Research Article

Physiological and Agronomic Implications of Foliar Potassium Application on Sunflower Productivity in Calcareous Soils

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Abstract | Soils of Sindh are highly calcareous, consequently limiting potassium (K) supply to crops including sunflower due to low K activity ratio. The research was conducted to ascertain whether K foliar applications can improve growth, and yield of sunflower in calcareous soil. The sunflower cultivar (HO-1) was tested in field with three foliar K sources (Kfs) (MoP, SoP and NoP) and three foliar K times (Kft) treatments (2% once at leaf development stage (LDS), 2% in two equal splits (1% at LDS and 1% inflorescence emergence stage (IES), and 2% in three equal splits (0.67% at LDS, 0.67% IES and 0.67% flower bud development stage (FS). Three repeats of treatments arranged in randomized complete block design. The Kfs affected growth related parameters, chlorophyll concentration, leaf K concentration, seed yields significantly. Application of NoP and SoP raised the seed yield by 9.09% and 8.66% , respectively, over control. Oil content increased by 15% with NoP and 13% with SoP, over control, respectively. The significant Kft variations were also observed for most of the variables studied for field-grown sunflower plants. Among interaction of Kfs x Kft, seed and oil yields were obtained to be highest in T3 when NoP>SoP>MoP were sprayed with 0.67% spray each at LDS, IES and FS stage. It can be concluded that under the calcareous conditions of Sindh, foliar application of 2% K (2 or 3 equal splits at LDS, IES and FS) through NoP, SoP, and MoP sources increase the growth, seed and oil content of sunflower.

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Introduction

Sunflower is a non-traditional and profit-oriented oil seed crop with the potential to bridge the gap between edible oil imports and domestic production in Pakistan (Hameed and Azeem, 2017; Rana *et al*., 2022). However, the average sunflower yields in the country during 2021 was 1377 kg ha^{-1} (GOP, 2021) are far below potential yield 3073-3083 kg ha^{-1} which has been recorded by research centres and

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organisations (Nasim *et al*., 2012; Sadozai *et al*., 2013). This difference could be ascribed to a variety of causes, including limited K availability in calcareous soils (Weil and Brady, 2017). For each tonne of sunflowers produced, 100-126 kg of potassium are removed from the soil (Naidu *et al*., 2011; Magomadov *et al*., 2021). The potassium plays an important role in improving crop yield and quality of produce as one of the most essential nutrients (Bakht *et al*., 2010; Zamani *et al*., 2020). The seed and oil yields are strongly influenced by application of different nutrients especially K during crop growth (Aown *et al*., 2012; Faisal *et al*., 2013; Ahmad *et al*., 2017). It is generally known K has the greatest impact on the growth and development parameters of sunflowers (Akram *et al*., 2009; Raza *et al*., 2018). Although K is not a component of any plant structures or functional molecules, it is engaged in a number of physiological and biochemical processes essential for robust, healthy crop growth and viable yields (Marschner, 1995; Singh *et al*., 2017). K is involved in the transport systems in plants that allow materials produced by photosynthesis in the leaf to be transported to other areas of the plant for growth, seed production, and oil deposition (Singh *et al*., 2017). K also plays a role in stress tolerance, turgor maintenance, photophosphorylation, enzyme activation, stomatal regulation of transpiration and photosynthesis, photophosphorylation, and transport of photoassimilates (Singh *et al*., 2017). Potassium plays an important role in numerous processes crucial to sunflower cultivation, including osmotic regulation and photosynthesis translocation (Santos *et al*., 2023). The uptake of K changes significantly depending on the stage of growth of sunflower, for instance, at the seedling stage, sunflower has weak roots and poor nutrient uptake ability, so an adequate supply of nutrients is essential at this stage of growth (Li *et al*., 2014). Plants have difficulty absorbing K from calcareous soils due to soil texture, high $CaCO_3$, alkaline pH, nutrient interaction, and nutritional imbalances (Wakeel *et al*., 2017; Taalab *et al*., 2019; Narayanasamy *et al*., 2023). Around 20 million hectares of agricultural soils in Pakistan are calcareous and 1/4th of the Indus plains (Recent, sub-recent, flood plains, estuaries, delta, creeks etc.) are calcareous in nature (Rashid, 2005). The major districts in Sindh that cultivate sunflower crop are Sujawal, Badin, and Hyderabad. The fields of lower Sindh including these districts have been reported as moderately to strongly calcareous under deficiency of macronutient potassium (Ali *et al*., 2014; Arain *et al*., 2017; Memon *et al*., 2023). The modern high yielding sunflower varieties are reported to remove significant quantities of K from soil, even greater than those that remove N and P (Naidu *et al*., 2011; Li *et al*., 2014). Generally, Pakistani farmers overlook K fertilization and focus on applying N and P to improve the production of their crops (Memon *et al*., 2023).

This research focuses on the potential of K foliar application to improve sunflower yields in calcareous soils. The application of potassium foliarly has been demonstrated to be beneficial in reducing the detrimental effects of environmental stresses (Shabbir *et al*., 2015; Adhikari *et al*., 2020; Bukhari *et al*., 2022; Beltagi *et al*., 2023; Shafei *et al*., 2023). Foliar applications of nutrients are generally practiced whenever soil-derived nutrients are restricted by increasing environmental stresses (Ishfaq *et al*., 2022). Increasing the absorption of K by crops through foliar fertilization may be an effective K management strategy (Machado and Serralheiro, 2017; Soumare *et al*., 2022). Application of K solutes may result in crop output that is sustainable and subsequent growth (Raza *et al*., 2014). Foliar application bypasses soil limitations, potentially enhancing K uptake and minimizing yield losses (Abid *et al*., 2016; Ishfaq *et al*., 2022). Optimizing K management through foliar application is crucial for successful sunflower growing (Jabeen and Ahmad, 2011; Ishfaq *et al*., 2022). It is generally known K has the greatest impact on the growth and development parameters of sunflowers (Akram *et al*., 2009; Raza *et al*., 2018). Improved sunflower yields could help to reduce dependency on edible oil imports, raise farmer income and economic growth, and improve food security and nutrition (Hameed and Azeem, 2017; Rana *et al*., 2022).

Calcareous soils present several challenges for K availability and plant uptake due to several issues, including: High levels of $CaCO_3$, high pH, high EC levels, antagonistic relationship of K with Na, Ca and Mg, low microbial activity (Sahai, 2004; Taalab *et al*., 2019; Babar *et al*., 2022; Wang *et al*., 2023), fixation by clay minerals, Low cation exchange capacity, presence of carbonates, lack of organic matter, soil texture and the precipitation of K (Ertiftik and Zengin, 2015; Wakeel *et al*., 2017; Narayanasamy *et al*., 2023). The increase in soil exchangeable Ca and Mg during the prolonged period is responsible for the decrease in leaf tissue K content and its subsequent uptake (Xie *et al*., 2020). This can have a negative impact on crop growth and production by creating a competitive ionic effect in the soil (Taalab *et al*., 2019). Calcareous soils limit K availability for plant uptake in Pakistan, resulting in declining crop yields. According to Chohan *et al*. (2015); Talpur *et al*. (2016), high $CaCO_3$ in soils is the major factor for lowering K availability in soil. Calcareous soils are formed from alluvial parent material derived from calcareous rocks in the Himalayas (Rashid and Rafique, 2017). The alluvial material is transported and deposited by the Indus River during flood episodes. The extent of calcareousness is expanding over time due to the regular inflow of lime from hilly areas through rainfall adjoining into the Indus River at various locations. The high calcium content of calcareous soil produces a low K activity ratio, resulting in a limited supply of K to the plants (Weil and Brady, 2017). The K activity ratio is the ratio of K ions to other base cations (Ca, Mg, etc.) in the soil solution (Basak, 2007). In general, a high K activity ratio indicates a greater supply of K, while a low ratio indicates a lesser supply of K (Sahai, 2004; Basak, 2007). Thus, calcareous soils with low K activity ratios, higher rates of K fertilizer needed, high K activity ratios, lower rates of K fertilizer may be sufficient (Basak, 2007). Furthermore, in calcareous soil, high $CaCO_3$ concentrations reduce the efficiency of K fertilizers and contribute to poor plant growth (Memon *et al*., 2023). In the stress reduction mechanism, K nutrient play a critical role in resisting environmental stresses, including calcareousness (Wang *et al*., 2013). In order to minimize the adverse effects of high calcareousness, various approaches, including cultivating calcicols/caliphytes, acidifying soils with H_2SO_4, using organic amendments, tillage practices, and optimizing nutrient management have been adopted (Sadozai *et al*., 2013; Li *et al*., 2014; Komel and Razzaq, 2019). However, these methods often have limitations, including high cost, environmental concerns, or limited effectiveness. K foliar application has shown promise in reducing stress effects on crops, including salt stress and drought. Research studies carried out in Pakistan discovered that K foliar application reaction was favourable in specific circumstances: (i) salt stressed and non-stressed conditions (Akram *et al*., 2009; Jabeen and Ahmad, 2011; Arshadullah *et al*., 2014; Jan and Hadi, 2015). (ii) draught conditions (Hussain *et al*., 2013, 2016) with different sources of K (Akram *et al*., 2009; Jabeen and Ahmad, 2011; Hussain *et al*., 2013, 2016). It is uncertain, however, whether such encouraging results can be attained under actual field circumstances with most widely used fertilizer K salts and time of their application.

Research knowledge regarding the sunflower response to K fertilization in calcareous soils in Pakistan is still limited and diverse, making it difficult to recommend K for reducing the adverse effects of high calcareous soils. We hypothesized in this study that K foliar treatments at different stages could improve the physiological performance of sunflower plants when soil K uptake is inadequate to meet their needs. Therefore, the present study aims to evaluate the effects of different K sources for foliar feeding on growth and yield and to determine optimal timing of K foliar spray in order for maximizing the seed and oil yields of sunflower grown on calcareous soils.

Materials and Methods

Experimentral site and weather conditions

The trial was carried out during the spring season of 2020 on moderately calcareous soil as shown in Table 1, in the experimental field of the Soil Salinity and Reclamation Research Institute Tandojam, Pakistan, which is located at coordinates 25°25'24.0"N 68°32'37.0"E. According to the Koppen classification, the region has a dry climates (with deficient precipitation during most of the year), categorized as BWh, Subtropical Desert and Steppe, with lowest temperatures occur in January and hover around 25°C, while the highest the highest average temperatures range from 35 to 42°C during April to August. There is virtually no rainfall during the year. The rainfall here averages 171 mm. During the experiment period there was virtually no rainfall i.e averages 10 mm and soil temperature at 20 cm depth showed normal to cooler trend ranged from 18.90 to 34.90 °C, while the air temperatures was around 17°C in December and highest average temperatures around 26 to 31°C in April were recorded (Pakistan Meteorological Department).

Experimental design, treatments and field management

Two factorial randomized complete block design (RCBD) was used to for this study with the main plots (8 m wide x 30 m long) being for K foliar source (Kfs) were randomized into 12 sub-plots of 4 m width x 5 m length for K foliar times (Kft) treatments. On calcareous soils under field conditions, in addition to control (S0= Without K (control); three Kfs treatments (S1 as MoP; S2 as SoP; S3 as NoP) and three Kft

Table 1: *Soil anlyses of the experimental site before sowing (0-20 cm).*

Soil property	Unit	Values	Categorizations
Sand	%	32	Medium texture
Silt	%	29	
Clay	%	39	
Texture Class (USDA)		Clay Loam	
ECe	(dS m^{-1})	0.11	Non-saline
pH	---	7.8	Slightly to mildly alkaline
Organic matter content	%	0.62	Poor
Lime content	%	9.16	Moderately calcareous
Exchangeable K (NH_4OAc)	mg kg^{-1}	120	Marginal
Phosphorus (AB-DTPA)	mg kg^{-1}	1.00	Low
Nitrogen	%	0.031	Low
Soluble Ca	meq L^{-1}	5.08	High
Soluble Mg	meq L^{-1}	2.56	Adequate
Soluble K	meq L^{-1}	0.51	Marginal
K activity ratios	$([K^+])/\sqrt{([Ca^{2+}]+[Mg^{2+}])}$	0.19	Low

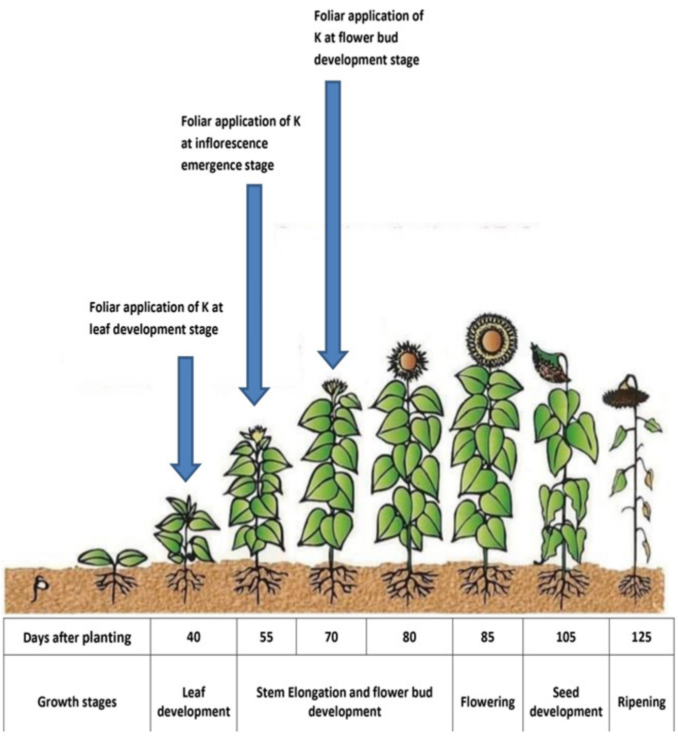

Figure 1: *Different stages of sunflower plant where K was applied through foliar.*

treatments (T1 = 2% once at at leaf development stage (LDS); T2 = 2% in two equal splits (1% at LDS and 1% inflorescence emergence stage (IES); T3 = 2% in three equal splits (0.67% at LDS, 0.67% IES and 0.67% flower bud development stage (FS) (Figure 1) were set up. The treatments were repeated thrice. As per treatments plan K was sprayed with a manual sprayer, when the sunflower plants had reached at the LDS, IES, and FS stage of sunflower. The foliar spray was performed during the morning when the uptake efficiency of foliar nutrients is the highest. The field plot was ploughed twice with desic harrow followed by clod crushing and levelling. Irrigation was used in the soaking dose. For each treatment in the experiment, the bunds and channels were prepared independently for the use of fertilizer and irrigation. The seeds of sunflower variety HO^{-1} were drilled 5 cm deep. The rowtorow distance was kept 70 cm (27.55 inch or 2.30 ft) and the planttoplant distance was maintained at 25.4 cm (10.0 inch or 0.83 ft) by thinning at four leaves stage. The irrigation was done by flooding method according to the requirements of crop and soil moisture conditions. Recommended doses of phosphorus (70 kg ha^{-1}) in the form of DAP (DAP, 18% N and 46% P_2O_5) was applied before sowing and nitrogen (140 kg ha^{-1}) in the form of urea (46% N) was applied in three splits (1/3 at the time of sowing, 1/3 at 1st irrigation and 1/3 at head emergence).

Soil sampling and analysis

The study collected soil samples (0-20 cm) following the methodology prescribed by Rowell (2014) to ensure accuracy. These samples were transported to the Department of Soil Science, SAU, Tandojam for comprehensive analysis. The methods used for soil analysis were as follows: Soil texture was determined through the hydrometer method (Bouyoucos, 1962), while pH and EC (dS m^{-1}) in 1:5 soil water extracts were assessed using digital pH and EC meters (Suntex Model SP-34, Model HI-8333), as described in Rowell (2014). Additionally, the flame photometer method was used to determine K levels (Estefan *et* *al*., 2013). Tritration methods as described in USSD (1954) were followed for the analyses of Ca and Mg. Calcium carbonate content (%) of soil was determined through Acid-Netrilization method (Estefan *et al*., 2013). The K activity ratio was calculated as mentiond by Basak (2007) using the following formulae:

$$\text{K activity ratio} = ([K^+])/\sqrt{([Ca^{2+}]+[Mg^{2+}])}$$

Plant sampling

Leaves were sampled at R2 stage from each treatment plot. Only identically sized plants with fully developed leaves approximately from the middle of each replication plant were used to standardise plant tissue samples. With distilled water, the sampled leaves wererinsed. Samples were prepared for chlorophyll and K analysis.

Determination of chlorophyll content

To ensure efficient homogenization, 0.5 g sunflower leaf samples were cut into small pieces and then treated with 80% (v/v) acetone in a pre-cooled mortar and pestle. The mixture was then centrifuged at 3,000 rpm for for fifteen minutes. The resultant supernatant was diluted to 25 mL with 80% (v/v) acetone. The absorbance of the supernatant was measured using a Hitachi-220 spectrophotometer at 645, 663, and 480 nm. Finally, chlorophyll a and b concentrations were calculated using Arnon's (1949) equation.

Determination of K concentration

Sunflower plant tissue samples were prepared for K analysis by a standardized dry ash techniques. To remove surface contaminants, samples were first washed with distilled water and then dried in an oven at 70°C for 48 hours. Each dried plant tissue sample was then powdered in a grinder, and 1.0 g of the ground sample was ashed in a muffle furnace at 550 °C for 05 hours. The resulting ash was dissolved in 2 N HCl and diluted to 100 mL with distilled water. This solution was then analyzed for K concentration using a Jenway PFP-7 flame photometer following the analytical method described by Estefan *et al.* (2013). Potassium concentrations were categorized based on the classification system proposed by Smith and Loneragan (1997).

Determination of oil content

The seed oil content was extracted using Pearson's (1973) soxhlet extraction unit. The soxhlet extraction was set up with the pre-weighed soxhlet flask; the process of extraction was carried out. The dry milling sample (116 g) was placed into the thimble, and the materials were continuously extracted using diethyl ether (37-40°C) as solvent for 6 hours. The extraction process was completed, and then thimble was taken off, and the flask and its contents were dried in an oven at 60°C for 10 minutes after the solvent was allowed to evaporate. Once the oil-containing flask had cooled in the desiccators, it was weighed, and dried several more times to get a cosnstant weight.

Yield and related traits

Five plants were randomly selected from each treatment aat maturity (120 days after sowing). Afterward, each plant was tagged and numbered individually in order to facilitate data collection: plant height, head diameter, seeds per head, weight of seeds per head, 100-seed weight, and seed yield. Standard procedures were followed to ensure the accuracy and consistency of these measurements.

Statistical analysis

The data on the yield and related traits, chlorophyll content and K concentration in plant tissue were analyzed for LSD and ANOVA Using Minitab® Ver. 17, these tests were run to ascertain the significance of the effect of K foliar sources, K foliar times, and their interactions at $p < 0.05$.

Results and Discussion

Growth and yield parameters

Plant height: Foliar K source (Kfs) caused significant (p<0.05) effects, while foliar K application time (Kft) and interaction (Kfs x Kft) had no significant (p>0.05) effects on the height of sunflower plants (Figure 2a). Among Kfs application of NoP lead to the tallest plants (163 cm) than with SoP (161 cm) and MoP (160 cm) as compared to minimum with control (without K) plants (147 cm). Among the Kft, T1 had smaller plants (154 cm) compared with T2 (158 cm) and T3 (162 cm).

Head diameter: The Kfs and Kft had significant (p<0.05) effects, while their interaction (Kfs x Kft) had no significant (p>0.05) effects on head diameter (Figure 2b). Mean data revealed that among the Kfs, application of NoP produced 7.99% bigger head diameter, followed by SoP (7.40%) and MoP (5.72%) as compared to the control (without K) plants. Among the Kft, the larger head diameter (21.01 cm) was recorded in T3 followed by T2 (20.58 cm) and T1 (20.00 cm).

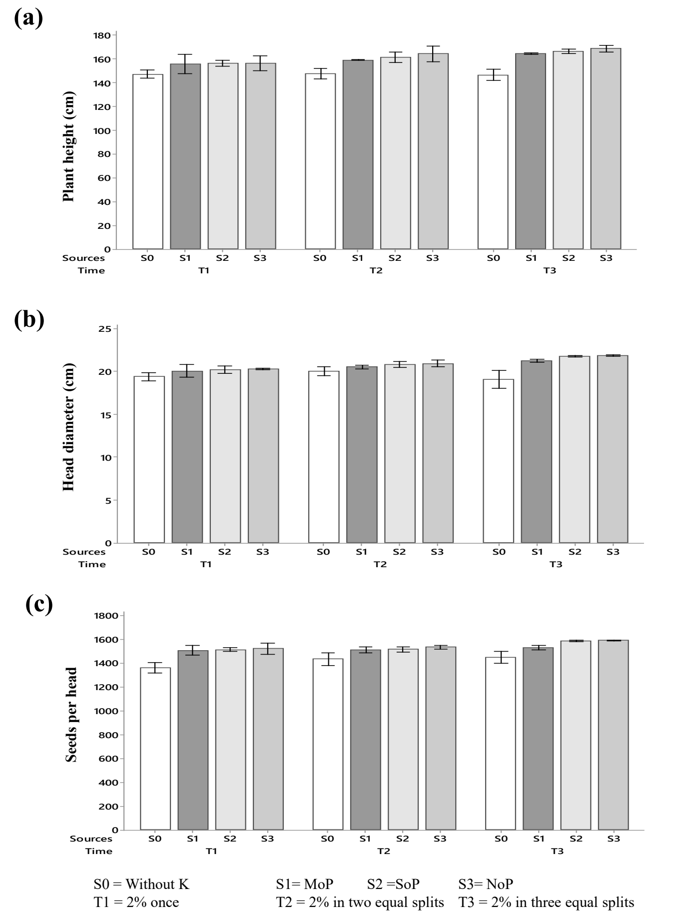

Figure 2: *Effect of K foliar sources and timing on sunflower grown on calcareous (a) plant height (b) head diameter (c) seeds per head.*

Seeds head^{-1}: The Kfs and Kft had significant (p<0.05) effects, while their interaction (Kfs x Kft) had no effects (p>0.05) on seeds head^{-1} (Figure 2c). Among the Kfs, application of NoP produced the highest number of seeds head^{-1} (1550), followed by SoP (1539) and MoP (1517) while the lowest number of seeds head^{-1} (1416) was recorded in the control (without K) plants. Among Kft, T3 produced more number of seeds head^{-1} (1540), followed by T2 (1500), and the minimum (1477 cm) at T1.

Seed weight head^{-1}: The Kfs and Kft had significant (p<0.05) effects, while their interaction (Kfs x Kft) had no significant (p>0.05) effects on seed weight head^{-1} (Figure 3a). The seed weight head^{-1} of sunflower plants increased significantly with the Kfs as compared to control (without K) plants. The seed weight head^{-1} increased from 75.94g control (without K) plants to 82.8, 81.9, and 80.4g with NoP, SoP and MoP, respectively. The Kft variation for foliar K requirement also existed in sunflower plants to produce heavier seeds per head. The maximum seed weight head^{-1} (82.11g) were produced from the plants at T3 followed by T2 (79.62g) and T1 (82.11g).

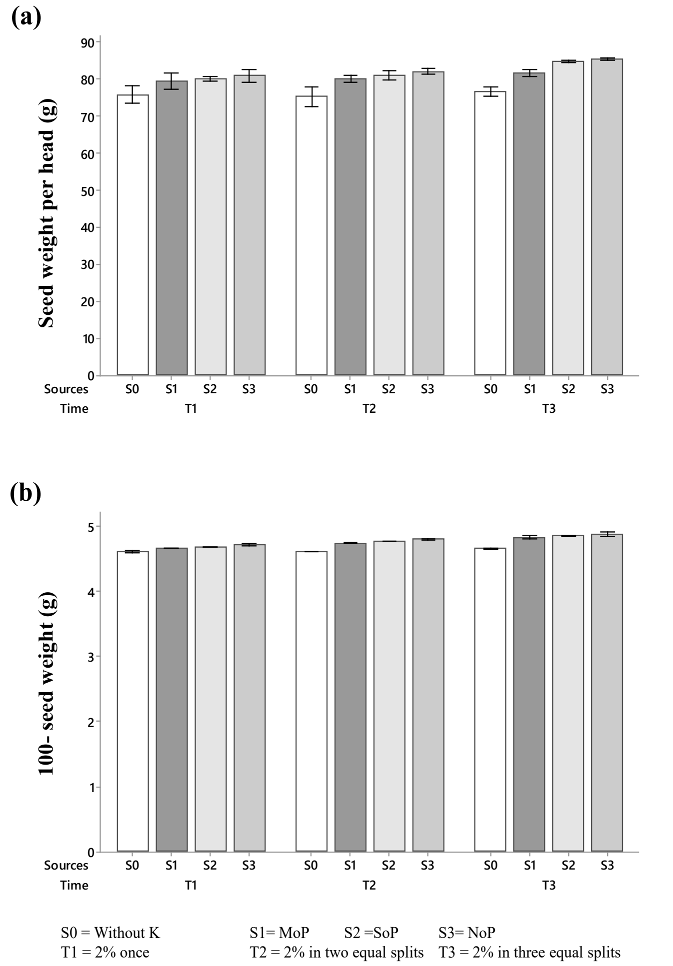

Figure 3: *Effect of K foliar sources and timing on sunflower grown on calcareous (a) Seed weight per head (b) 100-seed weight.*

100-seed weight: The Kfs, Kft and their interaction (Kfs x Kft) had significant (p<0.05) effects on 100-seed weight (Figure 3b). The average 100-seed weight increased with the Kfs, MoP, SoP and NoP were 2.61, 3.06 and 3.74%, respectively, greater than the 100-seed weight in control (without K) plotss. There was also significant effect among Kft of the average on the 100-seed weight with maximum average values for the T3 compared with T2 and T1.

Oil content: The Kfs and Kft had significant ($p<0.05$) effects, while their interaction (Kfs x Kft) had no significant (p>0.05) effects on oil content (Figure 4a). The average oil content with MoP, SoP and NoP were 35.62, 36.15 and 36.70%, as compared to the control (without K) plants 31.99%. There was also significant effect among Kft, the average oil content at T1, T2 and T3 were 34.17, 35.09 and 36.07%, respectively. Comparing the interaction (Kfs x Kft), the decreasing oil content trend were found as T3 with NOP (38.07%), followed by SoP (37.26%) and then MoP (36.77%). The lowest were measured at T1 with MoP (34.34%), T1 with SoP (34.98%) and at T1 with NoP (35.51%).

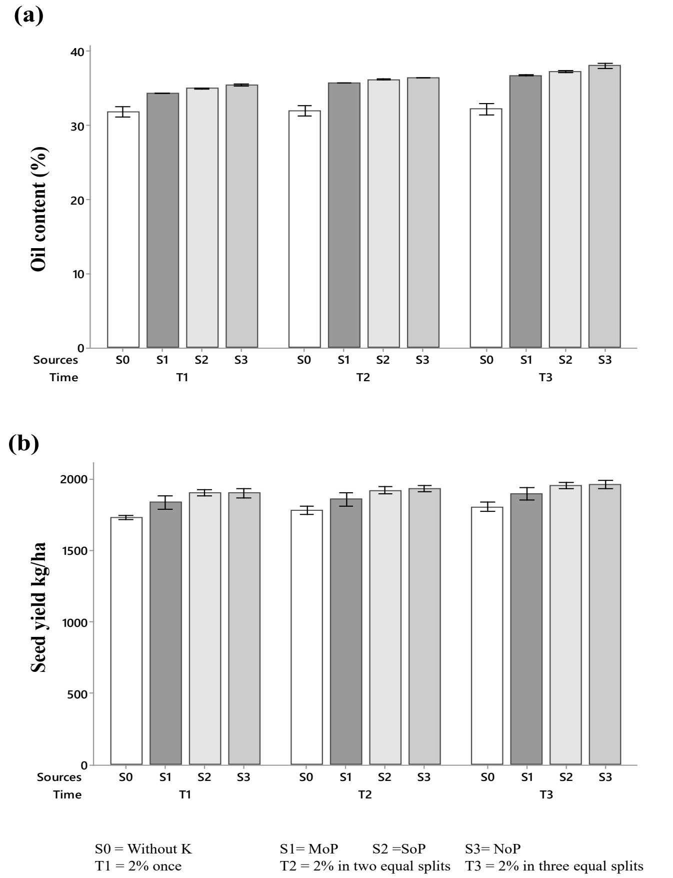

Figure 4: *Effect of K foliar sources and timing on (a) Oil Content (b) Seed yield of sunflower grown on calcareous soil.*

Seed yield: The Kfs and Kft had significant (p<0.05) effects, while their interaction (Kfs x Kft) had no significant (p>0.05) effects on seed yield (Figure 4b). Despite the moderately calcareous condition 11% $CaCO_3$ and K in medium (190 mg kg^{-1}) at sowing in the soil, we detected that, independently of the Kfs, on average over Kfs increased significantly sunflower seed yield. The average seed yield with MoP, SoP and NoP were 90, 154 and 161 kg ha^{-1}, respectively, greater than the seed yield of control (without K) plots. This corresponded to a relative yield increase of 5.12, 8.66 and 9.09%, respectively. Among Kft, the average seed yield at T1, T2 and T3 were 1843, 1874 and 1905 kg ha^{-1}, respectively. Comparing the interaction (Kfs x Kft), the seed yield increases were found at the T3 with NoP (10.9%), followed by SoP (10.2%) and MoP (7%). However,the lowest were measured at T1 with MoP (increase of 3.6% or 63.51 kg ha^{-1}), T1 of SoP (increase of 7.4% or 131.22 kg ha^{-1}) and at T1 of NoP (increase of 7.3% of 131.38 kg ha^{-1}).

Chlorophyll concentration: The Kfs and Kft had significant (p<0.05) effects, while their interaction (Kfs x Kft) had no significant (p>0.05) effects on Chlorophyll *a*, *b* and *total* concentration (Figure 5). Chlorophyll *a* concentration ranged from 1.36 mg g^{-1} fw with MoP to 1.41 mg g^{-1} fw with NoP, with an overall average of 1.30, 1.34, and 1.36 mg g^{-1} fw at T1, T2 and T3, respectively. Similar response to foliar K effect was observed for Chlorophyll *b* and *total* chlorophyll concentration of sunflower leaves.

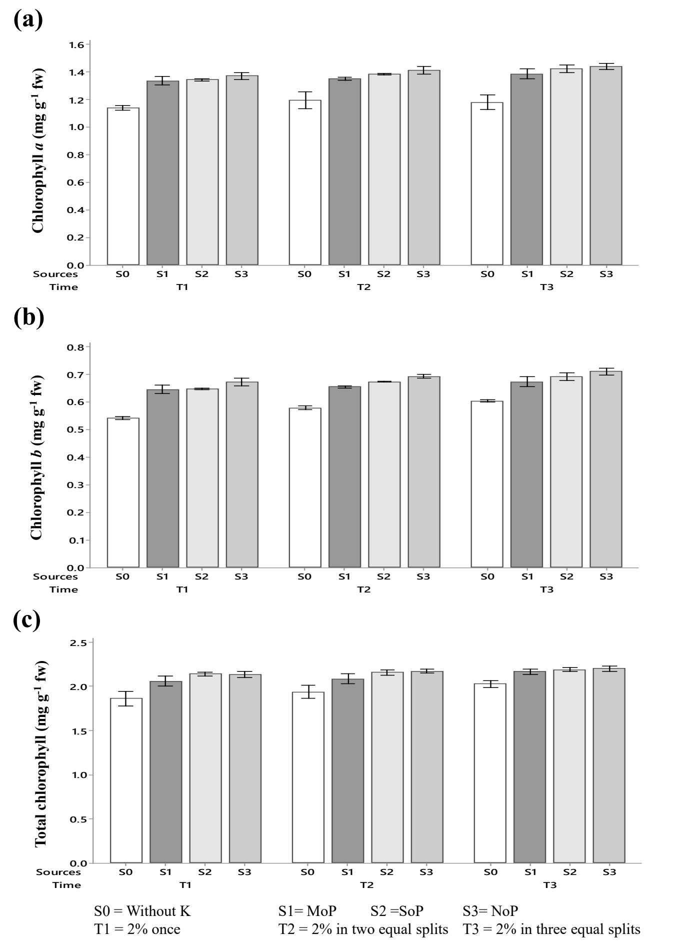

Figure 5: *Effect of K foliar sources and timing on (a) chlorophyll a (b) chlorophyll b (c) Total chlorophyll concentration of sunflower grown on calcareous soil.*

K concentration in leaf: The Kfs and Kft had significant (p<0.05) effects, while their interaction (Kfs x Kft) had no significant (p>0.05) effects on plant tissue K concentration (Figure 6a). Independently of the K sources, on average over three K spray times increased significantly sunflower K% in leaves. The average K concentration with MoP, SoP and NoP were 0.86, 0.93 and 1.01%, respectively, higher than the control (without K) plants. This corresponded to a relative increase of 26.29, 28.33 and 30.92%, respectively. There was also significant effect among Kft of the average K sources on the sunflower K% on leaves with highest average values at T3 compared with T2 and T1. K% in leaves increases were obtained in all times of foliar application at each source of foliar applied K.

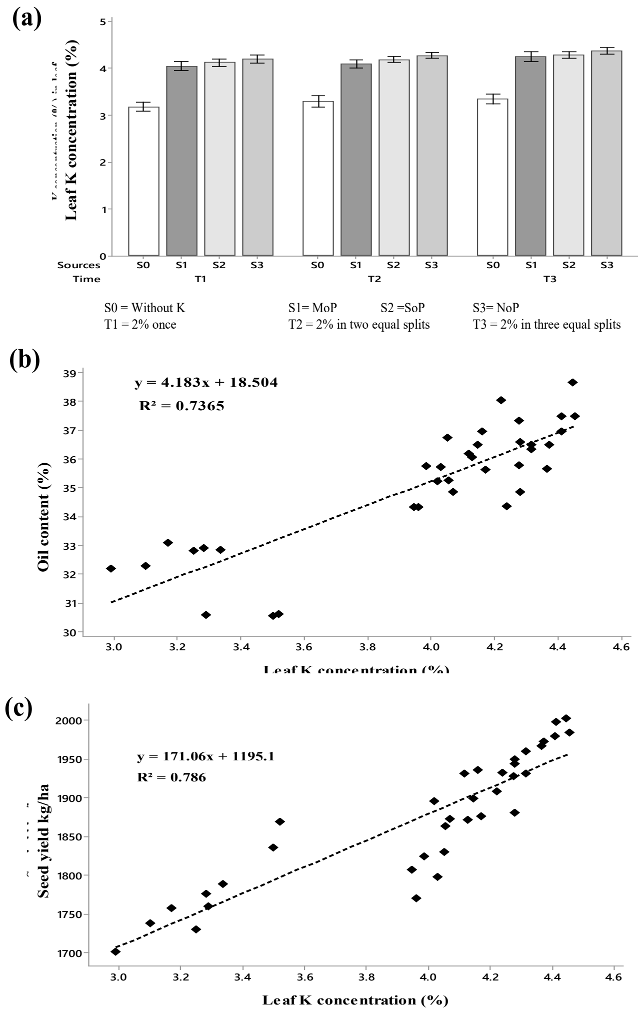

Figure 6: *Relationship of leaf K concentration (a) with oil content (b) with seed yield of sunflower grown on calcareous soil as affected by K foliar sources and timing.*

Relationship of leaf K concentration and oil content: The leaf K concentration and oil content relationship presented in Figure 6b. The leaf K concentration indicated a significant, positive and direct relationship with the oil content % of sunflower. The Pearson correlation coefficient "R^2" was 0.74.

Relationship of leaf K concentration and seed yield relationships: The leaf K concentration and seed yield relationship presented in Figure 6c. The leaf K concentration indicated a significant, positive and direct relationship with the seed yield kg ha^{-1} of sunflower. The Pearson correlation coefficient "R^2" was 0.79.

The findings of this research demonstrate that the foliar application of K with different sources have significant effect on various characteristics of sunflower crop, growth and yield parameters including plant height, head diameter, seeds per head, seed weight per head, 100-seed weight, seed yield per hectare, oil content; chlorophyll concentration and K concentrations in leaf. In the same manner, the Kft treatment demonstrated a significant effect on key parameters of growth and yield parameters chlorophyll concentration and K concentrations in leaf. The statistical analysis showed that the interaction between Kfs and Kft did not have a significant effect on any of the parameters measured. Improved plant height, head diameter, seeds per head, seed weight per head, 100-seed weight, and seed yield per hectare were produced with application of all Kfs (NoP followed by SoP and MoP) as compared to minimum without K). The observed increases in plant height, head diameter, seeds per head, seed weight per head, 100-seed weight, and seed yield per hectare under calcareous conditions with foliar K application can be ascribed to enhanced metabolic processes which led to rise in the amount of K present in the plant tissues, activation of key enzymes resulting in enhanced rates of both photosynthesis and photorespiration and eventually contributing to a significant increase in the development of larger, healthier seeds and overall yield. This increase with K foliar treatment is consistent with the studies of Akram *et al*. (2009) and Jabeen and Ahmad (2011) who showed that K application has a positive impact on the growth and yield contributing attributes of sunflower. Hussain *et al*. (2016) also achieved comparable findings indicating that sunflower growth increased with the foliar application of SoP and MoP. According to Kalaiyarasan *et al*. (2016), these improvement in growth and yield attributes can be endorsed to the crucial contribution of sulfur (S), which increases the availability of the macro nutrient NPK, enhances chlorophyll concentration, and boosts carbohydrate metabolism. The non-significant yield responses of control treatment plants were not surprising given that the soil in this research was marginal in exchangeable K. Our findings indicated that the sunflower plants were not obtaining sufficient K uptake from the moderately calcareous soil, and that the soil's K-supplying ability was low, despite its marginal K content before sowing. The experimental soil exhibits a limited capacity to supply K, as evidenced by the ratio of soil Ca and Mg activity to

K. This phenomenon is known to hinder K uptake, potentially due to competing and antagonistic uptake mechanisms (Garcia *et al*., 1999; Jifon and Lester, 2009; Brady and Weil, 2010). The foliar application of K at various splits provided protection to the plants from the harsh growth conditions, especially when NoP, SoP and MoP sprayed at T2 = 2% in two equal splits (1% at leaf development stage and 1% inflorescence emergence stage) and T3 = 2% in three equal splits (0.67% at leaf development stage, 0.67% inflorescence emergence stage and 0.67% at flower bud development stage). These results contributed to a relative increase in yield. Plants sprayed with NoP produced greatest oil content followed by SoP and MoP in comparison to control. This rise in seed oil content with foliar K spray may be for a variety of reasons including increases photosynthesis, reduced stress, and directly activation of oil synthesis enzymes, resulting in increased carbon fixation, stress-resistant plants, and increased oil production in seeds. Research studies of Akram *et al*. (2009) and Raza *et al*. (2018) affirmed the positive effect of foliar K on the yield-related characteristics. The evaluation of the effect of the foliar application of K with various sources (Kfs) under calcareous conditions in the present study showed the considerable rise in chlorophyll concentration. Sunflower plants sprayed with NoP elevated chlorophyll concentration followed by SoP and MoP in comparison to control plants. Our findings align with Akram *et al*. (2009) and Hussain *et al*. (2016) on sunflower hybirds that foliar applications of K have a positive impact on the photosynthetic activities. Ishfaq *et al*. (2023) noted the increase in chlorophyll contents in wheat and maize plants with foliar application of K. Chlorophyll concentration is a sign of abiotic stressor tolerance in plants (Shah *et al*., 2017). Potassium directly promotes chlorophyll synthesis by activating essential enzymes and stabilizes membranes in chloroplasts, as well as indirectly through efficient CO_2 uptake for photosynthesis via regulated stomatal function (Tranker *et al*., 2018). Sufficient K levels support effective chlorophyll synthesis and increase green pigment production through several mechanisms (Huang *et al*., 2022). In calcareous soils having poor soil K uptake by plants throughout the growth period, foliar K treatments appears to mediate physiological responses in plants by activating multiple enzyme or metabolic pathways. The results show a notable increase in K concentrations in leaves during the R2 stage, coupled with a positive response to foliar applications of K using Kfs. Smith and Loneragan (1997) have stated that during the R2 stage of sunflower growth, a sufficient level of K concentration in the leaves generally falls between 3.4-6.6%. Thus, it is important to note in our study that foliar K treatment bypassed soil limitations and poor K uptake caused by calcareous soils and cation competition, instead feeding leaves directly via stomatal and cuticular absorption, which may have improved internal translocation and modified leaf surfaces, increasing leaf K content. Akram *et al*. (2009); Arshadullah *et al*. (2014) also described increase in concentration of K by foliar K application as compared to control. To enhance the seed and oil yield of sunflowers to be grown in calcareous soil conditions, the most appropriate approach is to use 2% sprays of NoP or SoP in three equal splits (0.67% at LDS, 0.67% IES and 0.67% at FS). These sources proves to be more effective compared to using Mop as it leads to increased K supply and leaf K concentration, and simultaneously reduces the influence of Ca and Mg activity ratios with K in the soil.

Conclusions and Recommendations

Sunflower showed a good response to the foliar application of 2% potassium in 2 or 3 equal splits at leaf development stage, inflorescence emergence stage and flower bud development growth stage. All the potassium sources potassium nitrate, potassium sulfate and potassium chloride significantly increased the growth, fseed yield and oil content of sunflower. Foliar treatments kept plants well-nourished throughout the growing season, when soil conditions having poor potassium uptake in calcareous soils.

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Novelty Statement

Spraying sunflower leaves with a potassium solution in splits at leaf development, inflorescence emergence, and flowering stages using different K sources such as potassium nitrate, potassium sulphate, and/or potassium chloride can significantly boost sunflower growth, seed, and oil yield in calcareous soils where K supply is poor due to an antagonistic relationship of K with other cations.

Author's Contribution

Abdul Aleem Memon: Conceived the idea, designed the study, did chemical analysis, wrote abstract, introduction, methodology, data collection, data entry in Minitab and analysis, results and discussion, conclusion, and references.
Inayatullah Rajpar: Conceptualization, designed the study, supervision, elaborated the intellectual content and modifies the manuscript.
Ghulam Murtza Jamro: Conceptualization, designed the study, supervision, elaborated the intellectual content and, Reviewed, proof reading, manuscript revision, plagiarism check.
Javaid Ahmed Shah and Saima Kalsoom Babar: Reviewed proof reading, manuscript revision and modify the manuscript.

Conflict of interest
The authors have declared no conflict of interest.

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