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SULFUR APPLICATION IMPROVES THE YIELD AND QUALITY OF SUNFLOWER (*HELIANTHUS ANNUUS* L.) HYBRIDS

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SUMMARY

Sunflower (*Helianthus annuus* L.) is a globally prominent oil seed. Sulfur is a vital nutrient that plays a crucial role in the growth and development of crop plants. Compared with other crops, oilseed crops require more sulfur for their role in oil biosynthesis and as an essential constituent of amino acids, vitamins, proteins, and enzyme structure. Its deficiency results in poor utilization of NPK and, ultimately, crop reduction in yield and quality. Hence, the study investigated the effect of different levels of sulfur on the harvest and quality attributes of various sunflower hybrids. The experiment comprised four sulfur levels (0, 20, 30, 40, and 50 kg per ha) and four sunflower hybrids coded as C124 × RH344, C112 × RSIN82, C116 × RH344, and C208 × RH445. The recorded data underwent analysis statistically using Fisher's analysis of variance technique, and treatment means comparison followed Tukey's honest significant difference test (HSD) at a 5% probability level. The results showed maximum plant height at maturity (75.80 cm), head diameter (17.90 cm), leaf area per plant (2,309.21 mm^2), 100-achene weight (10.60 g), achene yield (2,806.61 kg ha^{-1}), harvest index (26.58%), and oil content (48.46%), while minimum days to flower initiation (40.33 days) were evident when sowing hybrid C124 × RH344 with an application of 20 kg per ha sulfur.

Keywords: Sunflower (*Helianthus annuus* L.), hybrids, sulfur, growth and yield traits, quality

Key findings: The 20 kg per ha application of sulfur performed best among all sulfur levels and hybrid C124 × RH344 gave superior performance among all four sunflower hybrids. Hence, sowing of hybrid C124 × RH344 with 20 kg per ha sulfur combined with recommended NPK (120–60–60 kg ha^{-1}) improved sunflower hybrids' growth, yield, and quality.

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INTRODUCTION

Sunflower (*Helianthus annuus* L.) is an exceptional oilseed crop with great nutritional benefits due to its high concentration of linoleic acid. Its oil is of excellent quality, with unsaturated fatty acids and anti-cholesterol properties. Sunflower yields high oil and is an early-maturing, short-duration crop. It can survive under a wide range of climatic and soil conditions. Moreover, it is less sensitive to photothermal, requires less water, and is more responsive to agronomic practices. It is an oilseed crop with more area under cultivation and more oil yield than other oilseed crops (Adeleke and Babalola, 2020). It is a globally indispensable oilseed crop due to the high contents (900 g kg^{-1}) of unsaturated fatty acids in the oil, making it the best source of vegetable oil, second to soybean. Likewise, it is a potential oilseed crop that can increase oil production by applying adequate nutrients (Adeleke and Babalola, 2020). Its seeds are rich sources of mineral nutrients, such as, iron, magnesium, selenium, zinc, potassium, and vitamins. Direct consumption of its seeds enhances digestion, cardiovascular system functions, and brain strengthening (Hu *et al*., 2019).

Sunflower introduction in Pakistan was first as an oilseed crop in the 1960s, cultivated in different parts of the country. During 2020–2021, the area under sunflower cultivation increased from 61,108 (151000 acres) to 102,385 ha (253000 acres) with 2,723,000 t of production and a per hectare yield of 1,076 kg (Anonymous 2021–2022). Its cultivation is best on acidic to alkaline soil, having a pH range from 6.0 to 7.5. It is an extensive crop that feeds heavily from the earth yet depletes nutrients fast, hence, needing more nutrients than other oil seed crops (Geetha *et al*., 2012; Rana *et al.,* 2015; Dudhe *et al*., 2017). Pakistan, producing only 30% locally, tries to meet its 70% domestic edible oil needs by importing from other countries. Pakistan requires around 3 million t of cooking oil annually for domestic use, with about 0.646 million t produced in the country and the remaining 2.32 million t imported, valued at 720.2 million USD (207 billion PKRs) (PARC, 2019). There is a wide gap between potential yield and national yield. According to one estimate, yield-limiting factors (weeds infestation, inappropriate management practices, and improper nutrition) caused the non-achievement of about 69% yield of sunflowers (PARC, 2019).

Knowing the key issues that reduce the yield is imperative (Ravikumar *et al.*, 2016). The primary constraints related to lower harvests are weed infestation, small land holdings, poor farmers, unavailability of high-yielding varieties, inadequate management practices, and insufficient application of proper nutrients to sunflower crops (Kastner *et al.,* 2014). Among all yield-reducing constraints, unavailable high-yielding sunflower hybrids to farmers and applying insufficient nutrients to sunflower crops are the most common. High-yielding crosses play an influential role in achieving high yields of sunflowers. If farmers do not select high-yielding hybrids and improved management practices, it will result in lower yield, wasted resources, and, ultimately, higher production costs (Rauw *et al*., 2020). The performance and response of sunflower hybrids vary from location to location and agronomic practices. Therefore, there is a dire need to select a high-yielding sunflower hybrid responding to management practices (Sher *et al*., 2018). Sulfur is an essential nutrient for oil seed crops, especially for obtaining high protein and oil contents and achene yield, as it improves soil quality due to its function in different enzymatic activities and seed formation (Naser *et al*., 2012). The sulfur application significantly increased plant height, biological yields, dry biomass, achene yield, head diameter, and oil contents of sunflowers (Saleem *et al*., 2019; Kundu *et al.*, 2022).

Some studies have shown that the soil of Pakistan lacks available sulfur, thus, affecting the yield of other oilseed crops and sunflowers (Khalid *et al.,* 2011). Sulfur is the fourth most critical elemental plant nutrient, after NPK (Zenda *et al*., 2021). Sulfur is one of the most necessary components of cysteine, methionine, amino acids, and chlorophyll (Narayan *et al*., 2022). All oilseed crops need more sulfur for synthesizing oil and the formation of bold grains to produce oil. Consequently, the sulfur requirement of oil seed crops is higher for proper growth, development, and oil contents (Saleem *et al*., 2019). Sulfur also plays a significant role in enhancing the achene yield of sunflowers and increasing the efficacy of applied crop nutrients like phosphorus and nitrogen (Najar *et al*., 2011).

Sulfur application with other nutrients (NPK recommended dose) increased dry matter yield, plant height and achene weight, head diameter, oil contents, and biological outputs of oilseed crops compared with its non-application with other nutrients (Babu and Hegde, 2010). Bonari *et al.* (2013) depicted that increasing the applied amount of sulfur led to an increased yield of sunflower crops. The sulfur requirement of crops varies from crop to crop and growth stages. However, oil seed crops need more sulfur for oil biosynthesis than cereal crops. About 16 kg per ha sulfur is required to increase the achene yield to one ton. Barbara *et al*. (2008) stated that obtaining optimum achene yield and good quality oil of sunflower results from applying sulfur. Hence, it is urgent to select high-yielding sunflower hybrids and optimize the dose of sulfur to obtain maximum achene yield and quality sunflower oil. Therefore, the latest study aimed to assess the performance of sunflower (*Helianthus annuus* L.) hybrids under varying sulfur levels under agro-climatic conditions in Sargodha, Pakistan.

MATERIALS AND METHODS

Experimental site

A field study designed during the spring of 2020 determined the effect of sulfur application on the yield and quality of different sunflower (*Helianthus annuus* L.) hybrids at the College of Agriculture, University of Sargodha, Pakistan. Soil analysis of the site preceded the experiment. The soil samples collection used a soil auger at a depth of 15 cm. The soil was well drained and sandy loam with a pH of 7.9, containing organic matter (OM, 0.93%), total N contents at .047% (477 ppm), available phosphorus (8 ppm), available sulfur (2.01 ppm), and available potassium (150 ppm).

Experimental design and the treatments

The study consisted of a randomized complete block design with a split-plot arrangement having four replications. The net plot size was 3 m × 2.1 m, having a row-to-row distance of 75 cm and a plant-to-plant distance of 20 cm. The study comprised two factors: sunflower hybrids and sulfur levels. Sulfur levels tested were 0, 20, 30, 40, and 50 kg per ha, and sunflower hybrids selected were H_1 = C124 × RH34, H_2 = C112 × RSIN82, H_3 = C116 × RH344, and H_4 = C208 × RH445. Sunflower hybrids remained in the main plot, while sulfur levels were in the subplots.

Crop husbandry

The experimental seedbed started by cultivating the field twice with a tractor-mounted cultivar, followed by planking. The seed sown manually had a seed rate of 2.5 kg ha^{-1} in respective plots, followed by different levels of sulfur application, according to the treatment plan. The hybrids of sunflowers came from the Department of Plant Breeding and Genetics, College of Agriculture, University of Sargodha, Pakistan. First irrigation immediately ensued after sowing, then applying subsequent irrigations every 15 days interval had five irrigations. Thinning the crop at two to four leaf stages maintained a plant × plant distance of 20 cm. All agronomic practices, such as, irrigation, hoeing, and plant protection, proceeded uniformly. Manual crop harvesting ensued when 90% achene per head reached maturity, with threshing also done manually.

Observations

Data recording of the following parameters used standard procedures: Leaf area per plant (mm^2) measurement by a leaf area meter (CI-202, Portable Laser Leaf Area Meter) on a randomly selected plant; the height of three plants with a meter rod, choosing three plants from respective plots, then calculating the average plant height; determination of head diameters on heads of three randomly selected plants with the help of a measuring tape, then, averaged; 100-achene weight from randomly selected 100 achenes from each treatment, the achene yield per ha measurement included heads removed from each treatment, then sun-dried, thrashed manually, with seeds cleaned and weighed by using an electric balance, subsequently converted into kg per ha. The harvest index (HI) is determined by taking the ratio between achene yield to biological yield, then expressed in percent (%).

HI (%) = (Grain yield / Biological yield) × 100

Days to flower initiation is the duration between the sowing date and flower initiation. Its recording began from the sowing date to about 5% of the opened flower in each plot. Determining oil contents of sunflower achene used Soxhlet fat extraction method, as described by Sambucetti and Zuleta (1996). The process comprised seeds dried at 105 °C in an oven for about 8 h. For analysis, grinding about two grams of achene per thimble ran in a grinder, where thimbles weighed separately had ground seeds added to it, then, recording the final weight. After that, placing the thimbles in the extraction apparatus, the weighing and recording of six clean and dry round bottom flasks followed. Adding petroleum ether as a solvent to the flasks and then connecting to extractors, these were placed on heating mantles and attached with condensers., Extraction continued for about 6 h by heating the flasks. After stopping the extraction and removing the thimbles, the flask continued reheating to collect all the solvents in the Soxhlet extractors. Then, allowing the apparatus to cool down and the flasks to dry at 105 °C for 1 h, weighing all the oil proceeded.

Statistical analysis

The analysis of variance (ANOVA) technique helped analyze the collected data of the experiment, with treatment means compared using the LSD test at a 5% probability level (Steel *et al*., 1997).

RESULTS

Growth and yield traits

Different sulfur levels significantly affect yield and yield-contributing traits of different sunflower hybrids. Statistically, sunflower plant height had different levels of sulfur and various crossbreeds influencing it (Table 1). Sulfur application at 20 kg per ha resulted in taller plants (71.98 cm) of sunflower, whereas the control produced shorter plants (52.61 cm). Likewise, the maximum plant height (65.15 cm) resulted from hybrid C124 × RH344, with the minimum (60.30 cm) from hybrid C208 × RH445. The interaction between sunflower hybrid and various levels of sulfur was also significant (Table 3). The tallest plants (75.80 cm) from sunflower hybrid C124 × RH344 occurred in a sulfur application at 20 kg per ha of sulfur, with the shortest (51.35 cm) under control from hybrid C208 × RH445. The head diameter of the sunflower was also statistically different under various doses of sulfur. The maximum head diameter (14.78 cm) emerged with the 20 kg per ha sulfur application, whereas the minimum (9.11 cm) was under

Table 1. Analysis of variance for sulfur level, sunflower hybrids, and interaction of sulfur level × hybrids effects on yield-attributing traits, yield, and oil content of different sunflower hybrids.

Variables	Sulfur level (d.f. = 4)			Hybrids (d.f. = 3)			Interaction Sulfur level × Hybrids (d.f. = 12)		
	MS	F	P	MS	F	P	MS	F	P
Plant height	846.089	1311.13	0.0000**	83.718	104.69	0.0000**	7.328	4.05	0.0001**
Head diameter (cm)	96.0784	42.12	0.0000**	7.2799	4.86	0.0052**	4.5085	3.01	0.0036**
Leaf area per plant (mm^2)	679509	21.63	0.0000**	66014	5.73	0.0021**	13003	1.13	0.3619^{NS}
Days to flower initiation	145.972	57.98	0.0000**	10.651	4.39	0.0086**	2.842	1.17	0.0322*
100-achene weight (g)	30.1902	42.16	0.0000**	4.4049	9.11	0.0001**	0.7563	1.56	0.0374*
Achene yield (kg per ha)	1528747	390.40	0.0000**	57996	18.26	0.0000**	8591	2.71	0.0078**
Harvest index (%)	105.499	349.83	0.0000**	4.495	6.42	0.0010**	1.426	2.04	0.0427*
Oil content (%)	653.272	783.02	0.0000**	15.419	16.87	0.0000**	0.827	0.90	0.05321*

d.f. = Degree of freedom, MS = Mean square, F = variance ratio*$P \leq .05$, **$P \leq .01$

Table 2. Effect of sulfur levels on yield-attributing traits, yield, and oil content of different sunflower hybrids.

Treatments	Plant height (cm)	Head diameter (cm)	Leaf area per plant (mm^2)	Days to flower initiation	100-achene weight (g)	Achene yield (kg ha^{-1})	Harvest index (%)	Oil content (%)
Sunflower Hybrid								
H_1	65.15a	14.38a	1887.41a	46.58b	9.23a	2473.11a	23.00a	42.53a
H_2	63.17b	13.32b	1823.81ab	47.28ab	8.54b	2408.51b	22.56ab	42.22a
H_3	61.95c	13.12b	1788.11b	47.60ab	8.7b	2375.00bc	22.18b	41.11b
H_4	60.30d	13.11b	1752.72b	48.34a	8.11b	2348.41c	21.91b	40.69b
$LSD_{0.05}$	0.75	1.03	90.55	1.31	0.58	47.54	0.70	0.80
Sulfur Levels (kg per ha)								
S_0	52.61e	9.11b	1542.40d	51.53a	6.31c	1875.00d	18.00d	30.74e
S_1	71.98a	14.78a	2088.60a	43.21d	9.85a	2637.51a	24.70a	46.99a
S_2	66.30b	14.56a	1910.20ab	46.63c	9.30ab	2553.70b	23.49b	45.24b
S_3	62.87c	14.36a	1817.00bc	47.33bc	9.04ab	2488.90b	23.05bc	43.30c
S_4	59.44d	14.61a	1706.81cd	48.56d	8.44b	2415.11c	22.80c	41.92d
$LSD_{0.05}$	0.90	1.70	200.07	1.9	0.95	70.63	0.61	1.03

H_1= (C124 × RH344), H_2= (C124 × RH344), H_3= (C124 × RH344), H_4= (C124 × RH344), S_0=0kg per ha, S_1=20 kg per ha, S_2=30 kg per ha, S_3=40 kg per ha, S_4=50 kg per ha.

Table 3. Interactive effect of sulfur levels × sunflower hybrids on plant height, head diameter, harvest index, days to flower initiation, 100-achene weight, achene yield, and oil content of sunflower hybrids.

Treatments	Plant height (cm)	Head diameter (cm)	Harvest Index (%)	Days to flower initiation	100-achene weight (g)	Achene yield (kg ha^{-1})	Oil content (%)
$H_1×S_0$	54.35i	9.67cd	18.80c	50.77abcd	7.66cd	2028.21h	31.60g
$H_1×S_1$	75.80a	17.90a	26.58a	40.33h	10.60a	2806.61a	48.46a
$H_1×S_2$	70.15bc	14.00b	23.45b	46.25efg	10.07ab	2579.61bcde	46.20abc
$H_1×S_3$	65.45d	15.08ab	23.20b	47.51bcdefg	9.23abc	2512.11cdefg	44.20cde
$H_1×S_4$	60.02fgh	15.24ab	22.91b	48.08bcdef	8.60abc	2438.91defg	42.20def
$H_2×S_0$	52.00ij	9.02d	18.38c	51.00abc	6.95d	1843.40i	30.63g
$H_2×S_1$	71.55b	14.16b1	24.27b	43.67gh	9.66abc	2695.71ab	47.81ab
$H_2×S_2$	68.07c	14.87ab	24.13b	46.33efg	9.10abc	2572.71bcdef	45.69bc
$H_2×S_3$	63.50de	14.28ab	23.13b	46.75cdefg	9.08abc	2503.21cdefg	44.14cde
$H_2×S_4$	59.72fgh	14.28ab	22.88b	48.66abcde	8.51bc	2427.71efg	42.89def
$H_3×S_0$	52.75ij	9.59cd	18.01c	51.41ab	6.31d	1821.90i	30.41g
$H_3×S_1$	71.17b	12.91bc	23.98b	43.95fgh	9.58abc	2601.52bc	46.01abc
$H_3×S_2$	65.00d	13.90b	23.22b	46.52defg	9.01abc	2544.00bcdefg	44.77cd
$H_3×S_3$	61.60efg	14.55ab	22.97b	47.50bcdefg	8.95abc	2496.00cdefg	42.51def
$H_3×S_4$	59.22gh	14.65ab	22.72b	48.67abcde	8.49bc	2411.51fg	41.86ef
$H_4×S_0$	51.35j	8.15d	16.82c	52.93a	4.89e	1806.51i	30.31g
$H_4×S_1$	68.40c	14.14b	23.96b	44.92efg	9.55abc	2590.21bcd	45.69bc
$H_4×S_2$	62.00ef	15.47ab	23.17b	47.46bcdefg	9.03abc	2518.40cdefg	44.37cde
$H_4×S_3$	60.95fgh	13.54b	22.92b	47.58bcdefg	8.92abc	2444.41cdefg	42.36def
$H_4×S_4$	58.80h	14.29ab	22.67b	48.83abcde	8.15bcd	2382.41g	40.73f
$LSD_{0.05}$	2.37	3.25	2.22	1.10	1.84	149.76	2.54

H_1= (C124 × RH344), H_2= (C124 × RH344), H_3= (C124 × RH344), H_4= (C124 × RH344), S_0=0kg per ha, S_1=20 kg per ha, S_2=30 kg per ha, S_3=40 kg per ha, S_4=50 kg per ha.

control. Among the hybrids, the maximum flower head diameter (14.38 cm) came from hybrid C124 × RH344, but the minimum (13.11 cm) was by sunflower hybrid C208 × RH445. The interactive effect of 20 kg per ha level of sulfur and hybrid C124 × RH344 produced a maximum head diameter (17.90 cm) and minimum (8.15 cm) under control by hybrid C208 × RH445 of sunflower. Leaf area (mm^2) per plant of sunflower was significantly different among hybrids (Tables 1 and 2), as well as, with various doses of sulfur.

Sulfur application at 20 kg per ha produced the maximum leaf area per plant (2,088.60 mm^2), while without sulfur resulted in a minimum leaf area per plant (1,542.40 mm^2) of sunflower. Among the hybrids, the observed maximum leaf area (1,887.41 mm^2) was in hybrid C124 × RH344, whereas C208 × RH445 hybrid produced a minimum leaf area per plant (1,752.72 mm^2). The interactive impact of various rates of sulfur × sunflower hybrids revealed statistically non-significant. Days to flower initiation of sunflower, presented in Tables 1 and 2, showed that different sulfur levels produced statistically significant effect on such trait. Sunflowers took more days to flower initiation (51.53 days) with no sulfur application and recorded fewer days to flower initiation (43.21 days) when applied with 20 kg per ha of sulfur. Sunflower hybrid C208 × RH445 took more days to flower initiation (48.34 days), while hybrid C124 × RH344 took less time (46.58 days).

The interactive effect of sulfur levels × sunflower hybrids was confirmed as statistically significant (Table 3). At 20 kg per ha of sulfur, hybrid C124 × RH344 took minimum days to flower initiation (40.33 days), whereas hybrid C208 × RH445 took the longest days to flower initiation (52.93 days) under control conditions. The 100-achene weight of sunflower hybrids also appeared statistically different under varied sulfur levels (Tables 1 and 2). Maximum 100-achene weight (9.85 g) of sunflower occurred with 20 kg per ha dose of sulfur and the minimum (6.31 g) under control condition (no sulfur). The 100-achene weight also differed among sunflower hybrids, with the maximum 100-achene weight (9.23 g) produced by hybrid C124 × RH344 and the minimum (8.11 g) from hybrid C208 × RH445. Similarly, the interactive effect of sulfur levels × hybrids was statistically significant (Table 3). The maximum 100-achene weight (10.60 g) by C124 × RH344 hybrid emerged at 20 kg per ha dose of sulfur and the least (4.89 g) by C208 × RH445 hybrid of sunflower with 0 kg per ha of sulfur.

Sulfur also produced a statistically positive impact on the achene yield of sunflower hybrids. The highest achene yield (2,637.51 kg per ha) of sunflower arose with a 20 kg per ha level of sulfur, while the minimum (1,875.50 kg per ha) was under control. A maximum achene yield (2,473.11 kg per ha) of sunflower hybrids resulted in hybrid C124 × RH344, whereas the minimum (2,348.20 kg per ha) in hybrid C208 × RH445. The interactive effect of 20 kg per ha level of sulfur and hybrid C124 × RH344 produced the maximum achene yield (2,806.61 kg per ha) of sunflower and the minimum (1,806.51 kg per ha) in hybrid C208 × RH445 under control (Table 3). The impact of sulfur application on the harvest index of sunflower hybrids showed that the various doses of sulfur produced a statistically significant influence on the harvest index of the crop. A 20-kg per ha dose of sulfur resulted in a maximum harvest index (24.70%) of sunflower and a minimum (18.00%) with no sulfur application. Among the hybrids, C124 × RH344 showed a maximum harvest index (23.00%), whereas a minimum (21.91%) by hybrid C208 × RH445. The interactive effect of no sulfur × C208 × RH445 hybrid produced the least (16.82%), and a 20 kg per ha sulfur with C124 × RH344 gave the maximum (26.58%) harvest index (Table 3).

Oil content

The data regarding the influence of various doses of sulfur on the oil contents of different sunflower hybrids appear in Tables 1 and 2. Sunflowers produced maximum oil contents (46.99%) with 20 kg per ha dose of sulfur, with the minimum (30.74%) under control. Sunflower hybrids varied significantly in oil contents, and hybrid C124 × RH344 produced maximum oil contents (42.53%), whereas the least (40.69%) by hybrid C208 × RH445. The interactive effect of sulfur level × sunflower hybrids was also significant (Table 3). Maximum oil contents (48.46%) of sunflower hybrids exhibited at 20 kg per ha of sulfur level by hybrid C124 × RH344 and the lowest (30.31%) under control by sunflower hybrid C208 × RH445.

DISCUSSION

Sulfur has a diversified role in plant growth and development; it improves nutrient availability from soil to plant by creating suitable conditions for nutrient uptake. Enhancing yield and yield-contributing traits of sunflowers are outcomes of these realistic effects of sulfur in the soil and the plant. Sulfur involves protein and amino acid synthesis, carbohydrates, and oil biosynthesis. The positive impact on growth, yield, and oil contents of sulfur was due to the synthesis of more carbohydrates, protein, and essential amino acids, which improved cell division, thus, improving plant height, diameter, leaf area, and other yield-contributing parameters (Chowdhury *et al.*, 2020). Singh *et al*. (2000) noted that sulfur enhanced cell division and plant height. Poonia (2000) and Pavani *et al.* (2013) revealed sulfur application at 25 and 30 kg per ha produced taller sunflower plants, respectively. Hussain *et al*. (2011) and Senthamizhkumaran *et al.* (2018) concluded that the sulfur application to sunflowers resulted in taller plants. Saleem *et al*. (2019) described that increasing sulfur availability results in a bigger diameter of the flower head of the sunflower. Singh *et al*. (2000) stated that larger sunflower head diameter occurred with sulfur supply.

The combined supply of sulfur at 60 kg per ha and 1 kg per ha of boron provided the maximum growth of sunflower head diameter (Usman *et al.,* 2020). The increase in leaf area due to the role of sulfur in the production of amino acids resulted in increased photosynthesis, growth, and leaf area per plant. Choubey *et al*. (2013) noted the maximum leaf area of sunflower due to 60 kg per ha sulfur application, then started decreasing. Moreover, Kalaiyarasan *et al*. (2020) reported that combined application of 60 and 1 kg per ha sulfur and boron gave a maximum leaf area and growth of sunflower. Furthermore, Poonia (2000) illustrated that the 25 kg per ha sulfur application reduced days to flower initiation. Pati *et al.* (2011) shared the same trend that 20 kg per ha dose of sulfur with nitrogen provided fewer days to flower initiation. Likewise, Usman *et al.* (2020) noted that the sulfur application to sunflowers caused less time to start flowering. Additionally, Wani *et al*. (2001) examined a considerable enhancement of the 100-achene weight with the sulfur application. Ravikumar *et al.* (2016) indicated that a sulfur supply gave a maximum 1000-seed weight.

The maximum 1000-achene weight underwent study with 60 kg per ha and 1 kg application of sulfur and boron, respectively (Usman *et al.,* 2020). The reason for an increase in the yield and oil contents of sunflower is due to the role of sulfur in the conversion of carbohydrates into oil, the synthesis of fatty acids, and various enzymatic actions, increasing oil contents and achene yield of sunflower (Haq *et al*., 2021). Our results gain support from Bonari *et al*. (2013), who found a rise in grain yield with sulfur application. Pati *et al.* (2011) also found that the 20 kg per ha sulfur application with nitrogen provided maximum achene yield compared with the control. Likewise, Rana *et al*. (2015) depicted that the 20 kg per ha of sulfur resulted in the maximum achene yield of sunflowers.

The increase in the dose of sulfur enhanced the production of grains, causing the harvest index to increase. Barbara *et al*. (2008) and Bonari *et al*. (2013) revealed that the improvement in total yield and harvest index of sunflower hybrids emerged with the sulfur application. Rana *et al.* (2015) also reported that sulfur application to sunflowers increased the harvest index of their hybrids. Improvement in achene oil contents was due to the dependence of the thiokinase enzyme on sulfur availability, which is further involved in the synthesis of fatty acid. Rasool *et al*. (2013) and Vala *et al*. (2014) explained that sulfur increased the oil % age in sunflowers. The supply of sulfur at 60 kg per ha with 1 kg per ha of boron resulted in the maximum oil contents of sunflower (Usman *et al*., 2020). Moreover, Rana *et al.* (2015) found that the sulfur at 20 kg per ha increases the oil contents of sunflowers.

CONCLUSIONS

The findings of this study have shown that hybrid C124 × RH344 proved to be best when sown with the application of 20 kg per ha sulfur with recommended NPK (120–60–60 kg per ha), which enhanced the oil % age, growth, and yield of this hybrid. However, the response of other sunflower hybrids to different sulfur doses under varying soil types requires further investigation.

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