ha^{-1}).

The distance of treatments from the SY axis indicates their standard deviation, with smaller distances being more favorable. Therefore, N80-S4, with its low variation, can be considered a suitable choice. For example, the treatment N40-S1 (40 kg ha^{-1} nitrogen and no sulfur) resulted in a low yield, even below the average (blue axis), and had a greater distance from the SY axis, indicating higher variation, making it one of the most unfavorable treatments. The application of nitrogen and sulfur led to an increase in seed yield, highlighting the importance of meeting nutritional requirements. This combination may help translate photo-assimilates into seeds and improve the economic components of safflower production, which is particularly crucial for managing safflower in rainfed, semi-arid environments (Beyyavas and Dogan, 2022). Achieving high seed yield in safflower requires balancing plant nutritional components, and in sodium and saline-sodium soils of semi-arid regions, using nitrogen without sulfur is not an efficient approach.

This study found that the fatty acid profile of safflower, consisting of both saturated and unsaturated components, is influenced by nutrient management, with the amount and source of applied fertilizers affecting the oil's quality. In semi-arid environments, soils often face fertility issues, such as high pH and low nutrient absorption, which can negatively impact oil quality (Soleymanifard *et al.*, 2022). To obtain high-quality oil with unsaturated fatty acids like linoleic, oleic, and linolenic acids, the application of 50 kg ha^{-1} of zinc sulfate (ZS) or elemental sulfur (ES) is essential. Similarly, research on rapeseed highlights the importance of jointly managing sulfur and nitrogen to maintain a balance between these nutrients, rather than relying on a single nutrient, which can improve oil quality (Poisson *et al.*, 2019). These conclusions highlight the synergistic relationships among nutrients, where providing one nutrient in optimal amounts enhances the absorption of others, promoting crop development and growth, and leading to higher quality and quantity of yield. One key aspect of the interaction between sulfur and nitrogen is their impact on sulfite reductase, with nitrogen potentially reducing enzymatic inhibition (Brychkova *et al.*, 2015). Sulfite reductase plays a significant role in crop growth, particularly in the light reaction of the photosynthetic system. In semi-arid soils, zinc deficiency is another concern, as the application of zinc sulfate positively influences both seed yield and the fatty acid profile. Therefore, future research should explore the interaction between zinc, sulfur, and nitrogen to better understand their combined effects on crop performance.

4. Conclusion

This study demonstrated that both the quantity and quality of safflower, in terms of agronomic traits and fatty acid profile, are influenced by nitrogen and sulfur fertilizer management. The N80-S7 treatment (80 kg ha^{-1} nitrogen and 50 kg ha^{-1} sulfur from zinc sulfate) was identified as the best for achieving higher values in most traits, including seed yield, oil performance, and linolenic acid content. Additionally, other unsaturated fatty acids such as oleic, linoleic, and arachidic acids were enhanced under the N0-S5 treatment (no nitrogen application and 50 kg ha^{-1} sulfur from elemental sulfur).

Abbreviation

PAL, palmitic acid 16:0; STE, stearic acid 18:0; OLE, oleic acid 18:1; LINL, linoleic acid 18:2; ARA, arachidic acid 20:0; LINN linolenic acid 18:3; OIL, oil percent; ASH, ash percent; PH, plant height; CD, capitulum diameter; CP, capitula per plant; SP, seeds per plant; SY, seed yield; HI, harvest index; TSW, thousand seeds weight; and CHL, chlorophyll content.

Conflict of interests

All authors declare no conflict of interest.

Ethics approval and consent to participate

No humans or animals were used in the present research. The authors have adhered to ethical standards, including avoiding plagiarism, data fabrication, and double publication.

Consent for publications

All authors read and approved the final manuscript for publication.

Availability of data and material

All the data are embedded in the manuscript.

Authors' contributions

Mohsen Janmohammadi performed experiment and measured traits, Naser Sabaghnia designed, analyzed and wrote manuscript, Mojtaba Nouraein edited the text, and all authors read and checked the manuscript.

Informed consent

The authors declare not to use any patients in this research.

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