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Kaolin Foliar Application Enhanced Physiological Functions and Pods Quality of (*phaseolus vulgaris* L.) under Deficit Irrigation Regimes

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ABSTRACT

Two field experiments were consecutively conducted during the fall seasons of 2018 and 2019 to examine the main and interactive effects of kaolin foliar application (Kao) and deficit irrigation (DI) at different physiological stages on physiological functions and pods quality of (*phaseolus vulgaris* L.). DI has been applied by skipping one irrigation at different physiological stages (DI-Vegetative growth, DI- Flowering and DI-Ripen) plus normal watering, as a comparison treatment. Kao-C foliar spray has been applied with different concentrations (without kaolin, Kao-1= 12.5 g / L and Kao-2 = 25 g / L) weekly after the first irrigation till the ripening time (a total of five times). The experimental layout was a Split-Plot System depending on Randomized Complete Blocks design with 3 replications. DI occupied the main plot and Kao foliar application allocated at the sub-plots. Kao foliar application enhanced drought stress tolerance in common bean plants by improving photosynthetic efficiency (Fv/Fm and PI) and plant water status as evaluated by membrane stability index and relative water content. The results showed that skipping one irrigation either DI-vegetative or DI-ripen combined with foliar spraying of kaolin (Kao-1 or Kao-2) had a noticeable positive effect on leaves chemical contents (N, P, K, chlorophyll, carotenoids and TSS) and plant water status (relative water content (RWC) and membrane stability index (MSI)), as well as pods chemical contents (N, P, chlorophyll, carotenoids, TSS), and fruit firmness.

1. Introduction

Green beans are young, unripe fruits of various cultivars of the common bean (*Phaseolus vulgaris* L.) dicotyledonous plants, a member of the Fabaceae (Leguminosae) family that contains many of the world's most popular garden and cash crops such as peas, broad bean and cowpea. Most of the common bean cultivars are grown for the production of green pods and/or dry seeds yield. The green pods and dry seeds play a vital role in human nutrition as a cheap source of protein, carbohydrates, dietary fiber, vitamins and minerals, It's also digestible, low in calories and ideal for health conscious weight watchers. [1]–[4].

The problem of fresh water shortage in the world is increasing at a rapid pace, considering the pace at which the population is growing and the rise in water use per capita as the economy induces a raised demand [5]–[8]. Farmers are already having to learn to use water in the most efficient way possible to get maximum production from each unit of water and each unit of land. Research on deficit irrigation has become needed to improve water productivity, although a high soil water potential throughout the growing season is necessary to maintain unimpaired crop growth and high economic yield, the imposition of some stress by longer irrigation intervals, higher moisture depletion or skipping irrigation during the early vegetative or during maturation could still attain similar economic yields as well as saving irrigation water and improving water use efficiency [9]–[17].

Kaolin clay (Aluminum Silicate) is considered one of the cheapest materials that may be used in the agricultural field as an anti-transpiration, a controller of heat, salinity stress, protect plants from insect infections and many diseases. Particle film materials are a valuable multifunctional new instrument for providing a heat stress decrease in vegetable plants and tree fruit production. Because of their unparalleled nature, they have been joined for using in farming with a pre-harvest interlude of zero days [18]. Deficit irrigation and the application of kaolin could mitigate climate change/drought impact and save water in agriculture. [19], [20]. Foliar Kaolin covers the crop with fine coating works on enhancing plant photosynthesis under drought conditions, lower heat pressure in plants by stating the infrared light spectrum, which in the end develops plant yields and fruit quality [21], [22].

Accordingly, the present investigation was proposed in order to investigate the main and interaction effects of water stress, as a result of deficit irrigation (DI) at different physiological stages, and kaolin clay (Kao-C) foliar spraying, in different concentrations (0, 12.5 and 25 g/L) on chemical content and physiological properties of green bean leaves and pods (*Phaseolus vulgaris* L.) Paulista cv., to determine best way to produce a crop with an economic return and high quality, providing a good amount of water used for irrigation.

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2. . Materials and Methods

2.1. Experimental layout and treatments

Two similar field experiments were carried out during the fall season of 2018 and 2019 to investigate the main and interaction effects of water stress, as a result of deficit irrigation (DI) at different physiological stages, and kaolin clay (Kao-C) foliar spraying, in different concentrations on chemical content and physiological properties of green bean leaves and pods (*Phaseolus vulgaris* L.) Paulista cv., in a private farm located at Sennores, Fayoum Governorate, Egypt between latitudes 29°24'27.7" and 29°24'31.0"N and longitudes 30°50'50.6" and 30°50'54.3"E. Deficit irrigation (DI) have been applied by skipping one irrigation at different physiological stages (DI-vegetative growth, DI- Flow., DI-ripen, and normal watering as a control). Suspension of kaolin clay (Kao-C) as a foliar application have been applied at different concentrations (without kaolin, Kao-1= 12.5 g / L, and Kao-2 = 25 g / L) weekly beginning from a week after the first irrigation (approximately three weeks after the beginning of germination) to time of ripening (a total of five times). The experimental layout of field experiments was split-plot system in a Randomized Complete Blocks design with 3 replications. Deficit irrigation (DI) occupied the main plot and kaolin clay (Kao-C) foliar spraying application was allocated at the sub-plots. Number of treatments of pre-harvest experiment was 12 treatments (4 Deficit Irrigation × 3 kaolin application). The area devoted for each experimental unit was 15 m2 including five rows of 5 meters length and 0.6 meter width. Each two adjacent experimental units were separated by 1 m alley to protect against border effects.

Soil samples to 25 cm depth, preceding the initiation of each field experiment, were collected to identify some physical and chemical properties of the experimental site (Table 1). Soil samples were analyzed at Soil Testing Laboratory, College of Agriculture, Fayoum University, according to the standard published procedures [23]–[25].

Table 1. Some important physical and chemical properties of the experimental site in 2018 (SI) 2019 (SII) seasons.

	Value	
Physical characteristics	2018	2019
Silt (%)	46.3	46.1
Clay (%)	43.7	44.2
Fine sand (%)	4.3	4.1
Coarse sand (%)	5.7	5.6
Soil texture	Silty Clay	Silty Clay
Chemical characteristics		
pH [at a soil: water (w/v) ratio of 1:2.5]	7.556	7.615
ECe (ds/m; soil – paste extract)	2.37	2.33
Organic matter (%)	1.42	1.45
Nitrate (NO3) (mg/kg)	255	260
Available (P) (mg/kg)	49.4	49.1
Available (K) (mg/kg)	370	382
Ca (mg/100g soil)	12.1	13.02
Mg (mg/100g soil)	6.1	4.9
CaCO3 (%)	3.6	4

During the preparation of experimental site, farmyard manure at the rate of 20 m3 fed-1, calcium superphosphate and agricultural sulfur at the rate of 290 and 50 kg fed-1, respectively, were broadcasted. Rowing with intra-row spacing of 60 cm was performed. The land was irrigated with complete immersion up to the end of the upper third of the rows, to wash the soil, reduce salinity, and ensure the homogeneity of fertilizers and additives before planting. The land was left until relatively dried out and became suitable for cultivation. In 20th and 16th September of 2018 and 2019, orderly, horizontal incisions were made on one side of the ridges in the upper third of the rows. Paulista dry bean seeds treated with a fungicide were placed straight in these cracks at a depth 3-5 cm. Then these cracks were filled in to cover the seeds with mulch of wet soil and then with a layer of dry soil to prevent cracking. After 21 days of seed sowing (14-16 days after germination approximately), the first irrigation was performed (rapid irrigation with no complete immersion). About 7 days after the first irrigation, the hoeing and weed purification process was carried out manually. The excess plants were thinned out, leaving two plants in each hole to achieve in-row spacing of 10 cm. All experimental units received identical doses of N, P2O5 and K2O at the rate of 60, 45 and 48 Kg fed-1, orderly. The respective forms of N, P2O5 and K2O were ammonium nitrate (33% N), calcium superphosphate (15.5% P2O5) and potassium sulphate (48 % K2O), respectively. Calcium superphosphate was broadcasted during soil preparation, whilst ammonium nitrate and potassium sulphate were side banded at two equal portions. All other agro-management practices such as cultivation, hoeing and pest control were performed whenever it was necessary and as recommended in the commercial production of common bean.

2.2. Data recorded

Sixty days after seed sowing, ten plants were randomly selected from each experimental unit, carefully cut off at the ground level and immediately carried to the laboratory. Leaves and pods N content was determined according to [26]. An Orange-G dye solution was prepared by dissolving 1.0 g of 96% (w/w) assay-dye in 1 liter of distilled water, with 21.0 g citric acid which acted as a buffer to maintain the correct pH, and 2.5 ml 10% (v/v) thymol in 10% (v/v) ethanol as an inhibitor of microbial growth. Ground plant material (0.2 g leaf or pod tissue from each plot) was placed in a centrifuge tube and 20 ml of the dye reagent solution was added. The contents of each tube were shaken for 15 min, then filtered using Whatman No. 1 filter paper. The solution was diluted 100-fold with distilled water and its absorbance was measured at 482 nm. N contents were calculated using the formulae:

$$N (\%) = 0.39 + 0.954 \times \text{Dye absorbed (g /100 g)} \text{ and } \text{Dye absorbed (g /100 g)} = (a - b / a)(cfv / w) \times 100$$

where, a was the absorbance of the dye reagent solution at 482 nm without plant material (the blank), b was the absorbance of the dye reagent solution at 482 nm with plant material, c was the concentration of the dye reagent (1.0 g l^{-1} distilled water), f was the purity factor of the dye reagent (96%), v was the volume of the dye reagent solution used per sample (20 ml), and w was the weight of ground dry material in g (0.2).

Leaves and pods P content was determined according to [27]. The molybdenum-reduced molybdophosphoric blue colour method, in sulphuric acid (with reduction to exclude arsenate), was used to determine P contents (in mg g^{-1} DW). Sulphomolybdic acid (molybdenum blue), diluted sulphomolybdic acid, and 8% (w/v) sodium bisulphite-H2SO4 solution were used as reagents.

Leaves and pods K content was assessed using a Perkin-Elmer Model 52-A Flame Photometer (Glenbrook, Stamford, CT, USA) as outlined by [25]. Total chlorophyll and carotenoid contents of leaves and pods were determined using dimethyl formamide (DMF) method [28], [29] with some modifications; where estimates are made for 1 g of green pods instead of leaf discs. Three leaf discs (5 mm diameter) were taken from the first fully expanded leaf of each plant. Leaf discs green pods samples were stored in separate eppendorf tubes with 1 ml of DMF and kept in the dark at 4^0C for > 48 h. Chlorophyll a and b contents were measured by the absorption at wave lengths of 647 nm and 664 nm respectively, orderly using a spectrophotometer (UV-Visible Spectroscopy System, Hewlett Packard 95-98). The concentration of chlorophyll a and b was calculated according to the following formulas:

Chlorophyll a (Chl a) = 11.65 A664 - 2.69 A647 (x)

Chlorophyll b (Chl b) = 20.81 A647 - 4.53 A664 (xi)

From the sample disc area and the measured chlorophyll, a and b concentrations, chlorophyll a and b contents (μg mm-2) were calculated using the following formulas:

Chlorophyll a (μg mm-2) = (x) / disc area or sample weight

Chlorophyll b (μg mm-2) = (xi) / disc area or sample weight

Total Chlorophyll = Chl a + Chl b

Total carotenoids content was measured by the absorption at the wave of length 480 nm via a spectrophotometer (UV-Visible Spectroscopy System, Hewlett Packard 95-98). Total carotenoids concentration was calculated according to the following formula:

Total carotenoids (car) = [1000A480 - 0.89 (Chl a) - 52.02 (Chl b)] /245 (xii)

From the sample disc area and the measured total carotenoid concentration, total carotenoids content (μg mm-2) was calculated using the following formula: Total carotenoids (μg mm-2) = (xii) / disc area or sample weight

Total soluble solids (TSS) content were determined in 0.2 g of dried leaves and pods samples as described by [30]. Samples were homogenized in 5 ml of 96% (v/v) ethanol, and then washed with 5 ml 70% (v/v) ethanol. The extracts were centrifuged at 3500 × g for 10 min, and the supernatants were stored at 4°C prior to determination. The reaction mixture of 0.1 ml of the ethanolic extract and 3 ml of freshly-prepared anthrone reagent [150 mg anthrone plus 100 ml of 72% (v/v) sulphuric acid] was placed in a boiling water bath for 10 min, and was then cooled. The absorbance of the mixture was recorded at 625 nm using a Bausch and Lomb-2000 Spectronic Spectrophotometer.

Membrane stability index (MSI) was determined using duplicate 0.2 g samples of fully-expanded leaf or pod tissue as described by [31]. Leaves or pods samples was placed in a test-tube containing 10 ml of double-distilled water. The content of the test-tube was heated at 40 °C in a water bath for 30 min, and the electrical conductivity (C1) of the solution was recorded using a conductivity bridge. A second sample was boiled at 100°C for 10 min, and the conductivity was measured (C2). The MSI was calculated using the formula: MSI(%)=[1-(C1/C2)] ×100

Relative water content (RWC) was estimated using 2 cm-diameter fully-expanded leaf discs [32]. The discs were weighed (fresh mass; FM) and immediately floated on double-distilled water in Petri dishes for 24 h, in the dark, to saturate them with water. Any adhering water was blotted dry and the turgid mass (TM) was measured. The dry mass (DM) was recorded after dehydrating the discs at 70 °C until the constant weight. The RWC was then calculated using the following formula: RWC(%)=[((FM-DM))/((TM-DM))]×100

Chlorophyll a fluorescence was measured using a portable fluorometer (Handy PEA, Hansatech Instruments Ltd, Kings Lynn, UK). One leaf (the same age) at solar noon was chosen per plant. Maximum quantum yield of PS II Fv/Fm was calculated using the formula; Fv/Fm = (Fm – F0) / Fm [33]. Fv/F0 reflects the efficiency of electron donation to the PSII RCs and the rate of photosynthetic quantum conversion at PSII RCs. Fv/F0 was calculated using the formula; Fv/F0 = (Fm – F0) / F0 [34]. Performance index (PI) of photosynthesis based on the equal absorption (PIABS) was calculated as reported by [35]. Relative chlorophyll content was measured using SPAD chlorophyll meter (SPAD-502; Minolta, Osaka, Japan).

Dry matter in fresh pods (%) was calculated according to the following formula: % Dry Matter in Fresh Pods =[(dry pods weight)/(fresh pods weight)]x 100 Pods Crispness (index) were evaluated by a team of six volunteers, each one of them gives a score from zero to five to the same sample and a certain number of repetitions for crispness of pods, so that the degree is 5 for the highest pod crispness, an average of those scores is made for each iteration. Pods Firmness (kg cm-2) was measured using a fruit firmness tester with a plunger 3 mm diameter Model 53200 fruit penetrometer, range till 13 kg (T. R. Turoni srl, Via Copernico 26, 47122 Forlì, Italy).

2.3. Statistical analysis

All data were subjected to an analysis of variance (ANOVA) procedures in Genstat statistical package (version 11) (VSN International Ltd, Oxford, UK). Difference between means was compared using Duncan's multiple range test [36], [37].

3. Results

3.1. Leaf chemical content and physiological properties

Leaf N, P, and K content

Other than the main effect of DI on leaf N content, the two study factors, almost, had no main effects with significant differences, on Leaf N, P, and K content, but, regarding the main effects of DI on leaf N content; the statistical analysis showed that the highest average values were from DI-Ripen and DI-Veg. treatments without any significant difference between them, in both seasons, with an increase of 6.13 % and 5.93 % for both treatments, respectively, in the first season and 11.23 % for both treatments in the second season compared to the control treatments, which gave the lowest average values in both seasons.

As for the interaction effect between the two study factors; the highest averages of leaf N content were from DI-Ripen with Kao-2 and DI-Veg. with Kao-1 treatments, with an increase of 0.41 % and 11.25 % in both seasons, respectively. Whereas, the lowest mean values resulted from DI-Flow., without kaolin (Control), with a decrease of -11.11 % and -15.01 % compared to the control treatments, in both seasons, respectively.

While the highest averages of leaf P content were from DI-Ripen with Kao-2 and DI-Veg. with Kao-1 treatments, with an increase of 62.09 % and 13.37 % in both seasons, respectively. While the highest averages of leaf K content were from DI-Veg. with Kao-1 and Kao-2 treatments, with an increase of 16.73 % and 21.18 % in both seasons, respectively.

Table 2. Main and interaction effects of deficit irrigation (DI) treatments and foliar application of Kaolin (Kao) on Leaf N, P, and K (mg $g^{-1\ D.W.}$) on common bean (*Phaseolus vulgaris* L.) during 2018 (SI) 2019 (SII) seasons.

Irrigation Treatments	Kaolin levels	Leaf N content (mg $g^{-1\ D.W.}$)		Leaf P content (mg $g^{-1\ D.W.}$)		Leaf K content (mg $g^{-1\ D.W.}$)	
		SI	SII	SI	SII	SI	SII
Normal Watering		9.222 B*	8.730 B	1.999 B	1.718 A	6.863 A	6.164 AB
DI-Veg.		9.769 A	9.710 A	2.126 AB	1.880 A	6.825 A	6.604 A
DI-Flow.		9.302 B	8.741 B	2.539 A	1.948 A	6.705 A	6.073 B
DI-Ripen		9.787 A	9.710 A	2.463 A	1.884 A	6.734 A	6.585 A
	control	9.464 A	9.274 A	2.100 B	1.916 A	6.735 A	5.920 B
	Kao-1	9.559 A	9.040 A	2.026 B	1.830 A	6.961 A	6.638 A
	Kao-2	9.537 A	9.354 A	2.719 A	1.827 A	6.649 A	6.512 A
	control	10.092 ab	9.238 abc	1.844 c	1.952 ab	6.437 cd	5.632 b
Normal Watering	Kao-1	9.839 abc	8.213 cd	1.821 c	1.523 b	7.342 abc	6.437 ab
	Kao-2	9.375 abcd	8.739 bcd	2.332 bc	1.678 ab	6.810 abcd	6.422 ab
	control	9.395 abcd	9.211 abc	1.856 c	1.702 ab	6.552 bcd	6.207 ab
DI-Veg.	Kao-1	9.211 cd	10.277 a	2.118 c	2.213 a	7.514 a	6.782 a
	Kao-2	9.299 bcd	9.641 ab	2.404 bc	1.726 ab	6.408 cd	6.825 a
	control	8.971 d	7.851 d	2.404 bc	2.023 ab	6.552 bcd	5.690 b
DI-Flow.	Kao-1	9.354 abcd	9.416 abc	2.261 bc	1.880 ab	6.839 abcd	6.509 ab
	Kao-2	9.340 abcd	8.958 abcd	2.951 ab	1.940 ab	6.724 abcd	6.020 ab
	control	9.395 abcd	9.231 abc	2.297 bc	1.987 ab	7.399 ab	6.149 ab
DI-Ripen	Kao-1	9.833 abc	9.819 ab	1.904 c	1.702 ab	6.149 d	6.825 a
	Kao-2	10.133 a	10.079 ab	2.989 a	1.964 ab	6.652 abcd	6.782 a

*Values marked with the same letter(s) within the main and interaction impacts are statistically similar using Duncan's multiple range test. Uppercase letter(s) refer to differences within the main effects and lowercase letter(s) refer to differences within the interaction effects. DI-Veg. = single water stress at vegetative stage, DI-Flow. = single water stress at flowering, DI-Ripen = single water stress at ripening, Kao-1= 12.5 g / L Kao-2 = 25 g / L

Leaf total chlorophyll, carotenoids and total soluble solids (TSS) content

Except for some minor differences, the two study factors, almost, had no main effects with significant differences, on all the above mentioned characteristics. As a main effect of irrigation treatments; the lowest mean values of total chlorophyll content resulted from normal watering in SII, the highest average values of carotene content in SII also, were produced from DI-Ripen treatment, with an increase of 30.69 % compared to the control treatment. As for the interaction effect between the two study factors; the interaction between DI-Veg., with Kao-2 gave the highest means values of total chlorophyll content, with an increase of 9.71 % and 35.68 %, compared to the control treatments in both seasons, respectively. DI-Veg., with Kao-2 in SI and DI-Flow., with Kao-1 in SII gave the highest means values of carotene content, with an increase of 58.97 % and 60.03 % respectively.

Table 3. Main and interaction effects of deficit irrigation (DI) treatments and foliar application of Kaolin (Kao) on total chlorophyll, carotenoids (mg mm^{-2}) and total soluble solids (TSS) (mg g^{-1} D. W.) content of common bean (*Phaseolus vulgaris* L.) during 2018 (SI) 2019 (SII) seasons.

Irrigation Treatments	Kaolin levels	Total chlorophyll content (mg mm^{-2})		Carotene content (mg mm^{-2})		T. S. S. content (mg g^{-1} D. W.)	
		SI	SII	SI	SII	SI	SII
Normal Watering		0.1145 A*	0.1247 B	0.006122 A	0.004431 B	1.1038 A	1.162 A
DI-Veg.		0.1236 A	0.1321 AB	0.005132 A	0.004819 B	0.8137 A	0.874 A
DI-Flow.		0.1214 A	0.1439 A	0.006105 A	0.005071 B	0.7689 A	1.060 A
DI-Ripen		0.1109 A	0.1506 A	0.004890 A	0.005791 A	0.6741 A	1.265 A
	control	0.1251 A	0.1331 A	0.006563 A	0.004863 A	0.7432 A	1.018 AB
	Kao-1	0.1096 B	0.1429 A	0.004531 B	0.005315 A	0.8826 A	0.893 B
	Kao-2	0.1181 AB	0.1375 A	0.005594 AB	0.004906 A	0.8946 A	1.359 A
	control	0.1298 ab	0.1124 b	0.004031 c	0.003660 c	1.4387 a	0.957 ab
Normal Watering	Kao-1	0.1096 ab	0.1275 ab	0.005250 bc	0.004791 abc	0.6575 abc	1.042 ab
	Kao-2	0.1042 b	0.1342 ab	0.004959 bc	0.004840 abc	1.2152 abc	1.486 ab
	control	0.1181 ab	0.1288 ab	0.005059 bc	0.004769 abc	0.5512 bc	0.790 ab
DI-Veg.	Kao-1	0.1104 ab	0.1343 ab	0.003931 c	0.004890 abc	1.3628 ab	0.746 b
	Kao-2	0.1424 a	0.1525 a	0.006408 a	0.004799 abc	0.5273 bc	1.085 ab

	control	0.1361 ab	0.1415 ab	0.006215ab	0.005128 ab	0.6141 abc	1.126 ab
DI-Flow.	Kao-1	0.1081 ab	0.1331ab	0.004910bc	0.005857 a	0.9374 abc	0.792 ab
	Kao-2	0.1200 ab	0.1317 ab	0.006190 ab	0.004227 bc	0.7552 abc	1.261 ab
	control	0.1061 b	0.1496 a	0.005821bc	0.005894 a	0.3689 c	1.198 ab
DI-Ripen	Kao-1	0.1101 ab	0.1514 a	0.00616a	0.005722 a	0.5729 bc	0.994 ab
	Kao-2	0.1166 ab	0.1510 a	0.004819bc	0.005757 a	1.0807 abc	1.604 a

*Values marked with the same letter(s) within the main and interaction impacts are statistically similar using Duncan's multiple range test. Uppercase letter(s) refer to differences within the main effects and lowercase letter(s) refer to differences within the interaction effects. DI-Veg. = single water stress at vegetative stage, DI-Flow. = single water stress at flowering, DI-Ripen = single water stress at ripening, Kao-1= 12.5 g / L Kao-2 = 25 g / L

Leaf membrane stability index (MSI) . relative water content (RWC)

In terms of the main effects, the results showed that all DI treatments (DI-Veg., DI-Flow., and DI-Ripen) had a significant negative impact on both MSI and RWC compared to the normal watering treatment. The largest reduction in MSI was observed under DI-Ripen treatment, which resulted in a 15.37% and 15.86% reduction in MSI in SI and SII respectively, compared to the normal watering (control) treatment. However, the largest reduction in RWC was observed under DI-Flow. treatment, which resulted in a 14.5% and 14.98% reduction in SI and SII respectively, compared to the control treatment. On the other hand, the Kao-C treatments had a significant positive impact on both MSI and RWC too, compared to the control treatment. The largest increase in MSI and RWC due to Kao-C was observed in Kao-2 treatment, where MSI and RWC were increased by 15.03% and 12.66% in SI, 15.59% and 13.16% in SII, respectively. Regarding the interaction effects between DI and Kao-C, the results showed that in most cases, Kao-C had a significant mitigating effect on the negative impact of DI on both MSI and RWC. The interaction between normal watering with Kao-2 achieved the highest mean values on both MSI and RWC, with an increase of 11.07% and 5.09%, in SI, 11.45% and 5.27% in SII, respectively, compared to the control treatments. The lowest mean of values was resulted from DI-Ripen and DI-Flow. without Kao-C on both MSI and RWC, and in both seasons.

Table 4. Main and interaction effects of deficit irrigation (DI) treatments and foliar application of Kaolin (Kao) on Percentage of Leaf membrane stability index (MSI) and relative water content (RWC) measurements (%)of common bean (*Phaseolus vulgaris* L.) during 2018 (SI) 2019 (SII) seasons.

Irrigation Treatments	Kaolin levels	MSI (%) SI	SII	RWC (%) SI	SII
Normal Watering		79.89 A*	77.39 A	76.69 A	74.19 A
DI-Veg.		77.64 A	75.14 A	71.53 B	69.03 B
DI-Flow.		71.62 B	69.12 B	65.57 C	63.07 C
DI-Ripen		67.61 C	65.11 C	67.41 C	64.91 C
	control	68.66 C	66.16 C	65.73 C	63.23 C
	Kao-1	74.93 B	72.43 B	71.12 B	68.62 B
	Kao-2	78.98 A	76.48 A	74.05 A	71.55 A
	control	75.70 cde	73.2 cde	74.42 abc	71.92 abc
Normal Watering	Kao-1	79.88 abc	77.38 abc	77.44 ab	74.94 ab
	Kao-2	84.08 a	81.58 a	78.21 a	75.71 a
	control	72.01 ef	69.51 ef	67.28 ef	64.78 ef
DI-Veg.	Kao-1	79.46 a-d	76.96 a-d	71.80 cde	69.30 cde
	Kao-2	81.46 ab	78.96 ab	75.50 abc	73.00 abc
	control	65.04 g	62.54 g	60.73 g	58.23 g
DI-Flow.	Kao-1	73.33 e	70.83 e	66.66 f	64.16 f
	Kao-2	76.50 b-e	74.00 b-e	69.32 def	66.82 def
	control	61.88 g	59.38 g	60.49 g	57.99 g
DI-Ripen	Kao-1	67.05 fg	64.55 fg	68.58 def	66.08 def
	Kao-2	73.89 de	71.39 de	73.15 bcd	70.65 bcd

*Values marked with the same letter(s) within the main and interaction impacts are statistically similar using Duncan's multiple range test. Uppercase letter(s) refer to differences within the main effects and lowercase letter(s) refer to differences within the interaction effects. DI-Veg. = single water stress at vegetative stage, DI-Flow. = single water stress at flowering, DI-Ripen = single water stress at ripening, Kao-1= 12.5 g / L Kao-2 = 25 g / L

Photosynthetic efficiency and relative chlorophyll content

Regarding the main effects of DI on photosynthetic efficiency (Fv/Fm and PI) and relative chlorophyll content; the highest mean values obtained from normal watering, while the lowest average values were obtained from DI-Flow., with a decrease of 4.089%, 4.015% for Fv/Fm, 17.357%, 17.131% for PI, and 8.896%, 8.613% for relative chlorophyll content, in both seasons, respectively, compared to control treatments. On the other hand, the Kao-C treatments had a significant positive impact on Fv/Fm, PI and relative chlorophyll content too, compared to the control treatments. The largest increase due to Kao-C was observed from Kao-2 treatment, where Fv/Fm, PI and leaves relative chlorophyll content were increased by 3.52%, 18.35% and 8.13% in SI, 3.45%, 18.06% and 7.853% in SII, compared to the control treatments, respectively. Regarding the interaction effects between DI and Kao-C, the results showed that Kao-C had a significant mitigating effect on the negative impact of DI on all traits studied. The interaction between normal watering with Kao-2 achieved the highest mean values with an increase of 3.538% and 3.472% on Fv/Fm, 26.13% and 25.744% on PI and 9.116% and 8.814% on relative chlorophyll content in both seasons, respectively, compared to the control treatments. The lowest mean of values was resulted from

DI-Flow. without Kao-C on Fv/Fm, PI and relative chlorophyll content, in both seasons.

Table 5. Main and interaction effects of deficit irrigation (DI) treatments and foliar application of Kaolin (Kao) on photosynthetic efficiency (F_v/F_m and PI) and relative chlorophyll content (SPAD value) of common bean (*Phaseolus vulgaris* L.) during 2018 (SI) 2019 (SII) seasons.

Irrigation Treatments	Kaolin levels	*Fv/Fm*		PI		Leaf relative chlorophyll content (SPAD value)	
		SI	SII	SI	SII	SI	SII
Normal Watering		0.8144 A	0.8294 A	9.489 A	9.614 A	45.64 A	47.14 A
DI-Veg.		0.7917 B	0.8067 B	8.498 B	8.623 B	43.37 BC	44.87 BC
DI-Flow.		0.7811 C	0.7961 C	7.842 B	7.967 B	41.58 C	43.08 C
DI-Ripen		0.7978 B	0.8128 B	8.273 B	8.398 B	43.73 AB	45.23 AB
	control	0.7812 C	0.7962 C	7.798 B	7.923 B	42.05 B	43.55 B
	Kao-1	0.7988 B	0.8137 B	8.549 AB	8.674 AB	43.22 B	44.72 B
	Kao-2	0.8087 A	0.8237 A	9.229 A	9.354 A	45.47 A	46.97 A
Normal Watering	control	0.80 bcd	0.815 bcd	8.343 bc	8.468 bc	43.88 bcd	45.38 bcd
	Kao-1	0.815 ab	0.8300 ab	9.600 ab	9.725 ab	45.17 abc	46.67 abc
	Kao-2	0.8283 a	0.8433 a	10.523 a	10.648 a	47.88 a	49.38 a
DI-Veg.	control	0.7767 ef	0.7917 ef	7.843 bc	7.968 bc	41.50 cd	43.00 cd
	Kao-1	0.797 bcd	0.812 bcd	8.398 bc	8.523 bc	43.32 bcd	44.82 bcd
	Kao-2	0.802 bcd	0.817 bcd	9.252 ab	9.377 ab	45.28 abc	46.78 abc
DI-Flow.	control	0.765 f	0.7800 f	7.238 c	7.363 c	40.67 d	42.17 d
	Kao-1	0.785 de	0.800 de	7.855 bc	7.980 bc	41.05 d	42.55 d
	Kao-2	0.793 cde	0.8083 cde	8.432 bc	8.557 bc	43.02 bcd	44.52 bcd
DI-Ripen	control	0.783 de	0.7983 de	7.767 bc	7.892 bc	42.13 bcd	43.63 bcd
	Kao-1	0.798 bcd	0.813 bcd	8.343 bc	8.468 bc	43.35 bcd	44.85 bcd
	Kao-2	0.812 abc	0.8267 abc	8.710 bc	8.835 bc	45.70 ab	47.20 ab

*Values marked with the same letter(s) within the main and interaction impacts are statistically similar using Duncan's multiple range test. Uppercase letter(s) refer to differences within the main effects and lowercase letter(s) refer to differences within the interaction effects. DI-Veg. = single water stress at vegetative stage, DI-Flow. = single water stress at flowering, DI-Ripen = single water stress at ripening, Kao-1= 12.5 g / L Kao-2 = 25 g / L

3.2. *Thermal analysis*

Green pods chemical content and physiological properties

Green pods N, P, and K

Regarding the main effects of different irrigation systems on green pods nitrogen content; the highest average values were from DI-Ripen and DI-Flow., in SI, without any significant statistical differences between them, and with an increase of 15.88 % and 14.14 % respectively, while there were no significant differences between all treatments in the SII. As for green pods phosphor content; the highest average values were from DI-Ripen with an increase of 18.98 % without any significant statistical differences between the four irrigation treatments in SI, but, In SII the highest average values were from DI-Ripen and DI-Flow., without any significant statistical differences between them, and with an increase of 59.67 % and 57 % respectively. As for green pods K content; the highest average values were from DI-Ripen with an increase of 1.61 % in SI, and from normal watering and DI-Veg., in SII without any significant statistical differences between them.

As for the main effects of foliar Kao-C spraying treatments; there were no significant effects on green pods nitrogen content in both seasons and on phosphor content in SI, but in SII the control treatment without Kao-C gave the lowest mean values, the highest average values were from kao-1 and kao-2, without any significant statistical differences between them, and with an increase of 14.70 % and 14.49 % respectively, compared to the control treatments. While as for green pods K content; the highest average values were from Kao-1with an increase of 3.97 % and 4.44 %in both seasons respectively.

Regarding the interaction effect between the two study factors on green pods nitrogen content; the interaction between DI-Veg., with Kao-1 gave the highest mean values, with an increase of 17.04 % in SI, but in SII the interaction between DI-Ripen and Kao-2 gave the highest mean values, with no significant differences between it and the control treatment. As for green pods phosphor content; the interaction between DI-Ripen and DI-Flow., both with Kao-1 gave the highest mean values with an increase of 40.58 % and 26.95 % in SI, 59.59 % and 39.20 % in SII, respectively.

As for green pods k content; the interaction between DI-Veg., with Kao-2 in SII and normal watering with Kao-1 in both seasons gave the highest means values with an increase of 3.78 %, 8.81 % and 3.43 % respectively.

Table 6. Main and interaction effects of deficit irrigation (DI) treatments and foliar application of Kaolin (Kao) on Green pods N, P, and K measurements (mg g$^{-1 D. W.}$) on common bean (*Phaseolus vulgaris* L.) during 2018 (SI) 2019 (SII) seasons.

Irrigation Treatments	Kaolin levels	Green pods N content (mg g$^{-1 D. W.}$)		Green pods P content (mg g$^{-1 D. W.}$)		Green pods K content (mg g$^{-1 D. W.}$)	
		SI	SII	SI	SII	SI	SII
Normal Watering		8.06 ^{B}	8.191 ^{A}	0.8568 ^{A}	1.200 ^{B}	8.564 ^{AB}	7.964 ^{A}
DI-Veg.		8.635 ^{AB}	7.896 ^{A}	0.8052 ^{A}	1.392 ^{B}	8.31 ^{B}	7.95 ^{A}
DI-Flow.		9.20 ^{A}	8.571 ^{A}	0.8965 ^{A}	1.884 ^{A}	7.668 ^{C}	7.318 ^{B}
DI-Ripen		9.34 ^{A}	8.537 ^{A}	1.0194 ^{A}	1.916 ^{A}	8.702 ^{A}	7.074 ^{B}
	control	8.792 ^{A}	8.297 ^{A}	0.9341 ^{A}	1.456 ^{B}	8.208 ^{B}	7.428 ^{B}
	Kao-1	9.139 ^{A}	8.146 ^{A}	0.7794 ^{A}	1.667 ^{A}	8.534 ^{A}	7.758 ^{A}
	Kao-2	8.496 ^{A}	8.453 ^{A}	0.9698 ^{A}	1.670 ^{A}	8.190 ^{B}	7.544 ^{AB}
	control	8.431 ^{abc}	9.007 ^{a}	0.8211^{abc}	1.398 ^{de}	8.319 ^{bcd}	7.932 ^{abc}
Normal Watering	Kao-1	7.680 ^{c}	7.849 ^{bc}	0.4641 ^{c}	0.952 ^{f}	9.052 ^{a}	8.204 ^{a}
	Kao-2	8.070 ^{bc}	7.636 ^{bc}	0.9639 ^{ab}	1.249 ^{def}	8.319 ^{bcd}	7.758 ^{abcd}
	control	8.343 ^{abc}	7.584 ^{c}	0.8806^{abc}	1.035 ^{ef}	8.534 ^{abc}	7.586 ^{bcde}
DI-Veg.	Kao-1	9.868 ^{a}	7.871 ^{bc}	0.6783 ^{bc}	1.541 ^{cd}	8.520 ^{abc}	8.032 ^{ab}
	Kao-2	7.695 ^{c}	8.232 ^{abc}	0.8568^{abc}	1.601 ^{bcd}	7.874 ^{cde}	8.232 ^{a}
	control	9.080 ^{abc}	8.527 ^{abc}	0.9282 ^{ab}	1.827 ^{bc}	7.644 ^{e}	7.356 ^{def}
DI-Flow.	Kao-1	9.573 ^{ab}	8.579 ^{abc}	1.0424 ^{a}	1.946 ^{a}	7.601 ^{e}	7.356 ^{def}
	Kao-2	8.947 ^{abc}	8.608 ^{abc}	0.9401 ^{ab}	1.880 ^{abc}	7.759 ^{de}	7.242 ^{efg}
	control	9.315 ^{ab}	7.989 ^{abc}	0.7854 ^{abc}	1.565 ^{bcd}	8.333 ^{bcd}	6.84 ^{g}
DI-Ripen	Kao-1	9.433 ^{ab}	8.284 ^{abc}	1.1543 ^{a}	2.231 ^{a}	8.966 ^{ab}	7.442 ^{cdef}
	Kao-2	9.271 ^{ab}	9.338 ^{a}	1.1186 ^{ab}	1.952 ^{ab}	8.807 ^{ab}	6.94 ^{fg}

*Values marked with the same letter(s) within the main and interaction impacts are statistically similar using Duncan's multiple range test. Uppercase letter(s) refer to differences within the main effects and lowercase letter(s) refer to differences within the interaction effects. DI-Veg. = single water stress at vegetative stage, DI-Flow. = single water stress at flowering, DI-Ripen = single water stress at ripening, Kao-1= 12.5 g / L Kao-2 = 25 g / L

Green pods total chlorophyll, Relative chlorophyll and carotenoid contents

Regarding the main effects of different irrigation systems; the highest average values were from DI-Flow., for all three characteristics mentioned above, with an increase of 11.77 % and 11.18 % on green pods total chlorophyll, 13.41 % and 34.35 % on relative chlorophyll content (SPAD value), 22.92 % and 20.71 % on green pods carotene content, in both seasons respectively.As for the main effects of foliar Kao-C spraying treatments; there were no significant effects on all three characteristics mentioned above in both seasons approximately.

Regarding the interaction effect between the two study factors on green pods total chlorophyll content; the interaction between DI-Flow., with Kao-2 gave the highest mean values with an increase of 25.63 % and 33.16 % in both seasons respectively. As for relative chlorophyll content; the interaction between DI-Flow., with Kao-1 gave the highest mean values in SI, but in SII DI-Ripen with Kao-2 gave the highest, with an increase of 12.58 % and 53.09 % respectively. As for green pods carotene content; the interaction between DI-Flow., with Kao-2 gave the highest mean values with an increase of 49.70 % and 35.89 % in both seasons respectively (Table 7).

Table 7. Main and interaction effects of deficit irrigation (DI) treatments and foliar application of Kaolin (Kao) on Green Pods total chlorophyll (mg g^{-1}), relative chlorophyll content (SPAD value) and carotene contents (mg g^{-1}) on common bean (*Phaseolus vulgaris* L.) during 2018 (SI) 2019 (SII) seasons.

Irrigation Treatments	Kaolin levels	Green Pods total chlorophyll content (mg g^{-1})		Relative chlorophyll content (SPAD value)		Green Pods Carotene content (mg g-1)	
		SI	SII	SI	SII	SI	SII
Normal Watering		5.344 ^{AB*}	5.270 ^{AB}	34.46 ^{B*}	25.24 ^{C}	0.2823 ^{AB}	0.2989 ^{AB}
DI-Veg.		4.721 ^{AB}	4.655 ^{AB}	35.92 ^{B}	25.93 ^{BC}	0.2670 ^{B}	0.2704 ^{AB}
DI-Flow.		5.973 ^{A}	5.859 ^{A}	39.08 ^{A}	33.91 ^{A}	0.3470 ^{A}	0.3608 ^{A}
DI-Ripen		4.363 ^{B}	4.156 ^{B}	36.77 ^{AB}	29.53 ^{B}	0.2358 ^{B}	0.2627 ^{B}
	control	5.196 ^{A}	5.113 ^{A}	37.93 ^{A}	27.85 ^{AB}	0.2785 ^{A}	0.2975 ^{A}
	Kao-1	5.008 ^{A}	4.732 ^{A}	35.76 ^{A}	27.25 ^{B}	0.2703 ^{A}	0.3113 ^{A}
	Kao-2	5.097 ^{A}	5.109 ^{A}	35.98 ^{A}	30.87 ^{A}	0.3003 ^{A}	0.2858 ^{A}
	control	5.279 ^{ab}	5.220 ^{abc}	37.13 ^{abc}	22.85 ^{c}	0.2787 ^{ab}	0.3048 ^{ab}
Normal Watering	Kao-1	4.909 ^{ab}	4.809 ^{abc}	35.20 ^{bcd}	23.10 ^{c}	0.2584 ^{b}	0.2702 ^{ab}
	Kao-2	5.845 ^{ab}	5.780 ^{abc}	31.03 ^{d}	29.78 ^{abc}	0.3096 ^{ab}	0.3217 ^{ab}
	control	4.924 ^{ab}	4.866 ^{abc}	38.47 ^{ab}	23.27 ^{c}	0.2606 ^{b}	0.2657 ^{ab}
DI-Veg.	Kao-1	4.804 ^{ab}	4.730 ^{abc}	32.13 ^{cd}	24.93 ^{bc}	0.2753 ^{ab}	0.2770 ^{ab}
	Kao-2	3.475 ^{b}	4.369 ^{bc}	37.17 ^{abc}	29.58 ^{abc}	0.2650 ^{b}	0.2685 ^{ab}
	control	6.238 ^{a}	6.243 ^{ab}	38.13 ^{ab}	30.28 ^{abc}	0.3211 ^{ab}	0.3410 ^{ab}
DI-Flow.	Kao-1	5.049 ^{ab}	4.384 ^{bc}	41.80 ^{a}	28.75 ^{abc}	0.3028 ^{ab}	0.3272 ^{ab}
	Kao-2	6.632 ^{a}	6.951 ^{a}	37.30 ^{abc}	29.55 ^{abc}	0.4172 ^{a}	0.4142 ^{a}
DI-Ripen	control	4.344 ^{ab}	4.125 ^{bc}	37.98 ^{ab}	32.20 ^{ab}	0.2534 ^{b}	0.2785 ^{ab}

	Kao-1	5.271 ab	5.006 abc	33.92 bcd	34.55 a	0.2446 b	0.2838 ab
	Kao-2	4.435 ab	3.337 c	38.42 ab	34.98 a	0.2095 b	0.2258 b

*Values marked with the same letter(s) within the main and interaction impacts are statistically similar using Duncan's multiple range test. Uppercase letter(s) refer to differences within the main effects and lowercase letter(s) refer to differences within the interaction effects. DI-Veg. = single water stress at vegetative stage, DI-Flow. = single water stress at flowering, DI-Ripen = single water stress at ripening, Kao-1= 12.5 g / L Kao-2 = 25 g / L

Green pods MSI, Dry Material in Fresh Pods and Pods T. S. S. contents

Regarding the main effects of different irrigation systems; the highest average values on MSI were from DI-Ripen and DI-Flow., with an increase of 36.01 % and 30.05 % in SI, 35.48 % and 30.40 % in SII. As for percentage of dry material in fresh pods; DI-Veg. SI and DI-Ripen in SII gave the highest mean values with an increase of 29.03 % and 16.14 % respectively. DI-Ripen in SI gave the highest mean values on pods T. S. S. content, with an increase of 17.30 %, while no significant differences were observed in SII.

As for the main effects of foliar Kao-C spraying treatments; the control treatment without Kao-C gave the lowest average values on MSI and percentage of dry material in fresh pods in both seasons. While it gave the highest average values on pods T. S. S. content in SI, and no significant differences were observed in SII.

Regarding the interaction effect between the two study factors; the interaction between DI-Ripen with Kao-2 gave the highest mean values on MSI with an increase of 63.60 % and 71.17 % in both seasons respectively. As for percentage of dry material in fresh pods; the interaction between DI-Ripen without Kao-C gave the highest mean values in SI, but in SII DI-Flow., with Kao-1 gave the highest, with an increase of 60.04 % and 32.34 % respectively. As for pods T. S. S. content; the interaction between DI-Veg., with Kao-1 gave the highest mean values with an increase of 105.16 % and 51.06 % in both seasons respectively. While normal watering treatment without Kao-C gave the lowest mean values on MSI and percentage of dry material in fresh pods, in both seasons (Table 8).

Table 8. Main and interaction effects of deficit irrigation (DI) treatments and foliar application of Kaolin (Kao) on Green Pods Membrane stability index (MSI), Percentage of Dry Material in Fresh Pods (%) and Pods T. S. S. contents (mg $g^{-1\ D.W.}$) on common bean (*Phaseolus vulgaris* L.) during 2018 (SI) 2019 (SII) seasons.

Irrigation Treatments	Kaolin levels	Membrane Stability Index (%)		Percentage of Dry Material in Fresh Pods (%)		Pods T. S. S. content (mg $g^{-1\ D.W.}$)	
		SI	SII	SI	SII	SI	SII
Normal Watering		58.96 C*	59.70 C	11.23 D	11.34 C	3.682 AB	4.124 A
DI-Veg.		65.91 B	68.10 B	14.49 A	11.00 D	3.078 B	4.707 A
DI-Flow.		76.68 A	77.85 A	14.28 B	12.73 B	3.035 B	4.589 A
DI-Ripen		80.19 A	80.88 A	14.14 C	13.17 A	4.319 A	4.390 A
	control	65.63 B	66.86 B	13.33 C	11.81 C	4.214 A	4.237 A
	Kao-1	71.63 A	72.62 A	13.74 A	12.39 A	3.003 B	4.811 A
	Kao-2	74.03 A	75.42 A	13.53 B	11.96 B	3.369 B	4.309 A
	control	50.72 f	49.35 g	9.96 k	10.11 k	2.326 e	3.913 bc
Normal Watering	Kao-1	63.65 de	65.87 ef	11.38 j	10.96 i	3.229 abcde	4.381 bc
	Kao-2	62.52 e	63.88 ef	12.34 i	12.17 g	3.047 bcde	4.077 bc
	control	61.43 e	67.41 def	14.11 e	10.95 i	3.986 abcde	4.694 abc
DI-Veg.	Kao-1	62.82 e	61.94 f	15.17 b	11.94 h	4.772 a	5.911 a
	Kao-2	73.47 bc	74.95 bcd	14.19 d	10.87 j	2.921 cde	3.515 c
	control	71.27 cd	72.00 cde	14.11 e	12.55 e	3.411 abcde	4.259 bc
DI-Flow.	Kao-1	81.60 ab	83.19 ab	14.95 c	13.38 a	2.439 de	4.891 abc
	Kao-2	77.17 abc	78.37 abc	13.78 f	12.25 f	3.255 abcde	4.618 abc
	control	79.12 abc	78.70 abc	15.94 a	12.88 d	4.685 ab	4.084 bc
DI-Ripen	Kao-1	78.47 abc	79.47 abc	13.48 g	13.29 c	4.017 abcd	4.062 bc
	Kao-2	82.98 a	84.47 a	13.00 h	13.33 b	4.255 abc	5.024 ab

*Values marked with the same letter(s) within the main and interaction impacts are statistically similar using Duncan's multiple range test. Uppercase letter(s) refer to differences within the main effects and lowercase letter(s) refer to differences within the interaction effects. DI-Veg. = single water stress at vegetative stage, DI-Flow. = single water stress at flowering, DI-Ripen = single water stress at ripening, Kao-1= 12.5 g / L Kao-2 = 25 g / L

Green pods firmness and crispness

Regarding the main effects of different irrigation systems; the highest average values on pods firmness were from DI-Flow., in SI and DI-Ripen in SII, with an increase of 2.50 % and 13.48 % respectively. As for pods crispness, no significant differences were found in the SI, while the lowest mean values were obtained from DI-Ripen treatment, with a decrease of -20.27 %. As for the main effects of foliar Kao-C spraying treatments, no significant differences were found for both traits in both seasons.

Regarding the interaction effect between the two study factors; the interaction between normal watering and DI-Flow., with Kao-2 gave the highest mean values on pods firmness with an increase of 25.14 % and 24.51 % in SI, DI-Veg., with Kao-2 with an increase of 22.50 %

in SII, more than the control treatments. As for pods crispness; DI-Flow., without Kao-C gave the highest mean values with an increase of 3.85 % and 8.33 % in both seasons respectively.

Table 9. Main and interaction effects of deficit irrigation (DI) treatments and foliar application of Kaolin (Kao) on Pods Firmness (kg cm^{-2}) and Crispness (index) on common bean (*Phaseolus vulgaris* L.) during 2018 (SI) 2019 (SII) seasons.

Irrigation Treatments	Kaolin levels	Pods Firmness (kg cm^{-2})		Pods Crispness (index)	
		SI	SII	SI	SII
Normal Watering		3.122 AB*	2.678 B	4.111 A*	3.833 A
DI-Veg.		2.978 AB	2.928 AB	4.222 A	4.222 A
DI-Flow.		3.200 A	2.811 AB	4.056 A	3.889 A
DI-Ripen		2.839 B	3.039 A	4.111 A	3.056 B
	control	3.017 A	2.842 A	4.083 A	3.875 A
	Kao-1	2.996 A	2.763 A	4.000 A	3.917 A
	Kao-2	3.092 A	2.987 A	3.708 A	3.458 A
	control	2.717 bc	2.667 bc	4.333 ab	4.000 ab
Normal Watering	Kao-1	3.250 ab	2.600 c	4.167 abc	4.000 ab
	Kao-2	3.400 a	2.767 abc	3.833 abc	3.167 bc
	control	3.200 abc	2.783 abc	4.167 abc	4.167 ab
DI-Veg.	Kao-1	2.800 bc	2.733 abc	4.333 ab	4.167 ab
	Kao-2	2.933 abc	3.267 a	4.167 abc	4.167 ab
	control	2.983 abc	2.900 abc	4.500 a	4.333 a
DI-Flow.	Kao-1	3.233 ab	2.800 abc	4.167 abc	4.000 ab
	Kao-2	3.383 a	2.733 abc	3.500 bc	3.333 abc
	control	3.167 abc	3.017 abc	3.333 c	2.667 c
DI-Ripen	Kao-1	2.700 bc	2.917 abc	3.333 c	3.333 abc
	Kao-2	2.650 c	3.183 ab	3.333 c	3.167 bc

*Values marked with the same letter(s) within the main and interaction impacts are statistically similar using Duncan's multiple range test. Uppercase letter(s) refer to differences within the main effects and lowercase letter(s) refer to differences within the interaction effects. DI-Veg. = single water stress at vegetative stage, DI-Flow. = single water stress at flowering, DI-Ripen = single water stress at ripening, Kao-1= 12.5 g / L Kao-2 = 25 g / L

4. Discussion

The results of the current study are consistent with previous studies that indicated that severe drought reduces leaf nitrogen (N) and chlorophyll contents [38]–[42]. Where drought stress inhibits chlorophyll synthesis at different metabolic stages from the formation of 5-aminolevuliniuc acid to the synthesis of chlorophylls a and b along with their inclusion into developing pigment–protein complexes of the photosynthetic apparatus. However, it has been demonstrated for several species of agricultural plants that, carotenoids are less sensitive to drought stress than chlorophyll. Under water-stress, the foliar implement of kaolin, significantly, improved leaf chlorophyll content [43], [44].

As for photosynthetic efficiency (Fv/Fm and PI); the results were consistent with what was expected, as the highestvalues were often caused by the full irrigation treatment, especially with the higher concentration of Kao-C treatment, the results showed that Kao-C had a significant mitigating effect on the negative impact of DI on all traits studied. Water shortage during growth stage causes accelerated leaf senescence, oxidative damage to photo assimilatory machinery, and assimilates translocation, which leads to a deficiency of photosynthetic efficiency. A reduction in Fv/Fm, Fv/F0 and PI under deficit irrigation on squash, which were attributed to the reduction in leaf photosynthetic pigments and relative water content needed for photosynthesis. The same result also was reported on onion grown under deficit irrigation conditions [45], [46].

Plants exposed to water stress presented a significant decrease in chlorophyll content (SPAD), the quantum efficiency of photosystem II (*Fv/Fm*, *Fv/F0*, and PI) and water status (membrane stability index and relative water content) [6], [7], [47], [48]. Also it can be concluded from the above that the green pods contents of N, P, K, total chlorophyll, relative chlorophyll and carotene not affected much by DI treatments or foliar Kao-C spraying. While the DI treatments and Kao-C spraying had a positive effect on the green pods membrane stability and percentage of dry material in Fresh Pods. Pods firmness also increased as a result of DI treatments. This is in agreement with the results of several previous studies that concluded that under contrasting moisture regimes, seed N and protein contents were not that much affected by drought, seed N and protein contents had the lowest reductions under drought. The experimental results on green bean color revealed that as the irrigation frequency decreased (irrigation interval increased) greenness increased. When the pod color values were considered, it was concluded that the irrigation water amount has no effect on pod color values [38], [49], [50]. Several studies have shown that the kaolin treatments did not result in any significant effect on fruit soluble solids, firmness and starch index. There was no significant difference between the juice quality and total soluble solids (TSS) in fruits from the kaolin-sprayed trees compared with those in the unsprayed control [51]–[54].

5. Conclusions

In summary, the results suggest that the application of Kao-C can improve the chemical content and physiological properties of common bean leaves and pods under different levels of water stress. However, the magnitude of the effect varies depending on the severity of water stress and the concentration of Kao-C applied.

Author Contributions

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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