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# Foliar Application of Gibberellin Alleviates Adverse Impacts of Drought Stress and Improves Growth, Physiological and Biochemical Attributes of Canola (*Brassica napus* L.)

**Nosheen Noor Elahi [1,*], Sadia Raza [1], Muhammad Shahid Rizwan [2], Bedur Faleh A. Albalawi [3], Muhammad Zubair Ishaq [4], Hafiz Munir Ahmed [5], Sajid Mehmood [6], Muhammad Imtiaz [7], Umer Farooq [4], Muhammad Rashid [1] and Allah Ditta [8,9,*]**

1 Institute of Pure and Applied Biology, Bahauddin Zakariya University Multan, Multan 60800, Pakistan
2 Cholistan Institute of Desert Studies, The Islamia University of Bahawalpur, Bahawalpur 63100, Pakistan
3 Department of Biology, University of Tabuk, Tabuk 71491, Saudi Arabia
4 Department of Plant Breeding and Genetics, Faculty of Agricultural Science s and Technology, Bahauddin Zakariya University Multan, Multan 60800, Pakistan
5 Nuclear Institute for Food and Agriculture (NIFA), Tarnab, Peshawar 25000, Pakistan
6 College of Ecology and Environment, Hainan University, Haikou 570100, China
7 Soil and Environmental Biotechnology Division, National Institute for Biotechnology and Genetic Engineering (NIBGE), Faisalabad 38000, Pakistan
8 Department of Environmental Sciences, Shaheed Benazir Bhutto University Sheringal, Dir (Upper), Sheringal 18000, Pakistan
9 School of Biological Sciences, The University of Western Australia, 35 Stirling Highway, Perth, WA 6009, Australia
* Correspondence: nosheenilahi@yahoo.com (N.N.E.); allah.ditta@sbbu.edu.pk or allah.ditta@uwa.edu.au (A.D.)



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**Abstract:** Under the current climate change scenario, water stress is one of the key factors that reduce the production of crops. Gibberellic acid ($GA_3$) is an efficient endogenous plant hormone that shows a vital role in plant growth and development. Production of canola (*Brassica napus* L.) and its oil contents are severely affected under drought stress. The present study was conducted to investigate the potential of $GA_3$ in alleviating drought stress in canola. Three levels of $GA_3$ ($G_0$ = 0 mg $L^{-1}$, $G_1$ = 100 mg $L^{-1}$, and $G_2$ = 150 mg $L^{-1}$) as foliar applications were applied under two drought-stress conditions ($D_1$ for three days of drought stress and $D_2$ for six days of drought stress) on two canola varieties (Punjab canola and Faisal canola). Irrigation was applied after 3 weeks of germination, while foliar application of $GA_3$ was done at intervals of 4 and 5 weeks after germination. When comparing the output of all the $GA_3$ treatments, it was noticed that in $G_0$ = 0 mg $L^{-1}$ (control plants), water-stress conditions markedly reduced plant production and seed oil contents but increased protein and linoleic acid. With the application of $G_2$ = 150 mg $L^{-1}$, the maximum values of plant height (90.83 cm), no. of siliqua plant$^{-1}$ (15.50), seed siliqua$^{-1}$ (15.55), siliqua length (5.08 cm), relative water contents (77.60%), yield plant$^{-1}$ (0.46 g), chlorophyll a (0.62), carotenoid contents (39.52), and oleic acid contents (60.20) were recorded under drought stress. Based on these results, it is concluded that the adverse effect of drought stress on different yield parameters of canola could be ameliorated by the exogenous application of $GA_3$ through foliar application at a dose of 150 mg $L^{-1}$. Moreover, the same treatment improves the quality parameters, i.e., the oleic acid contents of the oil, obtained from the canola.

**Keywords:** canola; drought stress alleviation; gibberellic acid; seed oil; protein contents; yield

## 1. Introduction

Canola (*Brassica napus* L.), which belongs to the family Brassicaceae (syn. Cruciferae), is the second largest oilseed crop globally after soybean (*Glycine max* L.) [1]. In Pakistan, mainly two traditional oilseed crops are grown, which are rapeseed and mustard, contributing to approximately 16–20% of the national oil production [2]. The genus *Brassica* economically contains oilseed, vegetables, and condiment crops. Brassica vegetables are essential for their nutritional value. These vegetables are a good source of various vitamins (e.g., C and E), soluble fibers, and different nutrients having anti-cancer properties [3]. The seed oil contents range from 42–48%, while seed meal contains 43.6% proteins [4]. Canola seeds are an important source of nutritional and anti-nutritional compounds, as they have less than 2% erucic acid, are cholesterol free, and have less than 30 μmoles per gram of glucosinolates; they also have high concentrations of unsaturated C:18 fatty acids (FA) and low levels of undesirable FA [5,6]. Due to the health benefits of canola oil, it is commonly used worldwide, and several countries are establishing lands for canola production [7].

Under the current scenario of climate change, increasing temperatures might be more severe and extreme, which will have a drastic impact on the growth and productivity of the crop because of the prolonged drought periods in some regions of the world that result in reduced quality of seed and seed yield in various crops [8–12]. The yield of various crops including canola is severely affected by drought stress, especially when it occurs during the stage from flowering to the end of the seed set [13,14]. Hence, canola is reported as a drought-sensitive crop [15]. Pillai et al. [16] also reported the flowering stage as the most sensitive growth stage for rapeseed under drought stress. Drought stress at the flowering stage resulted in a yield loss of 30% in rapeseed, which was larger compared to a 21% yield loss when the drought stress occurred at the silique developmental stage [17]. Drought stress can also interfere with seed protein and oil contents, especially when it occurs during the reproductive growth stages. Drought stress at the flowering stage accounted for a 0.39% to 2.1% decrease in oil concentration, which was equivalent to a 20 to 36% loss in oil yield [18]. Similarly, a yield reduction of rapeseed of approximately 30% was reported when the drought stress lasted from early flowering to the pod development stages [18]. The agronomic manipulations could be effective as drought management techniques by incorporating the exogenous application of growth hormones [19,20].

Among various plant hormones, gibberellins ($GA_3$) play an important role in the growth and development of plants by improving cell division, cell elongation, the development of pollen, growth of the pollen tube, growth of fruit, development, and germination of seeds [21]. Recently, $GA_3$ has extensively been used to enhance the growth and yield of vegetables and fruits such as tomatoes [22]. Gibberellic acid ($GA_3$) has been widely used to improve germination rate, seedling growth, and, consequently, yield [23]. However, $GA_3$ has been tested for its potential in ameliorating drought stress. Foliar application of $GA_3$ may have a positive impact on canola growing under drought-stress conditions. Based on this hypothesis, the objective of the present study was to investigate the impact of the foliar application of gibberellins on the physiological, agronomic, and yield characteristics, and oil contents of canola varieties under drought stress. The present research would help to devise a method for the amelioration of drought stress on canola yield and oil quality parameters.

## 2. Materials and Methods

A pot experiment was performed to investigate the effect of foliar application of gibberellic acid ($GA_3$) on the growth, physiological, yield, and quality parameters of two canola varieties under drought stress in the Botanical Garden of Bahauddin Zakariya University, Multan (71.50′ N latitude and 30°26′ E longitude) during the growing season of November 2017 to May 2018.

### 2.1. Soil Analysis

The soil used in the experiment was collected from a depth of 15 cm from the research area of the Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University, Multan. The soil was ground after the leaves, stones, and unwanted materials were discarded, and then the soil was sieved (2 mm). The soil was analyzed regarding physicochemical properties following the standard procedure as given by Estefan et al. [24]. The texture of the soil was determined through the hydrometer method. Electrical conductivity (EC) and pH were determined by electrical conductivity (VWR Conductivity Meter DIG2052) and pH meters (Beckman 45 Modal, US). For nitrogen and available phosphorus, the Kjeldahl and Olsen methods were used, respectively. Potassium was determined by using a Flame Photometer (PFP 7, Jenway). For organic matter, the Walkley–Black method involving the use of potassium dichromate was used. The soil was clay loam in texture with pH = 8, EC = 6.67 dS $m^{-1}$, saturation percentage = 32%, nitrogen = 0.21%, available potassium = 160, available phosphorus = 7.8, and organic matter = 0.62.

*2.2. Pot Experiment*

The plastic pots had a top diameter of 25.8 cm, a base of 19.6 cm, and a depth of 20.8 cm; a total of 10 kg of soil was used to fill each pot. Recommended doses of nitrogen (N), phosphorus (P), and potassium (K) (90–60–75 kg $ha^{-1}$) using urea, diammonium phosphate, and potassium sulfate, respectively, were applied by mixing the calculated amounts in the pots before seed sowing. In the present study, two canola varieties (i.e., Punjab Canola (PC) and Faisal Canola (FC)) with three levels of gibberellic acid ($GA_3$) concentrations (i.e., $GA_0$ = 0 mg $L^{-1}$, $GA_1$ = 100 mg $L^{-1}$, and $GA_2$ = 150 mg $L^{-1}$) under two drought-stress conditions (i.e., 3D = drought stress of 3 days and 6D = drought stress of 6 days) were experimented. The treatments were laid out in a completely randomized design (CRD) with three replications. After thinning, two plants were left in each pot. In the control treatment without any gibberellic acid, distilled water was sprayed on the plant by using a shower. For the gibberellic acid treatment, a few drops of surfactant (tween-20) were added to the leaf surface for better penetration of the $GA_3$ solution. After the application of the surfactant, three mL from the respective concentration of $GA_3$ was applied to each plant using a common plastic sprayer. Average rainfall, relative humidity, and temperature were also measured during the experimental period and are presented in Figure 1.

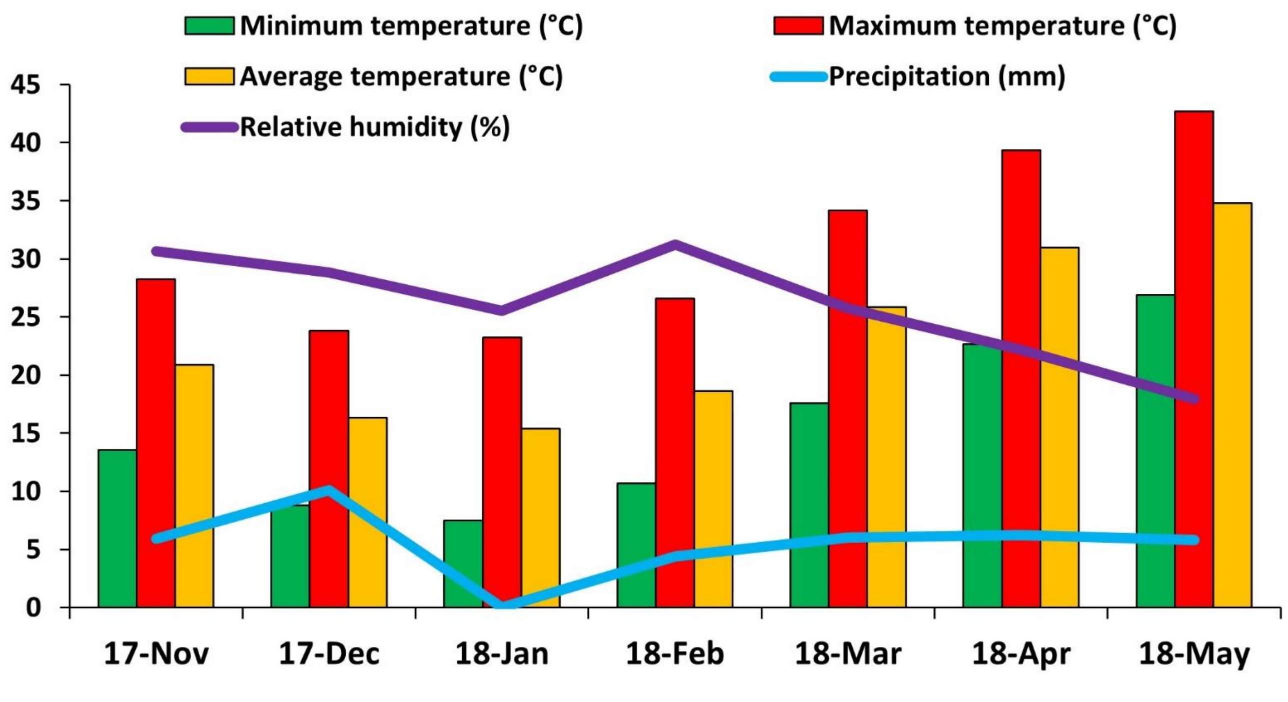


**Figure 1.** Temperature (maximum, minimum, and average), relative humidity, and precipitation. Data Source: https://power.larc.nasa.gov (accessed on 20 May 2022) Latitude: 30.268, Longitude: 71.5020).

*2.3. Data Collection*

Data were recorded regarding growth, physiological, biochemical, and yield parameters viz. plant height (PH), chlorophyll a (CHA), chlorophyll b (CHB), total chlorophyll (TCH), no. of siliqua $plant^{-1}$ (NSPP), seeds $siliqua^{-1}$ (SPS), siliqua length (SL), carotenoid

(CARC), relative water content (RWC), oil content (OC), protein content (PC), oleic content (OLEC), linolenic content (LINOC), seed weight plant$^{-1}$ (SW), and 1000 seed weight (TSW). The plant height was measured using a meter rod. Chlorophyll content was measured using the method given by Arnon [25]. The leaf sample (200 mg) was homogenized with acetone (80%) and ground well. The mixtures were centrifuged, and the supernatant was transferred into a test tube, bringing the volume up to 6 mL with acetone. The absorbance of each sample was recorded at 645 nm and 663 nm using a spectrophotometer (Shimadzu UV-1201).

$$\text{Chlorophyll a}\left(\mu\text{g g}^{-1}\text{FW}\right) = 12.7(\text{A663}) - 2.69(\text{A645})$$

$$\text{Chlorophyll b}\left(\mu\text{g g}^{-1}\text{FW}\right) = 22.9(\text{A645}) - 4.68(\text{A663})$$

The number of siliqua plant$^{-1}$ (NSPP) and seeds siliqua$^{-1}$ (SPS) was recorded by manual counting, while the siliqua length (SL) was measured using a measuring scale. The carotenoid contents in the leaf samples were estimated by using an acetonic (90%) extract of the leaves and analyzed at 480 nm wavelength using a UV-visible spectrophotometer (Shimadzu UV-1201). Acetone (90%) was used as the blank [25]. The carotenoid content was measured by using the following formula:

$$\textit{Carotenoid contents}\left(\mu\text{g g}^{-1}\text{ FW}\right) = A_{480} + (0.114 \times A_{663}) - (0.638 \times A_{645})$$

Relative water content (RWC) using the method given by Rao et al. [26].

$$\text{RWC}(\%) = \frac{\text{FW} - \text{DW}}{\text{TW} - \text{DW}} \times 100$$

Seed oil, protein, and fatty acids measurements were done on a Near Infrared Reflectance Spectrophotometer (NIRS-6500) at the Nuclear Institute for Food & Agriculture (NIFA), Peshawar, Pakistan. The NIRS instrument was standardized and verified against the suitable reference methods as defined by Tkachuk [27]. Seed weight plant$^{-1}$ (SW) and 1000 seed weight (TSW) were calculated using a digital balance.

### *2.4. Statistical Analysis*

For the statistical analysis of the collected data, analysis of variance (ANOVA) was calculated using Statistix 9 [28]. The correlation analysis was carried out using the method given by Kwon and Torrie [29]. R Studio was used to analyze the correlation using a library correlation plot.

## 3. Results and Discussion

Analysis of variance (ANOVA) results showed that both varieties (V) had a significant effect on all the traits except SL, TSW, and YP (Table 1). In the case of three different doses of foliar (F) applied GA (i.e., $GA_0$, $GA_1$, and $GA_2$), ANOVA results revealed that all traits were found to be significantly ($p < 0.05$) affected. Regarding the two drought stress levels (3D and 6D), all the traits were significantly affected except SL and TSW. The interaction between varieties and the foliar applications (V × F) was found significant for CHB, TCH, CARC, OC, PC, and LINOC. The interaction between varieties and drought stress (V × D) was also found significant for all traits except SL, OC, TSW, and YP. The interaction between the foliar application and drought stress (F × D) was found significant for all traits except CHA, SL, TSW, and YP. The performance of CHA, SPS, TSW, and YP was also non-significant. However, the performance of all other traits was found to be significant in the interaction among varieties, foliar applications, and drought stress (V × F × D).

**Table 1.** Analysis of variance of different agronomical, physiological, and yield contributing traits of canola.

| Source | Replication | Variety (V) | Foliar (F) | Drought (D) | V × F | V × D | F × D | V × F × D |
|---|---|---|---|---|---|---|---|---|
| **DF** | 2.00 | 1.00 | 2.00 | 1.00 | 2.00 | 1.00 | 2.00 | 2.00 |
| **PH** | 0.25 | 11.67 ** | 760.08 ** | 2.01 * | 0.36 ns | 57.51 ** | 25.69 ** | 61.69 ** |
| **CHA** | 0.00 | 0.02 ** | 0.19 ** | 0.01 ** | 0 ns | 0.02 ** | 0 ns | 0 ns |
| **CHB** | 0.00 | 0.03 ** | 0.39 ** | 0.49 ** | 0.00 * | 1.38 ** | 0.01 ** | 0.03 * |
| **TCH** | 0.00 | 2.11 ** | 0.55 ** | 1.42 ** | 0.02 ** | 3.03 ** | 0.1 ** | 0.03 ** |
| **NSPP** | 0.27 | 2.51 ** | 56.9 ** | 6.67 ** | 0.09 ns | 5.06 ** | 0.76 * | 0.56 * |
| **SPS** | 0.01 | 3.58 ** | 43.1 ** | 0.23 * | 0.13 ns | 10.84 ** | 0.55 ** | 0.13 ns |
| **SL** | 0.01 | 0.0 ns | 9.01 ** | 0.0 ns | 0.02 ns | 0.03 ns | 0.04 ns | 0.17 * |
| **CARC** | 0.19 | 31.51 ** | 498.39 ** | 58.93 ** | 9.86 ** | 37.5 ** | 4.39 ** | 8.05 ** |
| **RWC** | 0.07 | 1854.74 ** | 941.13 ** | 7.77 ** | 0.13 ns | 295.73 ** | 77.06 ** | 5.17 ** |
| **OC** | 0.11 | 13.94 ** | 64.04 ** | 65.61 ** | 2.7 ** | 0.22 ns | 2.35 ** | 1.26 ** |
| **PC** | 0.02 | 18.78 ** | 85.43 ** | 11.33 ** | 2.06 ** | 0.75 * | 4.29 ** | 1.2 ** |
| **OLE_C** | 0.19 | 4.91 ** | 54.55 ** | 2.3 ** | 1.47 ** | 47.84 ** | 1.02 * | 0.85 * |
| **LC** | 0.02 | 12.48 ** | 37.63 ** | 12.96 ** | 0.15 * | 8.03 ** | 1.51 ** | 0.12 * |
| **TSW** | 0.08 | 0.01 ns | 9.38 ** | 0.04 ns | 0.04 ns | 0 ns | 0.00 ns | 0.11 ns |
| **YP** | 0.00068 | 0.001 ns | 0.134 ** | 0.008 ** | 0.001 ns | 0.001 ns | 0.001 ns | 0.001 ns |

where * = Significant at $\alpha = 0.05$; ** = Significant at $\alpha = 0.01$; ns = non-significant at $\alpha = 0.05$; DF = Degree of freedom; PH = Plant height; CHA = Chlorophyll a; CHB = Chlorophyll b; TCH = Total chlorophyll; NSPP = No. of siliqua plant$^{-1}$; SPS = Seed siliqua$^{-1}$; SL = Siliqua length; CARC = Carotenoids; RWC = Relative water contents; OC = Oil content; PC = Protein content; OLE_C = Oleic content; LC = Linolenic acid; TSW = Thousand seed weight; and YP = Yield plant$^{-1.}$

An increase in plant height (PH) was observed in Punjab canola (PC), which was 90.83 cm under treatment of 3D stress and foliar treatment of $GA_2$. In contrast, a decline in PH was observed in the stress level of 6D with an application of $GA_0$ at 0 mg $L^{-1}$ (Figure 2). The present study showed that PH was reduced under drought stress. Due to the higher concentration of abscisic acid, the PH was reduced [30]. It is mainly due to the inhibitory effect of abscisic acid on cell growth by inducing stunted growth. Qaderi et al. [31] also mentioned that low PH in modified rapeseed varieties under drought stress was due to the formation of more abscisic acid as compared to the control treatment. Application of $GA_3$ by the foliar method seems to be an effective method to recover the damaging effect of drought by increasing PH, as the reduced cell division and cell elongation is enhanced by the endogenous gibberellic acid content under drought stress and by exogenous application of $GA_3$ [32,33]. In the present study, the foliar application of $GA_2$ at a dose of 150 mg $L^{-1}$ showed an increase in the PH value at both stress levels 3D and 6D. It was observed that plant growth was severely affected under drought stress.

An increase in NSPP (15.50) was observed in Faisal canola (FC) under $GA_3$ application at 150 mg $L^{-1}$ and 6D stress level. FC showed a decrease in NSPP that was 9.83 at 6D stress with no application of $GA_3$ (Figure 2). It was observed that $GA_3$ application at the 150 mg $L^{-1}$ level and 6D stress level increased NSPP. However, 6D drought stress decreased the NSPP in both PC and FC with a slight difference. The maximum value of SPS (15.55) was observed in PC under the 6D stress and foliar application of 150 mg $L^{-1}$, while a decrease in SPS (10.23) was observed under 3D drought stress with 0 mg $L^{-1}$ application of $GA_3$ (Figure 2). Under 3D stress and foliar application of $GA_3$ 150 mg $L^{-1}$, the SL increased. The highest SL (5.08) was found in PC compared to 3.15 under 3D and a $GA_3$ application rate of 0 mg $L^{-1}$ (Figure 2). Our result suggested that GA application increased the SL, and drought stress did not significantly affect the SL. Panda et al. [34] found the increase in NSPP directly impacts seed yield in mustard. In this research, we observed a significant response of NSPP and SL of exogenous application of GA under drought stress. The increase in the number of siliques and length of siliques was a very sudden response in yield factor. NSPP and SPS were reduced by giving drought stress, but the foliar application of $GA_3$ recovered it due to the formation of siliques in plant seed development [35]. Less carbon assimilation for tissue production is associated with a decrease in photosynthesis during the flowering stage. As a result, stressed rapeseed has fewer branches and pods [36]. Rapeseed's most vulnerable growth stage, when subjected to drought stress, is from flowering to pod development and pod filling [16]. The sink limitation associated with pod abortion occurs when rapeseed experiences a water shortage during the flowering stage; drought stress at this stage interferes with sexual reproduction and grain filling, and rapeseed is unable to recover or escape [37]. The reduction in yield caused by severe drought stress during the flowering stage is associated with a shortening of the reproductive growth stage [37]. In comparison to a 21% yield penalty for drought stress at the silique developmental stage, the yield loss at the flowering stage was 30% [17]. Similarly, when drought stress lasted from early flowering to pod development, yield reductions of approximately 30% were reported [18]. Drought stress may also interfere with seed protein and oil content during the reproductive growth stages. Furthermore, during the flowering stage, drought stress caused a 0.39–2.1% decrease in oil concentration resulting in a 20–36% loss in oil yield; however, it significantly increased protein concentration [18].

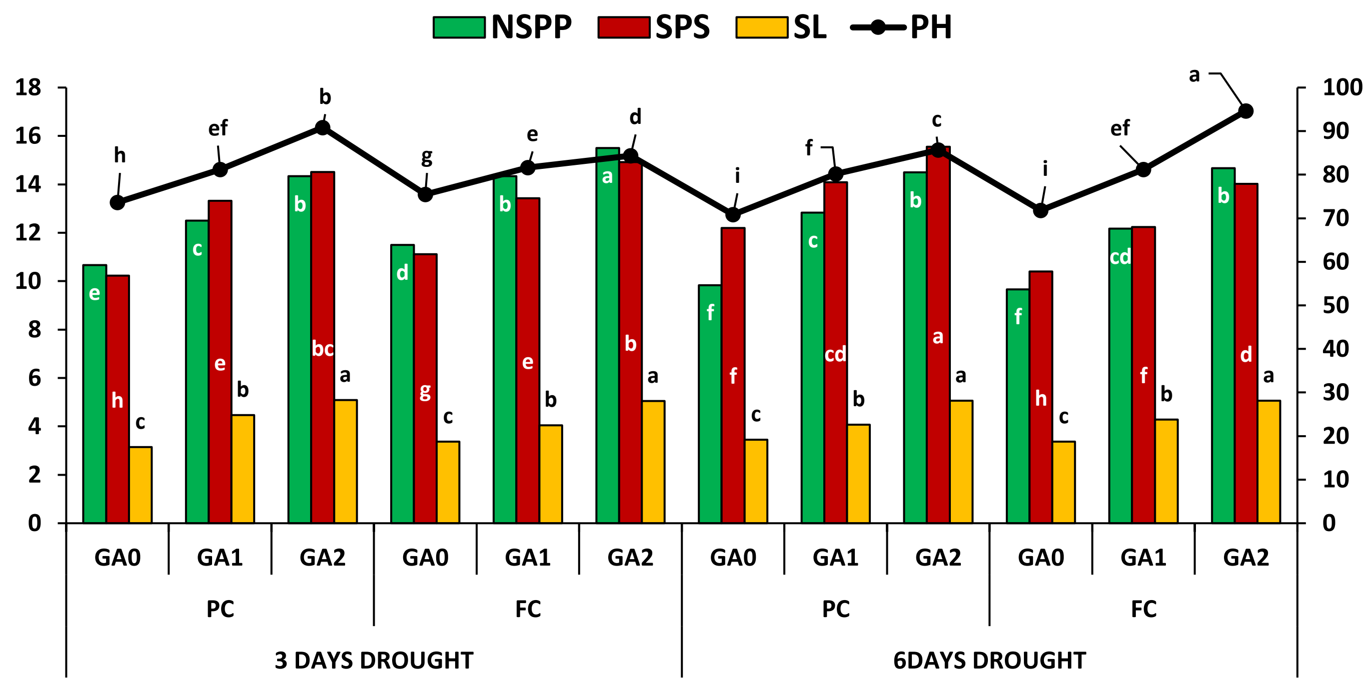


**Figure 2.** Mean performance of morphological traits of canola under water stress and exogenous application of GA. PC: Punjab Canola, FC: Faisalabad Canola, 3D: 3 days of drought stress, 6D: 6 days of drought stress, $GA_0$ (Control 0 mg $L^{-1}$), $GA_1$ (100 mg $L^{-1}$), $GA_2$ (150 mg $L^{-1}$). Plant height (PH), No. of siliqua plant$^{-1}$ (NSPP), Seed siliqua$^{-1}$ (SPS) and Siliqua Length (SL). The bars with different letters are statistically different from each other at $p \leq 0.05$ according to the least significant difference (LSD) test.

RWC was at a maximum (77.60) under 3D stress and $GA_3$ application (150 mg $L^{-1}$) in PC. In the control plant under the stress level 3D, a decrease in RWC was observed in FC (44.81) (Figure 3). The acceptance of plants to water stress situations mainly depends on the percentage of water in the plants [38]. The water potential and cell volume of plants are closely linked with the percentage of water in the plant. In this study, a reduced level of RWC was observed due to drought stress in both canola varieties. However, by the foliar application of $GA_3$, the declining effect of drought stress was recovered. In prevailing low moisture levels, both accepting and delicate maize cultivars faced reduced RWC [39].

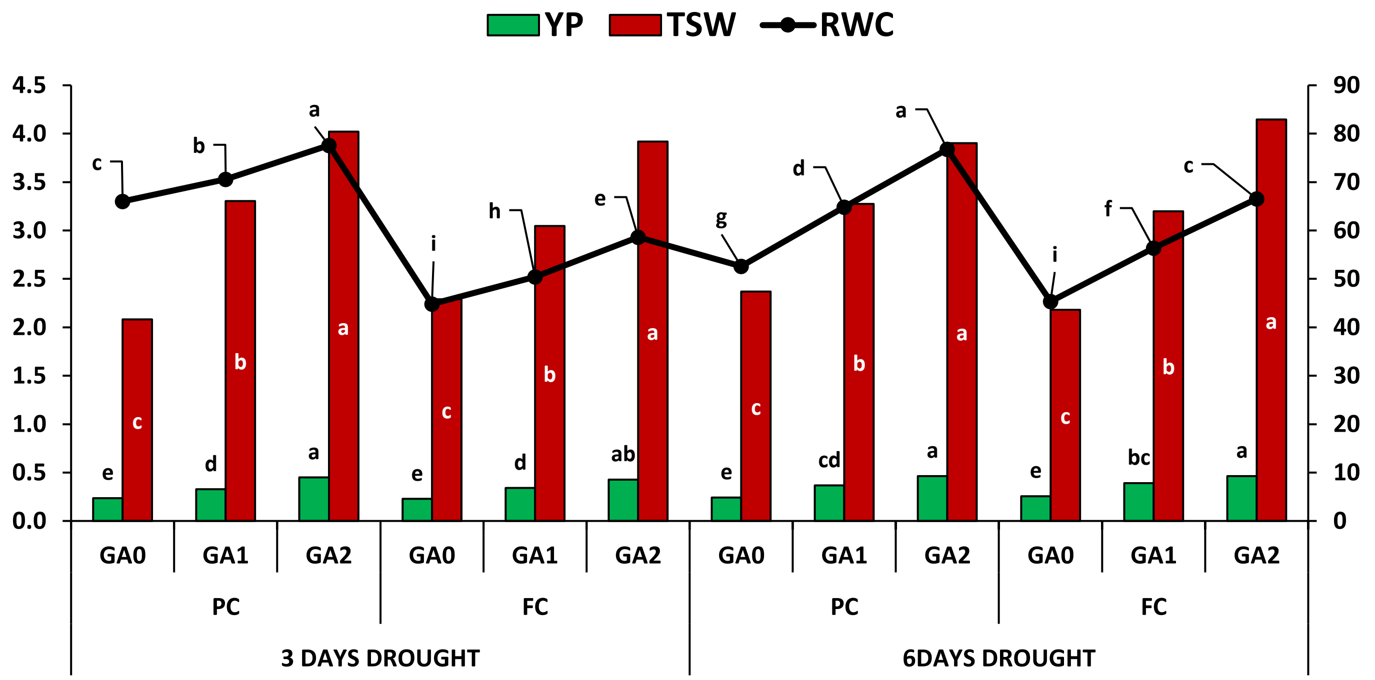


**Figure 3.** Mean performance of yield, 1000 seed weight, and relative water contents of canola under water stress and exogenous application of GA. PC: Punjab Canola, FC: Faisalabad Canola, 3D: 3 days of drought stress, 6D: 6 days of drought stress, $GA_0$ (Control 0 mg $L^{-1}$), $GA_1$ (100 mg $L^{-1}$), $GA_2$ (150 mg $L^{-1}$). Yield/plant (YP), 1000 seed weight (TSW), and Relative water contents (RWC). The bars with different letters are statistically different from each other at $p \leq 0.05$ according to the least significant difference (LSD) test.

YP performance was found to increase under the foliar application of GA at 150 mg $L^{-1}$ in both stress levels. The maximum YP was 0.46 in FC and PC under the treatment of 6D stress, and the $GA_3$ dose was 150 mg $L^{-1}$. As compared to a control plant with no application of $GA_3$, YP was 0.23 in FC under 3D stress (Figure 3). Thousand seed weight (TSW) is an important yield-contributing trait and has significant effects on yield. A significant increase in TSW was observed in FC (4.15) under 6D stress and foliar application of $G_2$ as compared to plants under 3D stress with no application of $GA_3$ (Figure 3). Similarly, the reduction in YP and TSW is due to the closing of stomata and decline in the process of photosynthesis, and also the expansion of the leaf area due to the inadequate quantity of water [40]. It was evaluated in different studies that disturbed embryos, loss of seed weight, and reduction in yield are due to a deficiency of water [41,42]. Therefore, the only way to improve the balance of hormones is the foliar application of these hormones. Similar results have been found in previous works [43]. Kamkar et al. [44] found that TSW was reduced under drought conditions. Declining photosynthesis has a great impact on the reduction of seed weight in growing seeds.

CHA and CARC were found to be at maximum, i.e., 0.62 and 39.52, respectively, in PC under the treatment of 3D stress and foliar application of $GA_3$ at 150 mg $L^{-1}$. However, the minimum values of CHA and CARC in PC were 0.41 and 22.55, respectively, under treatment of 3D stress with no foliar application of $GA_3$ (Figure 4).

Under 6D stress and a foliar application of GA (150 mg $L^{-1}$), an increase of CHB to 1.20 (FC) was observed, while a decrease was observed in FC (0.23) under 3D stress and GA at a dose of 0 mg $L^{-1}$ (Figure 4). TCH was found to be at maximum in PC (1.92) under the treatment of 6D stress and GA application at a dose of 150 mg $L^{-1}$, while the minimum value was found in PC (0.42) under 3D with no GA application (Figure 4). The ability of the basis to produce photosynthesis depends on the concentration of chlorophyll [45]. A preventing factor of photosynthesis is a low level of chlorophyll. The chlorophyll content remained very low in the plants under drought-stress conditions owing to the formation of ROS (relative oxygen species), which disturbs the chloroplasts [46]. Consequently, a significant plant output comes from a greater content of chlorophyll [25]. The key to regulating photosynthesis in plants grown under drought-stress conditions has been observed to be the foliar application of GA [47,48]. In this study, the foliar application of GA increased photosynthetic pigments CHA, CHB, THC, and CARC. Habibi [49] observed the same impact of drought on chlorophyll content and carotenoid content.

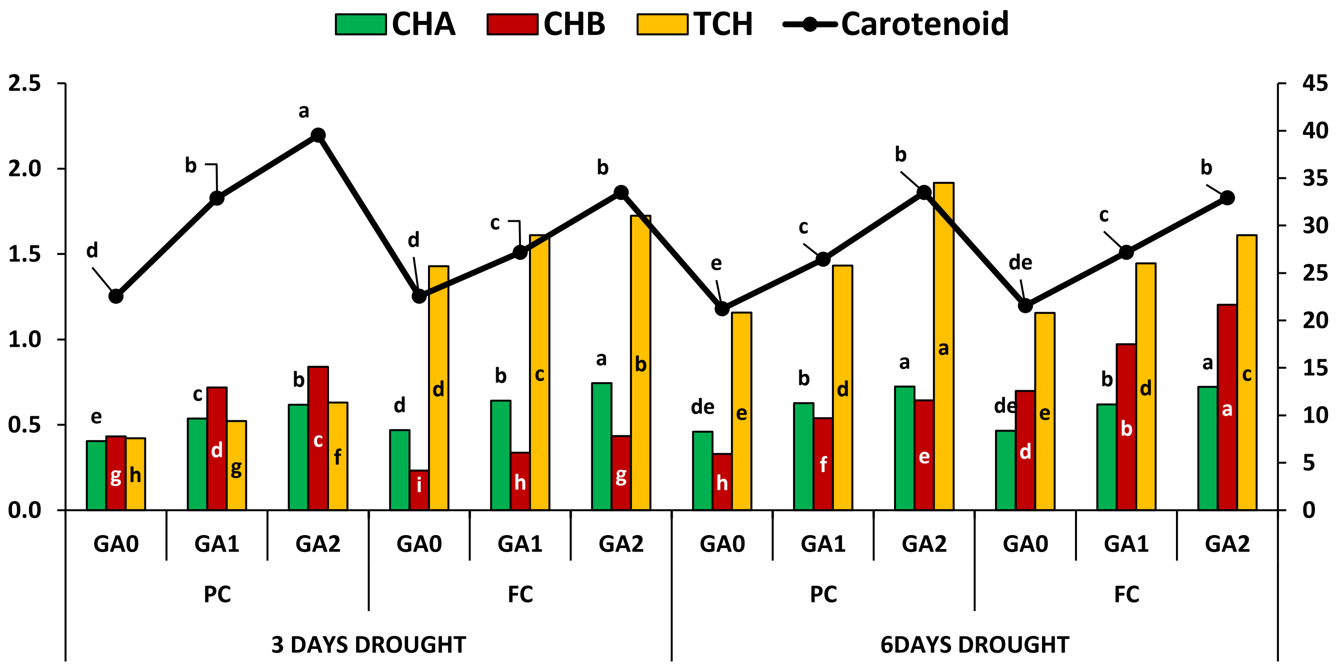


**Figure 4.** Mean performance of chlorophyll and carotenoid content of canola under water stress and exogenous application of GA. PC: Punjab Canola, FC: Faisalabad Canola, 3D: 3 days of drought stress, 6D: 6 days of drought stress, $GA_0$ (Control 0 mg $L^{-1}$), $GA_1$ (100 mg $L^{-1}$), $GA_2$ (150 mg $L^{-1}$). Chlorophyll a (CHA), Chlorophyll b (CHB), Total Chlorophyll (TCH), Carotenoid (CARC). The bars with different letters are statistically different from each other at $p \leq 0.05$ according to the least significant difference (LSD) test.

The OC was found to be at maximum in FC (40.93) at 6D stress and GA application at 150 mg $L^{-1}$, while at 3D stress with no application of GA, OC was 32.13 in FC (Figure 5). OLEC was increased with increasing doses of GA (Figure 5). OLEC was at maximum in PC (60.20) at 3D stress and $G_2$ treatment. However, in the control plant, 6D stress level showed a minimum OLEC in PC (52.53). Oil is the greatest entity for commercial purposes. The formation and content of oil are disturbed by external or environmental aspects [50]. Champolivier and Merrien [51] revealed that a deficiency of water caused a 12% reduction in oil content during the development of siliques in the flowering stage. In almost all oil seed crops, the same process of lowering oil content due to a deficiency of water is also noticed in current complete research [52]. Reduction in OC due to a water shortage was also observed by Dwivedi et al. [53]. In the current investigation, drought stress reduced oil content, but the foliar application of GA recovered it. A great response to the foliar application of GA was shown by OC under drought conditions.

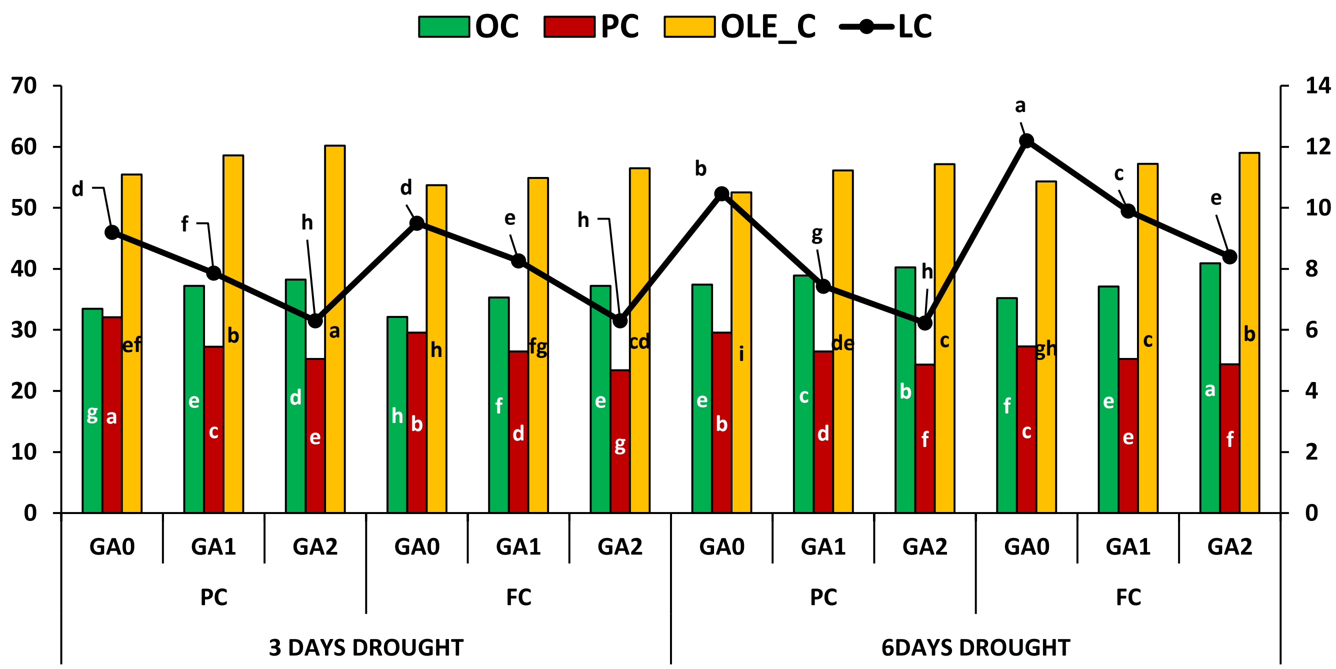


**Figure 5.** Mean performance of oil and protein content of canola under water stress and exogenous application of GA. PC: Punjab Canola, FC: Faisalabad Canola, 3D: 3 days of drought stress, 6D: 6 days of drought stress, $GA_0$ (Control 0 mg $L^{-1}$), $GA_1$ (100 mg $L^{-1}$), $GA_2$ (150 mg $L^{-1}$). Oil content (OC), Protein Content (PC), Oleic content (OLE_C), and linolenic acid (LC). The bars with different letters are statistically different from each other at $p \leq 0.05$ according to the least significant difference (LSD) test.

With the increase in drought stress and dose of GA, the protein content (PC) was decreased. The maximum PC was found in FC (32.07) at 3D stress and with no application of GA. As the dose of $GA_3$ increased, the PC decreased as shown in Figure 5. A minimum value of PC was observed in FC (24.37) under 6D stress and $G_2$. Under drought stress, the PC increased while the foliar applications of $GA_3$ decreased the PC in the seeds of canola. The modified composition of seed oil by polyamines was noticed in this research by their effect on stimulating the preparation of some enzymes, which are crucial in fatty acid metabolism [54] and proved to start penetration of fatty acid, a similar effect on enzymes that involve I synthesis of fatty acid [55,56]. Same as in PC, the LC was also decreased with the increase in $GA_3$ dose. As shown in Figure 5, a maximum LC was found in FC (12.20) under 6D stress and GA at 0 mg $L^{-1}$, while the minimum LC was observed in PC (6.23) at 6D stress and $G_2$. Under drought stress, α—linolenic acid increased and oleic acid decreased during water stress. In the present study, linolenic acid increased and oleic acid decreased under water stress but applying the foliar application of GA decreased the linolenic acid and increased the oleic acid. Similarly, $GA_3$ application might have led to an increase in the level of salicylic acid, which plays a vital role in abiotic stress tolerance in plants [20,57].

As shown in Figure 6, a highly significant correlation was observed between YP and SL (1.0 **); SPS (0.9 **); NSPP (0.9 **); TSW (1.0 **); PH (0.9 **); OLEC (0.8 **); OC (0.8 **); RWC (0.7 **); CARC (0.9 **); CHA (0.9 **); and significant correlation of CHB (0.6 *). TSW was significantly correlated with NSPP (0.9 **); PH (0.9 **); CHA (0.9 **); CARC (0.8 **); OLEC (0.6 *); and OC, TCH, and PC (0.5 *). OC content was significantly correlated with OLEC (0.6 *); PH (0.7 *); TSW (0.8 **); and SPS, SL, and YP (0.8 **). An increase in TSW was the goal of every research because TSW was a major yield-contributing trait. In our study, TSW was positively correlated with SL, PH, Caro, OC, TPW, SWP, SPS, NSPP, OlecC, and chlorophyll content [58–60].

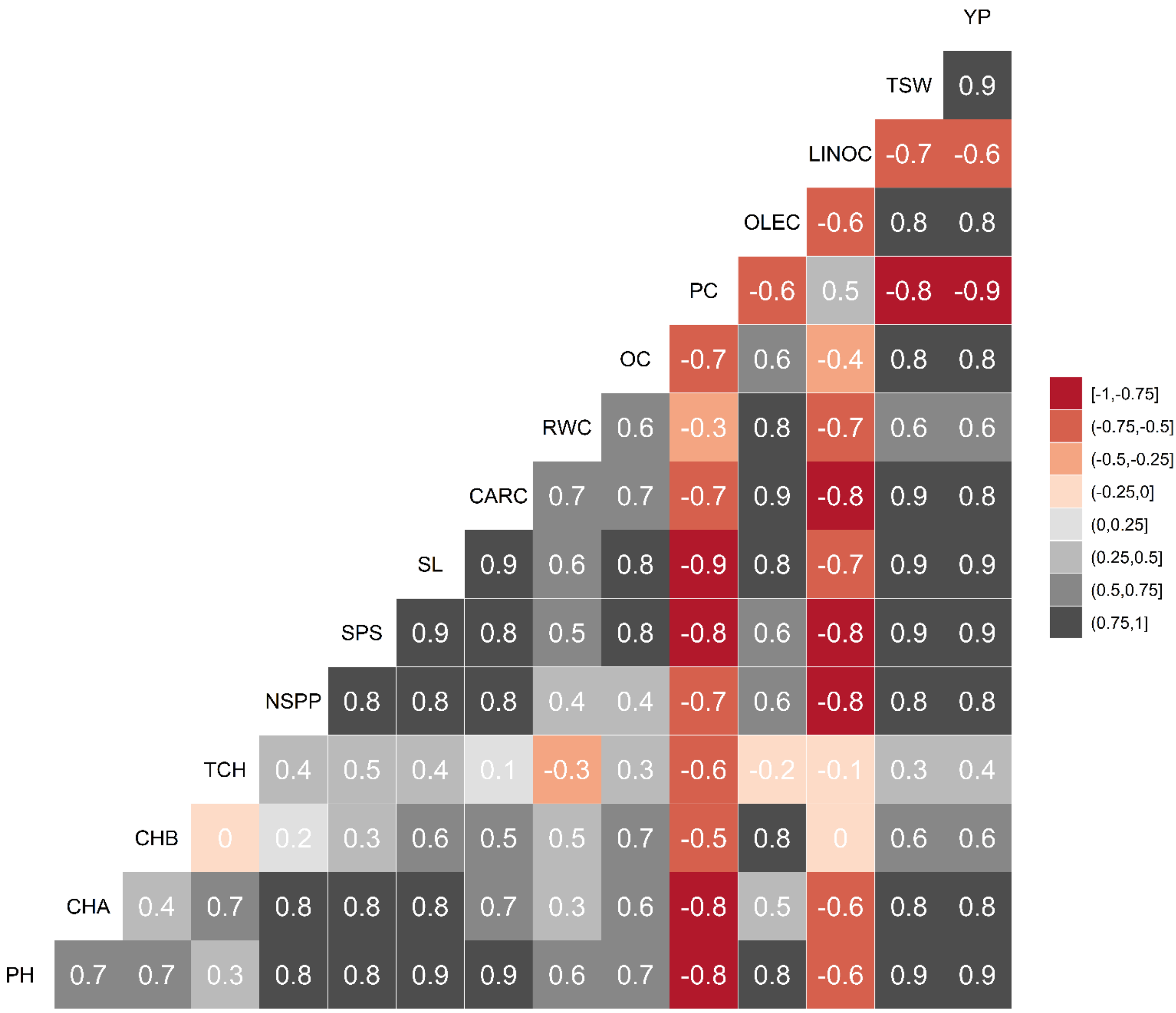


**Figure 6.** Correlation among various growth, physiological, yield, and quality parameters of canola under different treatments of gibberellic acid. Plant height (PH), Chlorophyll a (CHA), Chlorophyll b (CHB), Total Chlorophyll (TCH), No. of siliqua/plant (NSPP), Seed/siliqua (SPS), Siliqua Length (SL), Carotenoid (CARC), relative water content (RWC), Oil content (OC), Protein content (PC), Oleic content (OLEC), Linolenic content (LINOC), 1000 seed weight (TSW), and Yield/plant (YP).

From our results, it is concluded that FC performance was maximum under $GA_2$-6D for PH, CHB, CHA, SL, DSW, TSW, DRW, SW, OC, and NSPP. In the growing season, if drought stress prevailed for 6 days, its harmful effect was minimized by using $GA_3$ at a dose of 150 mg $L^{-1}$. The same trend was observed in PC; maximum performance was found for SW, OC, CARC, and SPS under 6D drought stress and foliar application of $GA_3$ ($G_2$) of 150 mg $L^{-1}$.

## 4. Conclusions

In this study, the impact of the foliar application of gibberellic acid ($GA_3$) was tested to ameliorate the negative impacts of drought stress on the growth, yield, and quality parameters of canola. The results showed that drought stress severely reduced the growth, yield, and quality parameters of canola. However, this stress was relieved on the growth, yield, and quality parameters of canola via the foliar application of $GA_3$. The impact in amelioration of drought stress on various parameters was dependent on the concentration of $GA_3$ applied. As the concentration of $GA_3$ was increased, various growth, yield, and quality parameters were significantly enhanced. The maximum increase in growth, yield, and oil quality parameters was observed with the foliar application of $GA_3$ at the rate of 150 mg $L^{-1}$ in canola. The results of this study suggest that the foliar application of $GA_3$ could ameliorate the negative impacts of drought stress on the growth, yield, oil contents, and oil quality of canola. However, more rigorous studies involving other crops under natural field conditions are required to authenticate the practical application of the treatment in the field.

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