1	ACCEPTED ARTICLE
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3	Potassium foliar application to enhance high temperature tolerance and
4	productivity of canola under late sown conditions
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12	Abstract
13	Potassium (K) mitigates the effect of high temperature on canola, especially during its later
14	growth stages when sowing of canola is delayed. To explore the effect of K on high temperature
15	tolerance and canola production a field experiment (2019 – 2021) was conducted. The experiment
16	had two sowing dates (October 15 and November 1) and four K treatments, i.e. control, soil
17	application (50 kg K ha <sup>-1</sup> ), soil application + 0.25% K foliar spray at pre- and post-flowering stages
18	and soil application + 0.50% K foliar spray at pre and post-flowering stages. Application of 50 kg
19	K ha <sup>-1</sup> as soil application along with 0.50% K-foliar sprays resulted in higher production of
20	biochemicals (superoxide dismutase, peroxidase, catalase, and total soluble sugars) besides net
21	photosynthetic rate and stomatal conductance along with less malondialdehyde production and
22	relative cell injury in crops sown on November 1 <sup>st</sup> than untreated plants. Moreover, it also enhanced
23	chlorophyll florescence and chlorophyll (a and b) contents of late- sown crops. Plants sown on
24	November 1 <sup>st</sup> and received 50 kg K ha <sup>-1</sup> as soil application along with 0.50% K foliar spray also
25	gave a higher yield components, yield and economic returns than control. Therefore, it is suggested
26	to supply 50 kg K ha <sup>-1</sup> at sowing and a foliar spray of 0.50% K at the pre- and post-flowering stages
27	to canola crops sown late in the season to achieve optimal and economical yield levels.
28	Keywords: high temperature; reactive oxygen species; antioxidant activities; foliar spray; lipid

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# INTRODUCTION

Climate change is contributing to global warming, which has implications for the regional distribution and cultivation conditions of crops (Nesar et al., 2022). From last many years, the air temperature of earth is increasing steadily and it is expected that the rise in temperature will continue which would result in significant rise in average temperature of earth (IPCC, 2018). High

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temperature can have a severe impact on crop productivity (Mostofa et al., 2022). Canola is 36 vulnerable to high temperature especially during its reproductive stage (Annisa et al., 2013). In 37 canola the highly heat sensitive stage is flowering stage and considerable yield reduction occurs 38 when temperature goes higher than 28-30°C at flowering stage (Chen et al., 2020). High 39 temperature can cause abnormal flower development, leading to fewer pods and seeds (Chen et al., 40 2021). The problem is further exacerbated when canola planting is delayed due to intensive 41 cultivation practices. Farmers often struggle to plant canola on time, especially after cultivating 42 kharif crops like cotton, rice, and potatoes (Yousaf et al., 2002). Pakistan is among the countries 43 which are facing the severity of climate change. Based on records from the International Disasters 44 Database (EM-DAT), Pakistan has experienced a significant rise in the frequency and intensity of 45 extreme meteorological as well as hydrological events, including droughts, storms, floods and 46 extreme temperatures, over the past three decades. In addition to that the annual average 47 temperature of Pakistan has also increased up to 1.68°C during 1901 to 2021 whereas the global 48 rise of average annual temperature during the same period is 1.1°C; hence the increase in Pakistan's 49 average annual temperature is also higher than the global annual average temperature rise. 50 Fertilization strategies significantly reduce abiotic stress impacts by promoting plant 51 development, structure, biochemical processes, and nutrients stores, enabling plants to tolerate 52 hostile ecological circumstances (Xu et al., 2021). Within vital group of macronutrients, K assumes 53 a predominantly pivotal part in affecting growth and development of plant, whether in typical or 54 challenging environmental conditions. Its primary function in plants revolves around boosting 55 stress tolerance. Through its ability to decrease transpiration rates and enhance water absorption, 56 K contributes to increased agricultural productivity (Aslam et al., 2021). Furthermore, it assists in 57 preserving turgidity of cell and counteracting detrimental impacts of reactive oxygen species (ROS) 58 (Jan et al., 2019). Enzymatic activities and metabolic processes are enhanced by K (Zaman et al., 59 2019), thus enhancing physiological systems and building up antioxidant defense mechanisms 60 (Hasanuzzaman et al., 2020). Importantly, K performs a pivotal function in stress mitigation by 61 accelerating the metabolism of plant proteins, which regulate numerous plant processes during 62 adverse environmental conditions. Furthermore, it supports proline synthesis, contributes to 63 osmotic regulation and bolsters plant resilience to stress (Zamani et al., 2020). 64

Implementing proper K fertilization strategies can, therefore, perform a crucial part in boosting
 productivity and health of plant, even in harsh conditions. Li *et al.* (2023) found that the application

67	of potassium dihydrogen phosphate foliar spray at flag leaf stage in wheat resulted in increase in
68	net photosynthetic rate (Pn), chlorophyll content, antioxidant enzymes activity, dry matter
69	accumulation, yield related traits and overall yield of crop as well as quality of produce facing high
70	temperature. Likewise, Sarwar et al. (2022) reported that high temperature considerably damaged
71	physiology of leaf as well as grain yield of wheat. Nonetheless, existing data are scarce concerning
72	the effectiveness of K foliar spray for mitigation of high temperature effects in canola plants.
73	Consequently, current research project was formulated with the following aims: (i) to monitor the
74	physiological and developmental responses of canola under high temperature conditions; (ii) to
75	appraise the influence of K foliar spray on physiology of canola which enables the plant to cope
76	with high temperature; and (iii) to evaluate the influence of K foliar spray on canola yield.
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78	MATERIAL AND METHODS
79	Experimental Site
80	Experiment was carried out at the Agronomic Research Station Khanewal, Pakistan (Fig. 1). This

81 field trial was conducted for two growing seasons, from 2019 to 2021. The experimental soil was

sandy loam with an 8.6 pH, 4 ds cm<sup>-1</sup> electrical conductivity (EC), 0.06% nitrogen (N), 6.9 ppm

- 83 phosphorus (P), and 206.7 ppm K.



Fig. 1: Geographic location of the experimental site.

# **Experimental Treatments and Design**

The experiment was laid out in RCBD with split-plot arrangement with two sowing dates (main plots) and four K application treatments (sub-plots) having net plot size on 7.0 m  $\times$  2.7 m and three replications. Sowing dates were: October 15<sup>th</sup>; November 1<sup>st</sup> and K treatments were: T<sub>1</sub>: control

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89 (no application of K), T<sub>2</sub>: 50 kg K ha<sup>-1</sup> (soil applied), T<sub>3</sub>: T<sub>2</sub> + foliar spray of 0.25% K at pre- and

90 post-flowering stages,  $T_4$ :  $T_2$  + foliar spray of 0.50% K at pre- and post-flowering stages. The

91 canola variety Faisal Canola was used in the study. Potassium nitrate (KNO<sub>3</sub>) was used as K source,

- 92 and K solutions were prepared distilled water as solvent and sprayed manually using a hand93 sprayer.
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# 95 Crop husbandry

Canola was planted in rows 45 cm apart with a rabi drill using 4 kg ha<sup>-1</sup> seed rate. At four- leaf stage, the crop was thinned to maintain 10 cm plant to plant distance. Weeds were removed manually when required. Overall 85 kg N and 74 kg P ha<sup>-1</sup> were given to crop; with all P and K fertilizers applied at sowing time and N fertilizer was applied in two equivalent splits at sowing and flowering. Three irrigations were provided, at 30 days after sowing, flowering, and pod formation. Harvesting for treatments sown on October 15<sup>th</sup> and November 1<sup>st</sup> took place on March 8<sup>th</sup> and March 24<sup>th</sup>, respectively, in both years of the study.

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# 104 **Observations**

## 105 Leaf Biochemical Analysis

Leaf samples (from middle portion of main branch) were collected 10 days after K-foliar sprays 106 application to recorded superoxide dismutase (SOD), peroxidase (POD), catalase (CAT), total 107 soluble sugars (TSS) and malondialdehyde (MDA). The SOD (U/mg protein) activity was 108 determined using procedure described by Winterbourun et al. (1993). The (POD) (U/mg protein) 109 110 activity was determined by employing the procedure described by Ogawa et al. (1985). The amount of CAT (U/mg protein) was determined by following the procedure described by Sinha (1972). 111 The TSS (mg/g dry weight) was determined using the procedure described by Dubois et al. (1956). 112 The MDA (U/mg) was determined by employing the procedure described by Velikova et al. (2000). 113

### **Relative Cell Injury**

Ten days following the K-foliar spray treatment, fresh leaf samples (from the middle region of the main branch) were taken to record relative cell injury. The following formula was used (Lutts et al., 1999). Electrical conductivity (EC) was measured using EC meter (Model, Jenway 4510) Hour).

120	Relative Cell Injury (RCI %) = (EC of the sample - EC of the control) / (EC of the maximum
121	leakage) $\times$ 100
122 123	Photosynthetic Parameters
124	Ten days following the application of K-foliar sprays, the net photosynthetic rate (Pn, $\mu$ mol m <sup>-2</sup>
125	$s^{-1}$ ) and stomatal conductance (Gs, mol m <sup>-2</sup> s <sup>-1</sup> ) were measured using infrared gas analyzer [LC]
126	Analyzer with Broad Head, Part Number LCi-002/B with Serial Number 32455) (Sarwar et al.,
127	2022). Chlorophyll fluorescence (Fv/Fm) was recorded to measure thylakoid membrane stability.
128	Chlorophyll was extracted from leaf samples (from middle portion of main branch) using a standard
129	procedure and the fluorescence was measured using a chlorophyll fluorimeter (OptiScience, UK
130	with Serial Number 0729501) (Murchie and Lawson, 2013). Fresh leaf samples (from middle
131	portion of main branch) were collected 10 days after K-foliar sprays to record chlorophyll a/b using
132	the following equations (Lichtenthaler and Wellburn, 1983):
133	Chlorophyll a = 12.7 (A663) - 2.69 (A647)
134	Chlorophyll b = 22.9 (A647) - 4.68 (A663)

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#### **Yield and Yield Related Traits** 135

When the plants reached maturity, ten were chosen at random from each plot. Measurements 136 included plant height, number of branches and pods per plant, and length of pod. The quantity of 137 seeds per pod was calculated by counting and threshing fifteen pods that were taken from the 138 chosen plants. After that, the complete plots were gathered and threshed. A total of 1000 seeds 139 were weighed and counted in order to record the weight. The yield per plot was calculated by taking 140 the total weight of seeds in each plot and converting it to yield per hectare. 141

#### **Economic Analysis** 143

The gross income per hectare (Rs.) was calculated by multiplying canola seed yield (kg ha<sup>-1</sup>) by 144 the market rate (Rs. /kg) of canola seed (Byerlee, 1988). Fixed and variable costs per hectare (Rs. 145 /ha) were calculated by combining the costs associated with standard field operations and 146 treatment-specific expenses, respectively. The total cost of production (Rs. /ha) was obtained by 147 combining the fixed and variable costs. Net income (Rs. /ha) was calculated by deducting the total 148 cost of production from the gross income. The benefit-cost ratio (BCR) for each treatment was 149 determined by dividing the net income by the total cost of production. 150

### 152 Weather

- 153 During 2019-20, average maximum temperature was 24.50°C, while average minimum
- temperature was 11.36°C and total rainfall was 232 mm from October to April. However, from
- 155 February to March of 2020, when the crop was in the reproductive stage, the highest temperature
- range was 25.50–36.50°C. During 2020-21, average maximum temperature was 27.27°C, while
- average minimum temperature was 10.87°C and total rainfall was 64.20 mm from October to April.
- 158 However, in February and March of that year the highest temperature range was 22.50–35.50°C.



Fig. 2: Climate conditions at the experimental location throughout the study duration.

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#### 160 **RESULTS**

#### 161 Leaf Physiology

Late sowing reduced SOD, POD, CAT, and TSS contents in leaves, and increased MDA 162 production. Foliar sprays of K enhanced these contents and reduced MDA production, especially 163 for plants sown on November 1<sup>st</sup> (Fig. 3, 4). Late sowing resulted in high RCI, which was reduced 164 by foliar sprays of K, especially at 0.50% concentration (Fig. 4). Delayed sowing reduced Pn and 165 Gs, which were preserved by foliar spray of K, especially at 0.50% concentration (Fig. 4). Late 166 sowing also reduced chlorophyll fluorescence and leaf chlorophyll contents (a and b), which were 167 maintained by foliar sprays of K, especially at 0.50% concentration (Fig. 5). Overall, foliar sprays 168 of K mitigated the negative effects of late sowing on canola plants. 169

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**Fig. 3:** Influence of two sowing dates and potassium application on biochemical of canola. Means sharing same case letter do not differ significantly at P<0.05.











**Fig. 5:** Influence of two sowing dates and potassium application on chlorophyll fluorescence (Fv/Fm) and chlorophyll contents of canola.

# 173 Yield and Yield Related Traits

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Data regarding yield and related traits has been presented in table 1. During 2019-20, the canola 174 crop sown on 15<sup>th</sup> of October resulted in 9% higher plant height as compared to canola crop sown 175 on November 1<sup>st</sup>. Moreover regarding number of pods per plant, 52% higher were recorded in crop 176 sown on October 15<sup>th</sup> and sprayed with 0.50% K-foliar spray than crop sown on same date but no 177 K-foliar spray was applied. Additionally, regarding pod length and number of seed per pod, 10% 178 and 21% higher pod length and number of seed per pod, respectively, were documented in plants 179 sprayed with 0.50% K-foliar spray as compared with control. Regarding 1000-seed weight, 14% 180 higher was recorded when canola was sown on October 15<sup>th</sup> than canola sown on November 1<sup>st</sup>. 181 whereas among K treatments, the 0.25 and 0.50% K-foliar sprays resulted in 29 higher 1000-seed 182 weight than control. Regarding yield, canola crop sown on October 15<sup>th</sup> and spraved with 0.50% 183 K-foliar spray resulted in 7% higher yield as compared with crop sown on same date but not 184 sprayed with K. Whereas, crop sown on November 1<sup>st</sup> and sprayed with 0.50% K-foliar spray 185 resulted in 43% higher yield as compared with crop sown on similar date but not sprayed with K 186 187 at pre- and post-flowering stages. During 2020-21, the canola crop sown on 15<sup>th</sup> of October resulted in 4% and 17% higher plant 188 height and number of branches per plant, respectively, than canola crop sown on November 1<sup>st</sup>. 189 Moreover regarding number of pods per plant, 39% higher were recorded in crop sown on 190 November 1<sup>st</sup> and sprayed with 0.50% K-foliar spray than crop sown on same date but no K foliar 191

191 November 1<sup>st</sup> and sprayed with 0.50% K-foliar spray than crop sown on same date but no K foliar

- spray was applied. Additionally, regarding pod length, 16% higher pod length was documented in
   plants sown on October 15<sup>th</sup> than plants sown on November 1<sup>st</sup> whereas among K treatments, crop
- 194 sprayed with 0.50% K-foliar sprays gave 7% higher pod length as compared with control.

195	Furthermore, regarding number of seed per pod, 48% higher number of seed per pod was recorded
196	in plants sown on October 15th as compared to plants sown on November 1st whereas among K
197	treatments, crop sprayed with 0.50% K-foliar sprays gave 48% higher number of seed per pod as
198	compared with control. Regarding 1000-seed weight, 14% higher was recorded when canola was
199	sown on October 15 <sup>th</sup> than canola sown on November 1 <sup>st</sup> , whereas among K treatments, the 27%
200	higher 1000-seed weight as compared with control. In case of yield, canola crop sown on October
201	15 <sup>th</sup> and sprayed with 0.50% K-foliar spray resulted in 7%, higher yield as compared with crop
202	sown on same date but not sprayed with K. Whereas, crop sown on November 1 <sup>st</sup> and sprayed with
203	0.50% K-foliar spray resulted in 43% higher yield as compared with crop sown on similar date but
204	not sprayed with K at pre- and post-flowering stages.

**Table 1:** Influence of two sowing dates and potassium application on yield and related traits of canola.

Treatments	Plant height (cm)		Number of branches per plant		Number of pods per Plant		Pod length (cm)		Number of seeds per pod		1000-seed weight (g)		Seed y	vield (g)
	2019- 20	2020-21	2019 20	2020-21	2019- 20	2020-21	2019- 20	·2020- 21	2019- 20	2020- 21	2019- 20	2020- 21	- 2019- 20	2020- 21
				S	owing	dates (D)	)							
15th October (D <sub>1</sub> )	197A	170 A	6	6 A	374 A	238 A	6.80	7.43 A	17	23 A	4.14 A	4.32 A	1170 A	2606 A
1st November (D <sub>2</sub> )	179 B	163 B	5	5 B	319 B	171 B	6.60	6.22 B	17	18 B	3.58 B	3.76 B	723 B	2232 B
HSD	10.79	4.19	-	0.16	10.79	17.14	-	0.34	-	1.26	1.06	1.24	43.56	32.66
				I	Treatm	ents (T)								
Control (T <sub>1</sub> )	182	165	5	5	254 D	175 C	6.43 B	6.54 B	15 C	13 C	3.04 C	3.22 C	849 D	2037 D
50 kg K ha <sup>-1</sup> (T <sub>2</sub> )	193	165	5	5	334 C	198 BC	6.63 B	6.68 AB	17 B	21 B	3.90 B	4.08 B	890 C	2278 C
0.25% K+50 kg K ha <sup>-1</sup> (T <sub>3</sub> )	190	168	5	5	379 B	209 AB	6.58 B	6.99 A	17 B	23 A	4.29 A	4.38 A	951 B	2601 B
0.50% K+50 kg K ha <sup>-1</sup> (T <sub>4</sub> )	190	168	5	6	419 A	235 A	7.17 A	7.07 A	19 A	25 A	4.20 A	4.47 A	1094 A	2760 A
HSD	-	-	-	-	26.86	31.37	0.52	0.44	1.52	1.78	0.18	0.18	41.23	87.11
					D	×T								
<b>D</b> <sub>1</sub> <b>T</b> <sub>1</sub>	167	170	5	6	234 d	219 ab	6.56	7.17	14	15	3.35	3.53	1156 bc	2280 de
<b>D</b> <sub>1</sub> <b>T</b> <sub>2</sub>	188	169	6	5	339 c	237 a	6.63	7.32	18	24	4.12	4.30	1097 с	2413 cd
<b>D</b> <sub>1</sub> <b>T</b> <sub>3</sub>	181	171	6	6	436 b	243 a	6.60	7.60	18	27	4.59	4.77	1186 ab	2752 b
<b>D</b> <sub>1</sub> <b>T</b> <sub>4</sub>	180	171	6	6	487 a	253 a	7.43	7.61	20	26	4.49	4.67	1240a	12980 a
<b>D</b> <sub>2</sub> <b>T</b> <sub>1</sub>	196	160	5	5	273 d	132 c	6.30	5.91	16	12	2.72	2.90	543 f	1794 f

D <sub>2</sub> T <sub>2</sub>	197	160	5	5	328 c	160 c	6.63	6.04	16	18	3.69	3.87	684 e	2143 e
<b>D</b> <sub>2</sub> <b>T</b> <sub>3</sub>	198	165	4	5	322 c	174b c	6.57	6.53	16	22	3.99	4.17	715 e	2450 c
<b>D</b> <sub>2</sub> <b>T</b> <sub>4</sub>	199	165	5	5	351 c	216 ab	6.90	6.37	18	20	3.92	4.10	949 d	2540 c
HSD	-	-		-	46.3 0	53.82	-	-	-	-		-	31.2 5	150.1 5
Means sha	aring same ca	ase lett	er do	not di	ffer sig	nificar	ntly at	P<0.	05					
<b>Economic</b> When the	e Analysis crop was sov	wed on	octol	ber 15	<sup>th</sup> and t	treated	with	0.50%	6 K-f	foliar	· spray	ys at t	he pr	e- and
post-flower	ing stages, co	ompare	ed to tl	he con	trol, th	ere wa	s a 23	% inc	crease	e in n	et rev	venue	and l	oenefit
cost ratio a	according to	the e	conon	nic an	nalysis	(Fig.	6). S	imila	:ly, v	when	crop	was	sow	ved on
November	1 <sup>st</sup> and treate	d with	0.50%	% K-fo	oliar sp	rays at	pre-	and p	ost-f	lowe	ring s	stages	, con	npared
to control, 4	40% higher n	et inco	ome w	as obt	ained,	likewis	se, wł	nen ci	op w	vas so	owed	on No	ovem	ber 1 <sup>st</sup>
and treated	with 0.50% ]	K-folia	r sprag	ys at p	ore- and	l post-f	lower	ring st	tages	, con	npared	d to c	ontro	1, 32%
higher bene	fit cost ratio	was o	btaine	d (Fig	. 6).									



Fig. 6: Economic analysis of two sowing dates and foliar spray treatments of canola.

# DISCUSSION

The findings of study demonstrated that K-foliar sprays resulted in improved physiological response and yield of canola plants which are likely to face high temperature at flowering under

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223	late sowing conditions. Under higher temperature exposure, the plant metabolism as well as many
224	biochemical reactions is disrupted (Hasanuzzaman et al., 2013). Potassium enhances tissue water
225	potentiality, which aids in extreme temperature tolerance, and it helps to activate numerous
226	physiological and metabolic processes like photosynthesis, respiration, and nutrition homeostasis
227	(Hasanuzzaman et al., 2018). In present study the activity of enzymatic antioxidants (SOD, POD,
228	and CAT) was significantly improved by spraying K solution of canola plants sown on $1^{st}$
229	November (Fig.3). These enzymes are protein in nature and their function is the transformation of
230	ROS into the form which is non-toxic/harmful for plants, hence play crucial role in defense
231	mechanism of plant which enables plant to mitigate the harmful effect of oxidative stress caused
232	by many abiotic stresses (Saez and Estan-Capell, 2017). These ROS cause lipid peroxidation of the
233	cell membrane (Fang et al., 2022).
234	A higher level of enzymatic antioxidant activity in plants supplied with K-foliar sprays might be
235	due to the role of K in enhancing the production/activity of enzymatic antioxidants in stressed
236	plants (Fang et al., 2022). One way K enhances their production/activity is by the regulation of
237	enzymes activity present in antioxidant defense pathways (Anschütz et al., 2014). Potassium also
238	aids in maintaining cellular ion balance and osmotic potential, which are crucial for enzyme activity
239	and overall plant health under stress. By regulating osmotic balance, K helps prevent cellular
240	dehydration and maintains turgor pressure, which is essential for optimal enzyme function
241	(Siddiqui et al., 2021). In addition, fewer contents of MDA and less occurrence of RCI (Fig. 4) in
242	plants sprayed with K-foliar sprays were also recorded in this study. Malondialdehyde contents in
243	plant leaves are used to estimate the lipid peroxidation (Houmani et al., 2022). As discussed above
244	the K application increase the efficacy and contents of enzymatic antioxidants defense systems in
245	plants (Siddiqui et al., 2021) thus reduce the cellular damage in plants. Hence less content of MDA
246	and less prevalence of RCI might be due to this protective role of K against ROS.
247	Additionally higher level of TSS in plants (Fig. 3) sprayed with K was also recorded.
248	Accumulation of TSS is mainly observed in mild stress which retard the growth of plant but any
249	how the process of photosynthesis is not much inhibited (Keunen et al., 2013). Mainly the
250	production of TSS is taken place during osmotic stress and act as osmo-protectants to stabilize the
251	activity of cell membrane as well as to main the turgor of cell (Dien et al., 2019). Many researchers
252	reported that K enhances the accumulation and assembly of TSS in plants facing abiotic stress
253	through several mechanisms such as osmotic adjustment (Tränkner et al., 2018;), the stimulation

254	of numerous enzymes, like RuBisCO (Weng et al., 2007) and governing the functioning of
255	photosynthesis machinery (Tavakol et al., 2022). Translocation of photo-assimilates from source
256	to sink is also governed by K (Cakmak, 2005).
257	Net photosynthesis and stomatal conductance (Fig. 4) was also enhanced by the foliar application
258	K on canola. Stomatal opening and closing is governed by K ions (Shabala, 2003). Potassium ions
259	are actively pumped into guard cells causing them to swell and leading to stomatal opening (Lu et
260	al., 2019). This process is crucial for regulating loss of water by transpiration and facilitating the
261	uptake of CO <sub>2</sub> for photosynthesis (Lu et al., 2019). Moreover K also influence the photosynthesis
262	as it performs crucial part in the activation of enzymes vital for photosynthesis, such as Rubisco,
263	which catalyzes the fixation of CO <sub>2</sub> during the Calvin cycle (Rawat et al., 2022). Canola plants
264	sown on November 1st and subjected to 0.50% K-foliar sprays exhibited an augmentation in
265	chlorophyll levels compared to untreated plants (Fig. 5) sown on the same date. Potassium plays a
266	crucial part in the production of precursor molecules for chlorophyll pigments and enhances the
267	capacity to transform radiation energy into chemical energy within the chloroplasts (Zhao et al.,
268	2001).
269	The supplementation of external K caused a noticeable increase in several important parameters
270	of canola crop sown on November 1 <sup>st</sup> . These parameters included the pod count per plant, seeds
271	per pod, and the weight of 1000 seeds (Table 1). This enhancement in pod and seed quantities can
272	likely be attributed to the ability of K to improve growth by its participation in numerous biological
273	functions, such as enzyme activation, assimilate and nitrate transport, water relations, stomatal
274	regulation and photosynthesis (Oosterhuis et al., 2014). The improvement in 1000-seed weight
275	(Table 1) due to the application of K, might be the function of K in photosynthesis and
276	transportation of sugars from source to sink (Oosterhuis et al., 2014). The increase in overall yield
277	(Table 1) observed in canola sown on November 1 <sup>st</sup> , attributed to K application, can be attributed
278	to a combination of factors. These factors include an improvement in membrane stability, enhanced
279	efficiency of photosynthesis, increased accumulation of carbohydrates, and effective translocation
280	of these substances to developing seeds (Sarwar et al., 2022). These combined effects contribute
281	to an overall increase in seed yield and benefit cost ratio.
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# CONCLUSIONS

This study has demonstrated that the foliar application of K triggers antioxidant activity withinplants, as evidenced by increased production of SOD, POD, CAT, and TSS. This timely activation

- 286 of the antioxidant defense system, brought about by K-foliar spraying, led to a significant decrease
- in MDA levels, reduced cell injury, and the maintenance of optimal photosynthesis rates, stomatal
- 288 conductance, and chlorophyll a/b contents. Furthermore, when a combination of 50 kg K ha<sup>-1</sup>
- applied at sowing and foliar spraying with 0.50% K at both pre- and post-flowering stages was
- employed, higher crop yield and improved benefit-cost ratios were obtained. Based on these
- <sup>291</sup> findings, it is recommended to apply 50 kg K ha<sup>-1</sup> at sowing and a foliar spray of 0.50% K at the
- 292 pre and post-flowering stages to canola crop sown late in the season to achieve optimal and
- 293 economical yield levels.
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