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# Efficiency of nitrogen, gibberellic acid and potassium on canola production under sub-tropical regions of Pakistan

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**The global demand for crop production is rapidly growing due to the continued rise in world population. Crop productivity varies generally with soil nutrient profile and climate. The optimal use of fertilizers might help to attain higher crop yield in canola. To circumvent nutrient imbalance issues in soil, two separate field trials were conducted to determine (a) the best source of nitrogen (N) between ammonium sulfate $(NH_4)_2SO_4$ and ammonium nitrate $(NH_4NO_3)$, (b) significance of gibberellic acid ($GA_3$) and potassium (K), in an attempt to enhance canola yield and yield attributes. Both experiments were carried out in randomized complete block design (RCBD) with three replicates. The nitrogen source in the form of $NH_4)_2SO_4$ (0, 10, 20 and 30 kg/ha) and $NH_4NO_3$ (0, 50, 75 and 100 kg/ha) was applied in the rhizosphere after 3 and 7 weeks of sowing, referred to as experiment 1 (E1). In another separate experiment (E2), the canola crop was sprayed with four level of $GA_3$ (0, 10, 15, 30 g/ha) and K (0, 2.5, 3.5, 6 g/ha) individually or in combination by using hydraulic spryer, 30 days after sowing (DAS). The data was collected at different growth stages of canola and analyzed statistically. The E1 trail showed that N fortification in the form of $NH_4NO_3$ (100 kg/ha) and $(NH_4)_2SO_4$ (30 kg/ha) had a positive effect on the plant height, number of branches, fruiting zone, seed yield per plant, seed yield per hectare of canola except oil percentage. Moreover, canola plants (E2) also displayed a significant improvement on all studied features with high doses of $GA_3$ (30 g/ha) and K (6 g/ha) individualy and in combined form. The correlation coefficient analysis of $(NH_4)_2SO_4$ and $NH_4NO_3$ was highly significant to plant height, number of branches, fruiting zone, seed yield per plant, seed yield per hectare of canola In a nutshell, compared to both source of N, $NH_4NO_3$ was more efficient and readily available source of N. $GA_3$ being a growth elicitor and potassium as a micronutrient serve as potential source to improve yield and to manage nutrient profile of canola.**

For several years now, arid and semi-arid areas located in certain third world countries have been facing massive shortage of edible oils which was met through imports in large quantities from other countries[1]. As a result, efforts aiming at reducing the imbalance between the production and consumption for edible oils have been made by under-developed countries. In this context, oil seed crops seemed to be an accurate option for these countries. Among these crops, canola appeared as a potential candidate for the domestic edible oil production[2]. This could be explained by to the low content of erucic acid and glucosinolates in oil and its seed cake, respectively[3]. Moreover, canola crop can survive under diverse environmental conditions due to a wide range of adaptability[4]. However, mismanagement and highly imbalanced application of micro and macronutrients found to be reducing the yield of canola crop, therefore, nutrients management strategies for optimizing the canola production are highly required[5].

Balanced fertilizer application influence the crop yield, quality and the soil productivity[6]. The adequate nitrogen supply is important in order to boost up the canola productivity and it holds a key role in plant tissue growth and development. Plus, it represents a part of chlorophyll, nucleotides, protein, and amino acids formation which directly affect the quality and quantitative traits of the crop. Other factors such as Soil profile, texture, and

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moisture content fluctuation at various critical stages of growth and development of canola may influence the nitrogen use efficiency on canola crop. Actually, this kind of crop can very responsive to fertilizer application, especially nitrogen which significantly impacts the plant height, number of branches/plant, number of flower/plant, number of pods/plant and their weights, and seed yield/ha. It also effects of the leaf area (LA) development and LA duration after flowering in canola crop[7,8].

Many natural and artificial plant regulators may be used with the aim of controlling the developmental process from germination to post-harvest preservation of crop plants and subsequently, optimizing their production[9]. Among these fertilizers, gibberellic acid ($GA_3$) is obviously a key regulator product for plant-growth and other physiological mechanisms. It can stimulates the root and stem elongation, seed germination, break dormancy, leaf expansion, fruit senescence, and flowering[10]. Moreover, GAs may influence the metabolic pathways including nitrogen metabolism, chlorophyll production and degradation, nitrogen redistribution, and translocation of assimilates[11]. It can also induces the expression of several hydrolytic enzymes involved in the conversion of starch to sugar which ultimately influence the plant growth at vegetative and reproductive stages[12], plant signaling mechanisms, gene expression, and plant morphology and physiology[13,14].

Besides nitrogen and phosphorus fertilizers, K found to be influencing the seed oil content percentage, yield and yield-contributing traits of the canola crop[15,16]. K is very important fertilizer which is involved in photosynthesis, regulation of stomata, control of the ionic balance, translocation of photosynthates, protein synthesis, enzymatic activities, and many other physiological and biochemical processes[17,18]. Therefore, K is considered as primary osmoticum that plays an important role at maintaining the low water potential in plant tissue and also impacts the plant growth and development.

For plant breeders, the efficient use of nutrients from the soil by the crop plants is a promising characteristic. Some plants may produce high yields with minimal inputs[14,18]. Many studies showed that significant variation exists among various genotypes of canola regarding efficient use of potassium[19].

Keeping in view the possible outcomes of efficient use of K and GA, the current study evaluates canola genotype (Surhan-2012) for four consecutive years for these traits. Hence, current manuscript demonstrated the influence of foliar application of $GA_3$ and K separately, or in combination in canola. This study carries immense importance as a reference for the impact of these two important nutrients on canola production and the multi-year screening of Surhan-2012 in this context. The main objective of the study to find out the best source of nitrogen and optimal combination of $GA_3$ and K for increasing the canola productivity. Being major oil importer country, overall objective to introduce cost effective technique to enhance canola production.

## Material and methods

### Site descriptions

The two field experiment was conducted at the agriculture farm of Nuclear Institute of Agriculture (NIA), Tando Jam, Sind, Pakistan (31° 25′ 0″ North, 73° 5′ 0″ East) and an altitude 30 m above from sea level. The experimental farm was irrigated by the canal water from the river Sindh. The experiment 1 (E1) trial was conducted at two growth seasons (2017–18/2018–19) while experiment 2 (E2) trial was managed for four consecutive years (2014–18). The physical and chemical properties of the soil at the study site are presented in Tables 1 and 2. This was carried out to ascertain the characteristics of the soil at the experimental site. The soil test result obtained showed that the soil was sandy loam and pH (7–7.5). The detail status of soil agronomy and characteristics was

| NIA exp. field | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | (meq/60 g soil) (μg/g soil) | | | | | | | |
| pH | OM (%) | Total N (%) | Na | K | Mg | P | S | Ca | Zn | B |
| 7.0–7.5 | 1.05 | 0.07 | 0.07 | 0.12 | 2.1 | 12.3 | 16.09 | 3.02 | 1.43 | 0.38 |

**Table 1.** Details status of soil agronomy research field. Source: Soil Science department (2018).

| Treatments | Potassium-K ($g/m^2$) | Gibberellic acid (g/ha) |
|---|---|---|
| T1 | 0 (control) | 0 (control) |
| T2 | 2.0 | 0 |
| T3 | 3.5 | 0 |
| T4 | 6.0 | 0 |
| T5 | 0 | 100 |
| T6 | 0 | 150 |
| T7 | 0 | 300 |
| T8 | 2.0 | 100 |
| T9 | 3.5 | 150 |
| T10 | 6.0 | 300 |

**Table 2.** Treatment levels/doses of potassium (K) and gibberellic acid ($GA_3$) on canola production.

depicted in (Table 1). The experimental area is semiarid with very low rain fall (100–300 mm, the about 70% rainfall occurs in summer and the remaining 30% occurs in winter season.

### Experimental design

Two field experiments of canola were designed to conduct at the farm of Nuclear Institute of Agriculture (NIA), Tando Jam, Sind, Pakistan (31° 25′ 0″ North, 73° 5′ 0″ East). The experiment dealing with ammonium sulfate $(NH_4)_2SO_4$ and ammonium nitrate $NH_4NO_3$ designated as experiment 1 (E1) to counter best source of N supplementation and application of K and $GA_3$ referred to as experiment 2 (E2). The E1 trial was conducted at two growth seasons (2017–18/2018–19) while E2 trial was managed for four consecutive years (2014–18). Data were collected under a randomized Complete Block Design (RCBD) with three replications per block. The both experiments was sown in winter season (September–March) during all growing seasons.

The canola seeds were collected from nuclear institute of agriculture and sown and thinned after 15–20 days of germination for the purposes of maintaining long distance dispersal of plants. The plant to plant and row to row distance was maintained 9 and 18 in., respectively. All the recommended agronomic and cultural practices that govern the production of the crop were applied efficiently during the plant growth cycle[20].

### Application of $(NH_4)_2SO_4$ $NH_4NO_3$ as N supplements

The four levels of $(NH_4)_2SO_4$ (0, 10, 20 and 30 kg/ha) and $NH_4NO_3$ (0, 50, 75 and 100 kg/ha) were used as nitrogen source. The $(NH_4)_2SO_4$ composed of 21% nitrogen and 24% sulfur and $NH_4NO_3$ contained 33.5% nitrogen. Both nitrogen fertilizers were applied in two split doses; the first dose was applied after 3 weeks of crop sowing whereas the second was undertaken after 7 weeks of sowing. One square meter ($m^2$) area of plants was chosen randomly from each plot for harvesting during two seasons (2017–18/2018–19). The agronomic parameters of crops were computed from the plant height (cm), number of branches/plant, fruiting zone length (cm), seed yield/plant (g), seed yield/ha (kg). The differences of oil content (%) of canola seeds were recorded, pooled and statistically analyzed in order to evaluate the effect of different sources/doses of nitrogen on the agronomic characters and traits of canola[16].

### The effect of K nitrate and $GA_3$ on canola yield and yield attributes

Ten different combinations (Table 2) of K and $GA_3$ were applied as foliar spray. The experiment was carried out using a randomized complete block design (RCBD) with three replications.

Before the foliar application, $GA_3$ was dissolved in ethanol. Various dilutions were then made in order to obtain solutions with several concentrations. The different combinations of $GA_3$ and K were sprayed after 1 month of sowing. The treatments were applied three times with an interval of 1 week and the control plants were sprayed with distilled water only. One $m^2$ area of plants was chosen randomly from each plot at harvesting time during four seasons (2014–18). The data of agronomic parameters including Plant height (cm), number of branches/plant, fruiting zone length (cm), seed yield/plant (g), seed yield/ha (kg) and oil content percentage have been recorded according to the protocol reported by A.O.A.C in 1980. Subsequently, the recorded data were analyzed using analysis of variance (ANOVA) combined with HSD. Tukey's test was also used to determine the significant difference between the treatments with the help of statistical software SAS (version 9.4) and finally calculation of the cost–benefit ratio.

### Ethical approval

All the plant studies were carried out in accordance with relevant guidelines and regulations of concern Institute (Nuclear Institute of Agriculture (NIA) Tandojam Sindh Pakistan).

## Results

### Impact of $(NH_4)_2SO_4$ on growth and agronomic parameters of canola plants

The statistical analyses performed on two seasons mean data showed significant differences on all studied features (Tables 3, 5). Results obtained in the current investigation (E1) suggested that $(NH_4)_2SO_4$ has more positive correlation with respect to plant height, number of branches per plant, fruiting zone length, seed yield per plant, seed yield per hectare and oil percentage compared to $NH_4NO_3$ (Tables 4, 6). Moreover, the effect of $(NH_4)_2SO_4$ was dose dependent, higher the amount of applied fertilizer, higher value of plant height, number of branches per plant, fruiting zone length, seed yield per plant, seed yield per hectare and oil contents of canola plants were recorded. Correlation analysis was performed in order to evaluate the agronomic characteristics after the $(NH_4)_2SO_4$ treatment and it was found that significant results have been achieved with plant height (0.998), number of branches per plant (0.953), fruiting zone length (0.987), seed yield per plant (0.994), seed yield per hectare (0.994) (Tables 4, 6).

### Impact of $NH_4NO_3$ on growth and agronomic parameters of canola plants

The $NH_4NO_3$ application has considerably influenced the crop's agronomic and quality traits compared to the control canola plants in the field. The recorded results including the maximum plant height (194 cm), number of branches per plant (9), fruiting zone length (156.2 mm), seed yield per plant (42.4 g) and seed yield per hectare (1007.2 kg) showed an increase in all of the aforementioned agronomic attributes (Tables 3, 5), except for the oil percentage when $NH_4NO_3$ dose increased to maximum (100 kg/ha) (Table 3). A highly positive correlation was also observed between yield attributes and $NH_4NO_3$ rates for plant height (0.987), number of branches per plant (0.887), fruiting zone length (0.957), seed yield per plant (0.953), and seed yield per hectare (0.953), while negative correlation with oil contents was detected (Tables 4, 6).

| Treatments | Plant height | No. of branches | Fruiting zone | Seed yield/plant | Seed yield/fed | Oil percentage |
|---|---|---|---|---|---|---|
| Nitrogen | | | | | | |
| Ammonium sulfate (kg/fed) | | | | | | |
| 0 | 141.5bc* | 5.5a* | 109.1ac* | 29.9ad** | 725.7a** | 43.02a* |
| 10 | 150.7b | 5.7a | 116.4a | 32.8a | 788.1b | 42.5a |
| 20 | 160.1ab | 6.4b | 121.7a | 35.2b | 833.7c | 43.5b |
| 30 | 168.4a | 7.1c | 131.5b | 37.8c | 908.2d | 43.8b |
| Ammonium nitrate (kg/fed) | | | | | | |
| 0 | 141.2d** | 5.3cd* | 110.4d** | 30.2c** | 729.0c** | 41.9b* |
| 50 | 157.1c | 6.3bc | 124.4c | 34.6b | 830.4b | 45.01a |
| 75 | 169.9b | 7.1b | 133.0b | 36.1b | 861.4b | 40.37c |
| 100 | 194.0a | 9a | 156.2a | 42.4a | 1007.2a | 38.19c |

**Table 3.** Impact of rate and source of nitrogen in the form of ammonium sulfate $(NH_4)_2SO_4$ and ammonium nitrate $NH_4NO_3$ on the mean yield and yeild attribute during 2017–18. Value within the column with the same letter are not significantly different (Tukey, HSD; p 0.05), **p 0.01 according to least significant difference (LSD) test.

| Correlation | R value | SE | p (r = 0) |
|---|---|---|---|
| Ammonium sulfate | | | |
| Plant height | 0.998 | 0.020 | 0.0000(***) |
| No. of branches | 0.953 | 0.029 | 0.0000(***) |
| Fruiting zone | 0.987 | 0.039 | 0.0000(***) |
| Seed yield/plant | 0.994 | 0.034 | 0.0000(***) |
| Seed yield/fed | 0.994 | 0.034 | 0.0000(***) |
| Oil percentage | 0.986 | 0.051 | 0.0000(***) |
| Ammonium nitrate | | | |
| Plant height | 0.987 | 0.034 | 0.0000(***) |
| No. of branches | 0.884 | 0.076 | 0.0000(***) |
| Fruiting zone | 0.957 | 0.045 | 0.0000(***) |
| Seed yield/plant | 0.953 | 0.048 | 0.0000(***) |
| Seed yield/fed | 0.953 | 0.048 | 0.0000(***) |
| Oil percentage | − 0.892 | 0.071 | 0.0000(***) |

**Table 4.** Correlation coefficient of nitrogen in the form of ammonium sulfate $(NH_4)_2SO_4$ and ammonium nitrate $NH_4NO_3$ on the mean yield and yeild attribute during 2017–18.

| Treatments | Plant height | No. of branches | Fruiting zone | Seed yield/plant | Seed yield/fed | Oil percentage |
|---|---|---|---|---|---|---|
| Nitrogen | | | | | | |
| Ammonium sulfate (kg/fed) | | | | | | |
| 0 | 140.2** | 5.4a* | 107.0b** | 30.1d** | 717.6a** | 41.83b* |
| 10 | 154.4b | 5.9ab | 118.1c | 33.5c | 802.7c | 43.1b |
| 20 | 162.1ab | 6.7bc | 125.2d | 36.0b | 862.6b | 43.2a |
| 30 | 172a | 7.3c | 132.9a | 38.8a | 929.0d | 43.47a |
| Ammonium nitrate (kg/fed) | | | | | | |
| 0 | 138.7a** | 5.2cd* | 109.3d** | 29.8d** | 712.9a** | 42.51a* |
| 50 | 155.3c | 5.9bc | 124c | 39.2c | 812.3c | 41.53ab |
| 75 | 168.1b | 6.7b | 132.4b | 36.7b | 874.2b | 40.45b |
| 100 | 193d | 8.9a | 153a | 41.5a | 994.0d | 39.54bc |

**Table 5.** Impact of rate and source of nitrogen in the form of ammonium sulfate $(NH_4)_2SO_4$ and ammonium nitrate $NH_4NO_3$ on the mean yield and yeild attribute during 2018–19. Value within the column with the same letter are not significantly different (Tukey, HSD; p 0.05), **p 0.01 according to least significant difference (LSD) test.

| Correlation | R value | SE | p (r = 0) |
|---|---|---|---|
| Ammonium sulfate | | | |
| Plant height | 0.986 | 0.041 | 0.0000 (***) |
| No. of branches | 0.963 | 0.066 | 0.0000 (***) |
| Fruiting zone | 0.992 | 0.046 | 0.0000 (***) |
| Seed yield/plant | 0.992 | 0.046 | 0.0000 (***) |
| Seed yield/fed | 0.976 | 0.036 | 0.0000 (***) |
| Oil percentage | 0.939 | 0.62 | 0.0000 (***) |
| Ammonium nitrate | | | |
| Plant height | 0.985 | 0.018 | 0.0000 (***) |
| No. of branches | 0.879 | 0.066 | 0.0000 (***) |
| Fruiting zone | 0.967 | 0.042 | 0.0000 (***) |
| Seed yield/plant | 0.867 | 0.078 | 0.0000 (***) |
| Seed yield/fed | 0.865 | 0.078 | 0.0000 (***) |
| Oil percentage | − 0.273 | 0.154 | 0.0867 (ns) |

**Table 6.** Correlation coefficient of nitrogen in the form of ammonium sulfate $(NH_4)_2SO_4$ and ammonium nitrate $NH_4NO_3$ on the mean yield and yeild attribute during 2018–19.

## Effect of foliar application of $GA_3$ and K on canola yield and yield components

Application of growth hormone $GA_3$ and K caused a significant increase in plant height compared to control plant during a 4-year period (2014–2018). Significant differences were also observed among the treatments ($F = 81.913$; $p \leq 0.0000$, $F = 99.79$; $p \leq 0.0000$, $F = 86.782$; $p \leq 0.0000$, and $F = 101.34$; $p \leq 0.0000$) during growth seasons (Table 7). The maximum plant height was reported with combined treatment of $GA_3$ (30 g/ha) and K (6 g/m$^2$) ($T_{10}$) followed by $T_9$ and $T_8$ (Table 7). However, both $T_4$ ($GA_3$ 0 and K 6.0) and $T_8$ ($GA_3$ 10 g/ha and K 2.0 g/m$^2$) showed an almost insignificant variation in the plant-height measurements compared to other treatments.

The foliar application of K and $GA_3$ significantly affected the number of branches per canola plant comparing to the control one ($T_1$). The highest number of branches per plant were recorded in $T_{10}$ (30$GA_3$ g/ha + 6.0 g/m$^2$ K) which appeared to have the same trend as that reported for canola plant height (Table 8). A considerable rise in the fruiting zone length (cm) was also observed when combined foliar applications were applied ($T_{10}$). The significant differences among the treatments ($F = 101.814$; $p \leq 0.0000$, $F = 123.32$; $p \leq 0.0000$, $F = 126.62$; $p \leq 0.0000$ and $F = 122.4$; $p \leq 0.0000$) were also recorded for over 4 years of the study (Table 9).

Another agronomic trait, number of seeds per plant influenced positively, when foliar applications of K and $GA_3$ were applied (individually or combined), it was found that canola plants produce more number of seeds per plant when combined $GA_3$ and K were applied ($T_{10}$) during the four seasons of 2014–2018 (Table 10). This parameter seemed to be improved immeasurably in all treatments ($T_2$–$T_{10}$) compared to the control plant ($T_1$). Therefore, it can be concluded that improvement of this agronomic parameter can be successfully attained with higher dose of the foliarly applied K and $GA_3$.

| Treatments | Plant height (cm) | | | |
|---|---|---|---|---|
| | 2014/15 | 2015/16 | 2016/17 | 2017/18 |
| T1 (control) | 139.5g | 141g | 140.5f | 140g |
| T2 (100 g/ha $GA_3$) | 154.6f | 153.8e | 155d | 154.8e |
| T3 (150 g/ha $GA_3$) | 169.4e | 169.0d | 168.5b | 170.0d |
| T4 (300 g/ha $GA_3$) | 178.3d | 175.2c | 177.2c | 176.5c |
| T5 (2.0 cm$^{-1}$ K) | 152.1f | 150.3f | 151.8e | 151.9f |
| T6 (3.5 g/m$^2$ K) | 159.5b | 156.3e | 158.5d | 159.4e |
| T7 (6.0 g/m$^2$ K) | 170.3e | 168.9d | 169.0b | 171.3d |
| T8 (100 g/ha $GA_3$ + 2.0 g/m$^2$ K) | 177.9c | 176.4c | 178.4c | 176.9c |
| T9 (150 g/ha $GA_3$ + 3.5 g/m$^2$ K) | 179.5b | 180.2b | 180.5b | 181.0b |
| T10 (300 g/ha $GA_3$ + 6.0 g/m$^2$ K) | 183.4a | 184.1a | 184.0a | 184.9a |
| LSD 0.05 | 4.342 | 4.201 | 4.443 | 4.392 |
| F | 81.913 | 99.79 | 86.782 | 101.34 |
| p | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

**Table 7.** Impact of potassium (K) and gibberellic acid ($GA_3$ g/ha) on plant height (cm) of canola during four season 2014–18. Value within the column with the same letter are not significantly different (Tukey, HSD; p 0.05), **p 0.01 according to least significant difference (LSD) test.

| Treatments | Number of branches/plant | | | |
|---|---|---|---|---|
| | 2014/15 | 2015/16 | 2016/17 | 2017/18 |
| T1 (control) | 5.4b | 5.2b | 5.1f | 5.7a |
| T2 (100 g/ha $GA_3$) | 5.7bc | 5.7b | 5.8ef | 6.2a |
| T3 (150 g/ha $GA_3$) | 7.1ae | 7.1ce | 7.0cd | 7.6dc |
| T4 (300 g/ha $GA_3$) | 7.5ef | 8.2d | 7.6bc | 8.7e |
| T5 (2.0 $cm^{-1}$ K) | 6.1c | 5.9ae | 6.0e | 6.4be |
| T6 (3.5 $g/m^2$ K) | 6.7a | 6.6cd | 6.8d | 7.1cb |
| T7 (6.0 $g/m^2$ K) | 7.0ae | 7.2ce | 7.1cd | 7.7dc |
| T8 (100 g/ha $GA_3$ + 2.0 $g/m^2$ K) | 7.6ef | 7.9de | 7.7bc | 8.4ad |
| T9 (150 g/ha $GA_3$ + 3.5 $g/m^2$ K) | 8.3df | 8.2d | 8.2ab | 8.7e |
| T10 (300 g/ha $GA_3$ + 6.0 $g/m^2$ K) | 8.5d | 8.6d | 8.7a | 8.9e |
| LSD 0.05 | 0.503 | 0.524 | 0.407 | 0.556 |
| F | 45.761 | 43.56 | 45.07 | 48.097 |
| p | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

**Table 8.** Impact of potassium (K) and gibberellic acid ($GA_3$ g/ha) on Number of branches per plant (cm) of canola during four season 2014–18. Value within the column with the same letter are not significantly different (Tukey, HSD; p 0.05), **p 0.01 according to least significant difference (LSD) test.

| Treatments | Fruiting zone length (cm) | | | |
|---|---|---|---|---|
| | 2014/15 | 2015/16 | 2016/17 | 2017/18 |
| T1 (control) | 118.0h | 120.5d | 119.0h | 121d |
| T2 (100 g/ha $GA_3$) | 123.2g | 122.4f | 123.2g | 123.4f |
| T3 (150 g/ha $GA_3$) | 134.5ef | 132.3cd | 134.0ef | 133.4cd |
| T4 (300 g/ha $GA_3$) | 140.0cd | 139.5bc | 140.0cd | 138.5bc |
| T5 (2.0 $cm^{-1}$ K) | 121.3g | 118.5ef | 122.3g | 122.5ef |
| T6 (3.5 $g/m^2$ K) | 131.0f | 128.4d | 131.0f | 129.4d |
| T7 (6.0 $g/m^2$ K) | 136.7de | 134.0cd | 135.5de | 136.0cd |
| T8 (100 g/ha $GA_3$ + 2.0 $g/m^2$ K) | 143.5bc | 141.3bc | 141.5bc | 143.5bc |
| T9 (150 g/ha $GA_3$ + 3.5 $g/m^2$ K) | 146ab | 145.9ab | 148.0ab | 146.9ab |
| T10 (300 g/ha $GA_3$ + 6.0 $g/m^2$ K) | 147.5a | 149.0a | 147.5a | 148.5a |
| LSD 0.05 | 3.507 | 3.231 | 3.403 | 3.306 |
| F | 101.814 | 123.32 | 126.62 | 122.4 |
| p | 0.0000 | 0.000 | 0.0000 | 0.000 |

**Table 9.** Impact of potassium (K) and gibberellic acid ($GA_3$ g/ha) on fruiting zone length (cm) of canola during four season 2014–18. Value within the column with the same letter are not significantly different (Tukey, HSD; p 0.05), **p 0.01 according to least significant difference (LSD) test.

Since seed yield $ha^{-1}$ is considered as the main interest for canola breeders, and current trial (E2) also showed significant influence of K and $GA_3$ on seed yield $ha^{-1}$ (individually or combined) with respect to non-sprayed plants ($T_1$), particularly with maximum concentration of K and $GA_3$. This important rise in seed yield$^{-1}$ (883.2) was recorded with 30 g/ha $GA_3$ and 6 $g/m^2$ K foliar application ($T_{10}$). The significant differences were also detected among the following treatments ($F = 44.576$; $p \leq 0.0000$, $F = 49.903$; $p \leq 0.0000$, $F = 48.765$; $p \leq 0.0000$ and $F = 51.273$; $p \leq 0.0000$) applied during the experimental period (Table 11).

The changes in oil percentages, in response to K and $GA_3$ application were also investigated. The highest oil percentage was observed at the $T_{10}$ treatment followed by $T_3$ and $T_5$ during the four cropping seasons of 2014–18 (Table 12).

## Discussion

Application of different forms of fertilizers either in rhizosphere or as foliar application is considered as major agro-inputs as cost effective and increased productivity. For proper care of the health and vigor of canola plants to obtain high yield, a well-maintained fertilization is requisite at certain periods throughout the year. Moreover, nitrogen in that order are major nutrients required for the enhanced yield with appropriate concentration[21]. Further, ammonium sulfate delivers precarious plant nitrogen (N) and sulfur (S) nutrients[22]. The balanced application of S and N is vital with the objective of further improving the canola seeds quality and production[23]. Karamanos et al.[24] suggested that the optimal ratio of N:S ranging from 7:1 to 5:1 can maximize canola production.

| Treatments | Number of seed/plant (g) | | | |
|---|---|---|---|---|
| | 2014/15 | 2015/16 | 2016/17 | 2017/18 |
| T1 (control) | 30.2a | 31.2a | 32.3c | 30.3a |
| T2 (100 g/ha $GA_3$) | 32.4ef | 32.4ae | 32.5a | 31.5g |
| T3 (150 g/ha $GA_3$) | 34.6bc | 34.6cd | 37.4ef | 36.4be |
| T4 (300 g/ha $GA_3$) | 36.0bd | 36.0bc | 38.1dh | 37.1cd |
| T5 (2.0 $cm^{-1}$ K) | 33.9abe | 33.9ade | 34.4a | 33.4g |
| T6 (3.5 $g/m^2$ K) | 33.5be | 33.5de | 35.08f | 34.08b |
| T7 (6.0 $g/m^2$ K) | 36.3cd | 36.3bc | 37.2dh | 36.2cd |
| T8 (100 g/ha $GA_3$ + 2.0 $g/m^2$ K) | 37.8d | 37.8b | 38.4bh | 37.4fc |
| T9 (150 g/ha $GA_3$ + 3.5 $g/m^2$ K) | 37.6d | 37.6b | 39.1bg | 38.1fh |
| T10 (300 g/ha $GA_3$ + 6.0 $g/m^2$ K) | 40.0f | 40.0f | 41.7g | 40.7h |
| LSD 0.05 | 1.184 | 1.172 | 1.195 | 1.245 |
| F | 50.765 | 46.486 | 49.987 | 51.073 |
| p | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

**Table 10.** Impact of potassium (K) and gibberellic acid ($GA_3$ g/ha) on number of seeds per plant (g) of canola during four season 2014–18. Value within the column with the same letter are not significantly different (Tukey, HSD; p 0.05), **p 0.01 according to least significant difference (LSD) test.

| Treatments | Seed yield | | | |
|---|---|---|---|---|
| | 2014/15 | 2015/16 | 2016/17 | 2017/18 |
| T1 (control) | 685.3e | 657.7g | 686.3e | 667.7g |
| T2 (100 g/ha $GA_3$) | 715.0de | 684.0fg | 716.0de | 694.0fg |
| T3 (150 g/ha $GA_3$) | 781.0c | 762.2de | 782.0c | 762.2de |
| T4 (300 g/ha $GA_3$) | 807.4bc | 795.2bcd | 808.4bc | 795.2bcd |
| T5 (2.0 $cm^{-1}$ K) | 717.2de | 729.0ef | 718.2de | 727.0ef |
| T6 (3.5 $g/m^2$ K) | 734.8d | 751.4de | 735.8d | 753.4de |
| T7 (6.0 $g/m^2$ K) | 800.8bc | 785.6cd | 801.8bc | 788.6cd |
| T8 (100 g/ha $GA_3$ + 2.0 $g/m^2$ K) | 827.3 | 824.8bc | 828.3 | 823.8bc |
| T9 (150 g/ha $GA_3$ + 3.5 $g/m^2$ K) | 829.5 | 835.7b | 830.5 | 834.7b |
| T10 (300 g/ha $GA_3$ + 6.0 $g/m^2$ K) | 878.9a | 881.3a | 879.9a | 883.3a |
| LSD 0.05 | 26.724 | 27.167 | 25.574 | 26.543 |
| F | 44.576 | 49.903 | 48.765 | 51.273 |
| p | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

**Table 11.** Impact of Potassium (K) and gibberellic acid ($GA_3$ g/ha) on seed yield of canola during four season 2014–18. Value within the column with the same letter are not significantly different (Tukey, HSD; p 0.05), **p 0.01 according to least significant difference (LSD) test.

In fact, a study conducted by Brennan and M.D.A, 2008 proven that the canola production can be extremely limited in case of sulfur deficiency in soil[25]. The supply of artificial sulfur promotes the nitrogen uptake efficiency of canola production and consequently elevates the level of protein in leaves: this will definitely enhance the crop productivity and yield[26].

Our results are in agreement with those reported by Chien et al.[28] in which the plant height and number of branches were boosted when higher rates of ammonium sulfate were applied. Other researchers have reported similar results, indicated that the 1000-seed weight increases proportionately with sulfur and nitrogen levels[28]. Others have suggested that biological yield increases significantly with increasing proportions of nitrogen and sulfur[29].

Another important factor that must be taken into account is the nutrient deficiency (N) can severely hampers canola productivity[30,31]. Furthermore, the canola yields can be enhanced by a better management of N at the optimum growth stages of canola[2,16]. Nitrogen is an essential plant nutrient that simulates its meristematic activity, cell elongation, and elevates the photosynthesis of canola. These factors will ultimately boost growth and yield of the canola plant[32]. A pervious study published by Khan  et al.[16], they haves demonstrated that 3.8 qt/ha (Quintal/hectare) oil yield was achieved through rigorous application of 60 kg of nitrogen per hectare. Similar findings have been made in other studies highlighting the importance of nitrogen supplementation in the refinement of the rapeseed yields in diverse agro-climatic conditions[33].

As far as current data suggested, N has strongly and significantly correlated with the seed yield per hectare, plant height, number of branches per plant, fruiting zone length, and number of seed per plant, in addition to the

| Treatments | Seed oil percentage | | | |
|---|---|---|---|---|
| | 2014/15 | 2015/16 | 2016/17 | 2017/18 |
| T1 (control) | 41.09bc | 41.65ab | 42.36a | 42.50c |
| T2 (100 g/ha $GA_3$) | 42.53bc | 41.53ab | 42.35a | 43.35c |
| T3 (150 g/ha $GA_3$) | 42.96bc | 42.94ab | 42.89a | 43.05c |
| T4 (300 g/ha $GA_3$) | 42.51c | 41.51b | 42.55cda | 42.59cbe |
| T5 (2.0 $cm^{-1}$ K) | 42.79bc | 42.80ab | 42.69cd | 42.90be |
| T6 (3.5 $g/m^2$ K) | 42.87ab | 42.86ac | 42.95be | 42.99ad |
| T7 (6.0 $g/m^2$ K) | 43.17a | 43.17c | 43.02e | 43.08a |
| T8 (100 g/ha $GA_3$ + 2.0 $g/m^2$ K) | 42.64bc | 42.79ab | 42.48de | 42.60bc |
| T9 (150 g/ha $GA_3$ + 3.5 $g/m^2$ K) | 42.66bc | 42.87ab | 42.74bc | 42.84de |
| T10 (300 g/ha $GA_3$ + 6.0 $g/m^2$ K) | 44.56bc | 43.85ab | 45.54cd | 44.69be |
| LSD 0.05 | 0.1567 | 0.1893 | 0.2101 | 0.2043 |
| F | 7.753 | 9.873 | 16.874 | 17.765 |
| p | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

**Table 12.** Impact of potassium (K) and gibberellic acid ($GA_3$ g/ha) on seed oil percentage of canola during four season 2014–18. Value within the column with the same letter are not significantly different (Tukey, HSD; p 0.05), **p 0.01 according to least significant difference (LSD) test.

enhancement of the number of pods per seed, 1000 seed weight, biological yield, seed yield, and oil yield[29,33]. On this basis, it can be concluded that the canola production depends on the selection of the correct dose, source, and timing of nitrogen fertilizer application. Unbalanced application of nitrogen fertilizer may adversely affect the canola production[6]. The source of N fertilizer may also change the plant N uptake and soil N availability and hence impacting the ultimate canola productivity[34]. In our experiments, two sources of N were tested and compared one with another. The subsequent results showed that ammonium sulfate had significantly contributed to the enhancement of canola production comparing to the ammonium nitrate[35]. However, it has been reported that the application of ammonium sulfate reduces the pH of the soil as well as dissolution of many other nutrients resulting in negative impacts on plant growth and development compared to ammonium nitrate[36]. Based on N management concept, it is well accepted fact that ammonium-based fertilizers are issue to ammonia ($NH_3$) volatilization in soils with pH > 7, but this has been ignored in choice of making on S fertilization. The influence of various treatments related to the application of $GA_3$ and K fertilizers were also studied in accordance with the yield parameters of canola. The results of the present study provide evidence that all the agronomic traits and oil percentage tend to increase with increasing levels of foliar application of K and $GA_3$ solely or in combined form compared to the unsprayed plants. A significant increase was recorded using different treatments of $GA_3$ and K in plant height, number of branches per plant, fruiting zone length, seed yield per plant, seed yield/ha and seed oil percentage compared to control ($T_1$–$T_{10}$).

In view of the aforementioned findings, it can be concluded that combined form of $GA_3$ and K ($T_{10}$) presents a potential strategy to enhance growth performance of canola. The promoting effect of $GA_3$ and K treatments contribute to the metabolic and other physiological processes leading to better crop yields. Interestingly, for the majority of the studied traits, the K application ($T_4$) acts similarly and almost insignificantly to the combined application ($T_8$) of K (3.5 $g/m^2$) and $GA_3$ (15 g/ha), this could be attributed to the key role of K in improving canola yields (Tables 7, 8, 9, 10, 11, 12).

$GA_3$ and K fertilizer application is necessary to increase the vegetative and reproductive growth of canola plant[37]. These fertilizers could be involved in improving defence mechanisms of canola plant which may consequently affect the seed yield. Similar results have been reported using these same treatments on sesame plant[30]. Likewise, foliar application of potassium and gibberellic acid alone or in combination increases the plant vegetative and reproductive growth of the plant resulting in the enhancement of the yield per unit[38]. In fact, in a study reported by Imran and Khan[39], the application of K fertilizer not only enhances the yield per unit, fresh nut and kernel dry mass (splitting percentage), it also reduces the blank percentage. It was also observed that in absence of gibberellic acid applications, the blank percentage and splitting percentage could be ameliorated[40].

Jan et al.[41] reported that high concentrations of potassium K and Zing Zn after the simultaneous foliar applications of $GA_3$ and K separately or in combination could be found in canola plant leaves. The evidences of this study suggest that the interactive effects of $GA_3$ and K can be employed in the aim of improving morphological aspects and yield attributes of canola. It can also be expected that these interactive effects may elevate the plant resistance against various biotic and abiotic stresses, carbohydrate translocation, and the photosynthesis process[40]. Khan et al. (2019) also mentioned that these fertilizers ($GA_3$ and K) might strengthen the defence mechanism of the plant which ultimately impacts the plant growth and yield[42,43]. In short, with appropriate application of N fertilizers, $GA_3$, and K, canola yields can be substantially improved.

## Conclusion

Nitrogen is an essential nutrient for the metabolic function and production process of the canola plant or any other plant. Therefore, the canola yields can be monitored with the application of N fertilizers pertaining to different sources and proportions. The optimum levels of N fertilizer were found to be 30 kg/ha ammonium sulfate and 100 kg/ha ammonium nitrate. These data have been obtained according to the agronomic yields of a 4-year study (2014–18). Another fact to consider is that Ammonium nitrate ($NH_4NO_3$) is more efficient and readily available source of nitrogen compared to ammonium sulfate [$(NH4)_2NO_3$]. This study has recommended the optimum value and source in subtropical region of the world. On the contrary, gibberellic acid and potassium influence the plant growth and its development, enable the plant to survive in nutrient deficient soil and increase the yield in the four growing seasons (2014–18). It is suggested that canola plant illustrated maximum potential of yield at high dose of $GA_3$ (30 g/ha) and K (6.0 g/m$^2$) alone or in combination.

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## Author contributions

M.M.A. conduct experiment, write the initial draft and technically improved the contents of manuscript. F.F. help to collect data, manuscript writing and improved its statistical interpretation. S.Z. assist in statistical analysis. M.A.S. conceive the idea and supervise the experiment and manuscript writing. M.A. helped us to technically improve the contents of manuscript. M.A.S. technically improved the article and added latest literature of the subject.

## Competing interests

The authors declare no competing interests.

## Additional information

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