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Potential role of kaolin or potassium sulfate as anti-transpirant on improving physiological, biochemical aspects and yield of wheat plants under different watering regimes

Maha Mohamed Shater Abdallah[1*], Hala Mohamed Safwat El-Bassiouny[1] and Mohamed Aly AbouSeeda[2]

Abstract

Background and objective: Certain substances with some physical and chemical activities can be used to decrease the transpiration rate and alleviate plant water stress through rising leaf resistance to the diffusion of water vapor. Wheat plant is considered as one of the most important and economic winter plants. So, the objective of this work is to evaluate the response of wheat plants (*Triticum aestivum* L.) cultivar Gimeza 7 to various concentrations of foliar application of anti-transpirant substances as kaolin (3 and 6%), potassium sulfate (100 and 200 mg/l).

Materials and methods: Two pot experiments were conducted during 2016/2017 and 2017/2018 successive growing winter seasons under greenhouse conditions at the Experimental Station, in the National Research Centre, Egypt. The plants were exposed to various levels of water holding capacity (WHC) 80, 60, and 40%.

Results: Water stress led to a decrease in growth parameters, yield components, photosynthetic pigments, and carbohydrate contents as compared to 80% of WHC. Meanwhile, water stress caused significant increases in some compatible solute (total soluble sugar, free amino acids, and proline) and some antioxidant enzymes activities. Foliar treatments of wheat plants with kaolin or K_2SO_4 led to an increase in growth parameters, yield components, photosynthetic pigments, and carbohydrate constituents. More accumulation of the organic solutes of leaves (total soluble sugar and free amino acids), antioxidant enzyme activities, and some minerals (N, P, K, and Ca) was observed. Data also illustrated that the nutritional values of the grain yield of wheat were also improved when sprayed with kaolin and K_2SO_4.

Conclusion: The used substances are safe for the environment, and for the plant, potassium is an essential nutrient and its ability controls several biochemical and physiological responses in plants. Kaolin also can ameliorate plant physiology and consequently lead to higher yield production.

Keywords: Antioxidant enzymes, Kaolin, K_2SO_4, Wheat, Water stress

* Correspondence: maha_eg1908@yahoo.fr
[1]Botany Department, Agriculture and Biology Division, National Research Centre, 33 El Bohouth St. Dokki, P.O. Box 12622, Giza, Egypt
Full list of author information is available at the end of the article

Introduction

Water deficit is one of the main abiotic stresses, restricting the growth and productivity of plants and causes alternations in plant physiology and biochemistry (Bakry et al. 2016). It affects plant growth and development; decreases water potential, cell division, net photosynthesis, and protein synthesis; changes hormonal balance of the main plant tissue (Fathi and Tari 2016); and also leads to a loss in yield by reducing total biomass, relative water content, and chlorophyll content (Bakry et al. 2016). Drought stress resulted in the creation of reactive oxygen species (ROS) which lead to leave damage and so decreasing the crop growth and yield (Cakmak 2005).

Certain chemicals for several biological activities can be used to decrease the transpiration rate and alleviate plant water stress through rising leaf resistance to diffusion of water vapor. According to the mechanism of action, anti-transpirant is divided into different groups, which are film-forming types (that cover leaf surface with thin coat which is unrealizable to water vapor), reflecting materials (which reflect backward a part of the radiation downfall on the upper surface of the leaves), and stomatal closing kinds (that influence the metabolic operations in leaf tissues) (Conde et al. 2016). Film-forming and reflecting anti-transpirant were found to be non-toxic and have a longer period of effectiveness than metabolic types. Kaolin is a non-toxic aluminosilicate ($Al_4Si_4O_{10}$ $(OH)_8$) clay mineral. Kaolin spray reduces leaf temperature through rising leaf reflectance which decreases transpiration rate more than the photosynthesis of plants grown at high solar radiation levels (Nakano and Uehara 1996). Studies by Cantore et al. (2009) reported that on tomato and potato, the foliar application of kaolin suspension reduces plant stress that is essential for the best plant growth, yield, and quality.

Plants adopted various mechanisms to survive with different stresses. The usage of minerals plays an important role in plant resistance versus abiotic stresses. Potassium is a necessary nutrient and it controls several biochemical and physiological responses of plants (Wang et al. 2013). Among the nutrients, K plays an essential role in growth development and participates significantly towards the plants' survival under drought stress. Saifullah et al. (2002) reported also that potassium plays an important role in different enzyme activities, photosynthesis, protein synthesis, osmoregulation, energy transfer, stomata movement, cation-anion balance, and stress tolerance, and thus, it is necessary for plants' growth. It is predestined that K has taken the vital place for the wheat physiological necessities. Whereas, wheat plant is the most important cereal crop due to its stabilized diet for the world population and participative with more calories and protein to the world diet more than any other cereal crop.

In the present study, we aim to focus on the effect of kaolin as physical anti-transpirant and K_2SO_4 as chemical anti-transpirant at different water regimes on growth and yield components of wheat plants and to improve the efficiency of wheat plants to resist water stress.

Materials and methods

Experimental conditions, plant materials, growth, and treatment conditions

Greenhouse experiments were conducted in the National Research Centre during two successive winter seasons 2016/2017 and 2017/2018. Wheat grains (*Triticum aestivum*) cv. Gimeza 7 was obtained from Agriculture Research Centre Research Institute Giza, Egypt. Foliar application of wheat plants with anti-transpirant (kaolin and K_2SO_4) was used to improve wheat drought tolerance under different levels of regimes. Grains were grown in pots (diameter 50 cm), containing equal amounts of loam soil. The soil texture of the experimental site was loam and some physical and chemical properties of a representative soil sample are illustrated in Table 1 present in the Research Approach and Methodology according to the method described by Chapman and Pratt (1978).

Wheat grains were sown by the end of November. Fertilization was done with the recommended dose, i.e., (5 g phosphorous/pot as triple phosphate, 6 g nitrogen/pot as urea, and 5 g potassium/pot as potassium sulfate) during the preparation of pots after sowing. The second dose of fertilization was added after 45 days from sowing as super phosphate (5 g/pot), potassium sulfate (25 g/pot), and urea (6 g/pot) were used. The irrigation treatments were given to plants with different levels, 80%, 60%, and 40%, of water holding capacity (WHC). To adjust the water holding capacity at 80%, 60% and 40% and the amount of water required to reach this level, the pots were weighed every week and the difference was added.

Kaolin concentrations (0.0, 1, and 2%) and K_2SO_4 concentrations (0.0, 100, and 200 mg/l) were sprayed after 40 and 47 days of cultivation. Each treatment consisted of five replicates distributed in a completely randomized design system.

The treatments were as follows:

No.	Treatments		
1	Control at 80% of WHC	9	K_2SO_4 (100 mg/l) + 60% WHC
2	Kaolin 3% + 80% WHC	10	K_2SO_4 (200 mg/l) + 60% WHC
3	Kaolin 6% + 80% WHC	11	Control at 40% of WHC
4	K_2SO_4 (100 mg/l) + 80% WHC	12	Kaolin 3% + 40% WHC
5	K_2SO_4 (200 mg/l) + 80% WHC	13	Kaolin 6% + 40% WHC
6	Control at 60% of WHC	14	K_2SO_4 (100 mg/l) + 40% WHC
7	Kaolin 3% + 60% WHC	15	K_2SO_4 (200 mg/l) + 40% WHC
8	Kaolin 6% + 60% WHC		

Table 1 Physical and chemical soil properties of the experimental soil

Macronutrient (mg Kg^{-1})			Cation (meq l^{-1})				Anion (meq l^{-1})			
N	P	K	Na^{+}	K^{+}	Ca^{+}	Mg^{+}	CO_3^{-}	HCO_3^{-}	Cl^{-}	SO_4^{-}
168.8	11.65	423.15	9.13	0.468	1.45	0.25	0.00	2.145	2.842	6.3
Particle size distribution (%)				Texture class loam						
F. sand %	C. sand %	Silt %	Clay %	pH (1:2.5)	EC (1:5)	O.C (%)	O.M (%)	WHC (mg 100 g $soil^{-1}$)		
25.89	9.28	47.38	13.19	6.83	1.12	0.75	1.30	21.0		

After 15 days from sowing, thinning was carried out, so 10 uniform plants were left in each pot. Five plants from each pot were used throughout the experimental period for biochemical analysis and the remaining five seedlings were left to grow for studying the effect of different treatments on the yield. Watering was carried out according to the water holding capacity. Samples were taken after 75 days from sowing to take the growth parameters (plant height, number of leaves/tiller, tiller fresh, and dry weight) and determine different biochemical aspects in plant leaves' photosynthetic pigments (chlorophyll a, chlorophyll b, and carotenoids), TSS, proline, free amino acids, lipid peroxi dation, antioxidant enzymes, nitrogen percentage, and the element compositions (potassium, sodium, calcium, and phosphorus). At harvest, the following characters were recorded on random samples of 10 plants to estimate the following characters: plant height (centimeters), spike length (centimeters), spike weight (grams), spikelet no./ spike, grain wt. (grams)/spike, and 1000 grains weight (grams), as well as the nutritive value of the grain yield, total carbohydrates percentage, protein percentage, nitrogen, phosphorus, and potassium and calcium contents.

Biochemical analysis

Photosynthetic pigments: total chlorophyll a and b and carotenoids contents in fresh leaves were determined using the method described by Lichtenthaler and Buschmann (2001). Total soluble sugars (TSS), were extracted and analyzed according to Homme et al., (1992) and Yemm, Willis, (1954). Determination of total carbohydrates carried out according to Herbert et al., (1971). Proline was assayed according to the method described by Bates et al. (1973). Free amino acid was determined with the ninhydrin reagent method of Yemm and Cocking (1955). Lipid peroxidation was determined by measuring the amount of produced malondialdehyde (MDA) by the thiobarbituric acid (TBA) reaction as described by Predieri et al. (1995). The antioxidant enzyme (peroxidase (POX, EC 1.11.1.7) activity was assayed spectrophotometrically by the method described by Kumar and Khan (1982). Superoxide dismutase (SOD, EC 1.12.1.1) and catalase (CAT, EC 1.11.1.6) activity assayed spectrophotometrically by following the decrease in absorbance at 560 and 240 nm, respectively, according to Chen and Wang (2006). Total N was determined by using the micro-Kjeldahl method as described in AOAC (1970). Macro- element contents of the leaves and yielded grains were determined according to Chapman and Pratt (1978). Phosphorus was determined using a Spekolspectro colorimeter (VEB Carl Zeiss; Jena, Germany), while the estimation of K+ contents was done using a flame photometer.

Statistical analysis

The experimental design is a factorial experiment with two factors in a completely randomized design. The two factors were watering regimes and anti-transpirant substances using kaolin and potassium sulfate. The irrigation regimes were maintaining wheat plants at different levels of 80%, 60%, and 40% of water holding capacity (WHC). The anti-transpirant substances utilized kaolin concentrations at 0.0, 3, and 6% and potassium sulfate at 0.0, 100, and 200 mg/l. The data were statistically analyzed according to Snedecor and Cochran (1980); combined analysis of the two growing seasons was carried out. Means were compared by using the least significant difference (LSD) at 5% levels of probability.

Results

Plant growth

Table 2 showed the influence of the foliar application of different concentrations of kaolin and K_2SO_4 on growth criteria of wheat plants subjected to different levels of water holding capacity (WHC). Exposure of plants to 60% and 40% of WHC in the soil induced significant decrease in the morphological parameters (plant height, number of leaves/plant, plant fresh, and dry weight) when compared to a plant grown under 80% WHC. Treatment of wheat plants with different concentrations of kaolin and K_2SO_4 significantly increased all growth criteria under different water levels as compared with the corresponding WHC. Maximum increases in plant fresh and dry weight were obtained by using high concentration K_2SO_4 (200 mg/l) and kaolin 6% under different WHC levels.

Table 2 Effect of different concentrations of kaolin or K_2SO_4 under different levels of water holding capacity on morphological criteria and area of stomata (upper and lower epidermis) of wheat plants after 75 days from sowing combined analysis of two seasons)

WHC (%)	Treatment	Plant height (cm)	Leaf no./ tiller	Tiller Fr. wt. (g)	Tiller Dr. wt. (g)	Amount of water (g)	Stomatal area μm^2	
							Upper	Lower
80%	Control	52.63	5.33	3.542	0.981	2.561	166	100
	Kaolin 3%	54.52	5.50	5.121	1.238	3.883	154	96
	Kaolin 6%	62.66	6.33	6.523	1.265	5.258	131	123
	K_2SO_4 (100 mg/l)	69.23	6.00	6.306	1.220	5. 086	200	105
	K_2SO_4 (200 mg/l)	65.70	6.00	6.490	1.300	5.190	183	90
60%	Control	57.63	5.03	3.422	0.953	2.469	118	64
	Kaolin 3%	59.54	6.00	5.401	1.088	4.313	110	73
	Kaolin 6%	58.30	5.33	5.660	1.185	4.475	92	54
	K_2SO_4 (100 mg/l)	64.77	5.67	5.583	1.131	4.452	108	85
	K_2SO_4 (200 mg/l)	62.00	5.67	5.784	1.268	4.516	69	42
40%	Control	55.67	4.69	3.117	0.792	2.325	29	26
	Kaolin 3%	64.53	5.33	4.405	0.834	3.571	38	31
	Kaolin 6%	64.23	5.67	4.483	0.882	3.601	36	28
	K_2SO_4 (100 mg/l)	59.90	5.80	4.461	0.848	3.613	64	44
	K_2SO_4 (200 mg/l)	61.67	5.83	4.620	0.893	3.727	35	28
LSD at 5%		0.07	0.10	0.071	0.071	0.033	0.041	3.90

Stomata opening area

In the present work, leaf stomatal area was significantly reduced with decreasing WHC percentage and with different treatments, as shown in (Table 2). The application of kaolin induced significant decrease in the stomata opening at upper and lower epidermis as compared with the corresponding control at 80% WHC except for kaolin at 6% induced significant increase in the lower epidermis. K_2SO_4 induced significant increase in the stomata opening in the upper and lower epidermis as compared to the control except for K_2SO_4 (200 mg/l) at the lower epidermis. At 60% WHC, kaolin (3%) and K_2SO_4 (100 mg/l) induced significant increase in the stomatal area of the lower epidermis, while the upper epidermis induced significant decrease as compared with the corresponding controls. On the other hand, kaolin (6%) and K2SO4 (200 mg/l) at 60% WHC induced the significant decrease in the stomata opening in the upper and lower epidermis as compared with the corresponding controls. At 40% WHC, kaolin and K_2SO_4 induced significant increase in the stomatal opening area in both upper and lower epidermis as compared with the controls at 40% WHC.

Photosynthetic pigments

The data given in Table 3 illustrated the influence of different concentrations of kaolin and K_2SO_4 on photosynthetic pigments (chlorophyll a, chlorophyll b, carotenoids, and total pigments) in wheat leaves under different levels of WHC. The decrease in WHC of soil to 60% and 40% induced significant reduction in photosy nthetic pigments as compared to 80% of water holding capacity (WHC). Wheat plants treated with different concentrations of kaolin and K_2SO_4 significantly increased photosynthetic pigments under different water levels as compared with the corresponding WHC. Maximum increases in total pigments were obtained by using 6% kaolin at 80% WHC, 3% kaolin at 60% WHC, and K_2SO_4 200 mg/l at 40% WHC. The ratio of increase was 12%, 9%, and 16%, respectively, as compared with the corresponding WHC levels.

Carbohydrates, proline, and free amino acid contents

The results in Table 4 illustrated that decreasing WHC to 60% and 40% induced an accumulation of compatible solutes (total soluble sugar proline and free amino acid) in plants. Treatment of wheat plants with different concentrations of kaolin and K_2SO_4 induced an additive increases in TSS and free amino acid content as compared with the corresponding control at WHC level. Concerning proline, K_2SO_4 induced an increase, while kaolin led to a decrease of 60% and 40% of WHC. Exposure of plants to 60% and 40% of WHC in the field conditions induced significant decrease in total carbohydrate contents as compared to 80% of water holding capacity. Foliar spray of different concentrations of kaolin and K_2SO_4 to wheat plants under the various levels of WHC caused an

Table 3 Effect of different concentrations of kaolin or K_2SO_4 under different levels of water holding capacity on photosynthetic pigments (μg/g fresh weight) of wheat plants after 75 days from sowing (combined analysis of two seasons)

WHC (%)	Treatment	Chl a	Chl b	Carotenoids	Total pigments
80%	Control	11.63	12.05	3.63	27.31
	Kaolin 3%	11.60	12.17	3.44	27.21
	Kaolin 6%	14.25	13.25	3.33	30.84
	K_2SO_4 (100 mg/l)	14.46	10.96	4.06	29.48
	K_2SO_4 (200 mg/l)	14.54	10.15	4.08	28.77
60%	Control	12.59	9.51	4.29	26.39
	Kaolin 3%	14.50	10.18	4.12	28.80
	Kaolin 6%	14.53	9.30	4.27	28.10
	K_2SO_4 (100 mg/l)	14.36	8.69	4.39	27.45
	K_2SO_4 (200 mg/l)	14.52	9.49	4.36	28.36
40%	Control	10.53	7.45	4.79	22.77
	Kaolin 3%	12.07	7.88	4.51	24.46
	Kaolin 6%	13.60	7.32	4.96	25.88
	K_2SO_4 (100 mg/l)	12.61	8.53	4.53	25.67
	K_2SO_4 (200 mg/l)	13.64	8.42	4.49	26.55
LSD at 5%		0.21	0.26	0.19	0.35

Table 4 Effect of different concentrations of kaolin or K_2SO_4 under different levels of water holding capacity on total soluble sugar (TSS), proline, and free amino acid (FAA) (mg/100 g dry weight) and carbohydrate contents (mg/g dry weight) of wheat plants after 75 days from sowing (combined analysis of two seasons)

WHC (%)	Treatment	TSS	Carbohydrates	Proline	FAA
80%	Control	1370	270.7	139.4	256.4
	Kaolin 3%	1514	288.3	237.2	328.4
	Kaolin 6%	2172	318.8	146.8	458.3
	K_2SO_4 (100 mg/l)	1606	339.4	157.6	364.1
	K_2SO_4 (200 mg/l)	2035	363. 8	196.3	335.3
60%	Control	1638	340.8	179.2	387.5
	Kaolin 3%	2215	356.7	169.8	472.2
	Kaolin 6%	1999	392.9	142.5	529.0
	K_2SO_4 (100 mg/l)	1927	366.4	183.9	482.7
	K_2SO_4 (200 mg/l)	2114	363.0	201.4	480.2
40%	Control	1610	314.5	229.0	534.4
	Kaolin 3%	2012	323.3	202.3	588.7
	Kaolin 6%	1744	346.5	151.6	665.1
	K_2SO_4 (100 mg/l)	1726	339.5	229.8	540.4
	K_2SO_4 (200 mg/l)	1988	364.3	331.1	834.0
LSD at 5%		20.1	13.01	6.47	6.86

increase in the carbohydrate contents as compared with the corresponding WHC levels (Table 4).

Lipid peroxidation

Results revealed that wheat plant exposed to 60% and 40% of WHC showed a gradual and significant increase in malondialdehyde (MDA) compared to a control plant at 80% of WHC (Table 5). The high level of MDA concentration in plant leaves indicated that it is affected by water stress exhibited by lipid peroxidation, which resulted in membrane damage. However, the plants that subjected to K_2SO_4 or kaolin exhibited lower values for MDA content as compared with the corresponding controls at WHC levels.

Antioxidant enzyme

The change in the activity of peroxidase (POX), in the leaves of wheat plants exposed to water stress (60% and 40% WHC) were significantly increased, as compared with control plants particularly at 80% of WHC (Table 5). The super oxide dismutase (SOD) and catalase (CAT) were decreased by decreasing the WHC from 60% to 40%. Application of kaolin or K_2SO_4 under water stress conditions (60% and 40%), POX, SOD, and CAT activities were markedly enhanced as compared to control plants. The maximum increase in SOD activity was recorded in plants sprayed with K_2SO_4 (100 mg/l), whereas POX activity was observed in plants treated

Table 5 Effect of different concentrations of kaolin or K_2SO_4 under different levels of water holding capacity on lipid peroxidation (μg malondialdehyde/g fresh weight) and antioxidant enzyme activity (g fresh weight/h) of wheat plants after 75 days from sowing (combined analysis of two seasons)

WHC (%)	Treatment	Lipid peroxidation	POX	SOD	CAT
80%	Control	20.87	26.04	96.24	96.84
	Kaolin 3%	17.12	36.84	84.48	23.82
	Kaolin 6%	16.32	33.49	82.36	48.96
	K_2SO_4 (100 mg/l)	15.74	46.44	56.27	81.18
	K_2SO_4 (200 mg/l)	17.18	64.14	45.66	66.60
60%	Control	21.82	46.14	24.81	25.40
	Kaolin 3%	19.72	68.67	55.58	43.86
	Kaolin 6%	18.91	48.98	44.58	82.04
	K_2SO_4 (100 mg/l)	16.84	46.59	78.44	86.82
	K_2SO_4 (200 mg/l)	17.64	58. 34	63.33	122.46
40%	Control	25.74	41.67	21.00	20.14
	Kaolin 3%	21.56	64.52	44.34	87.98
	Kaolin 6%	20.80	45.51	86.18	114.58
	K_2SO_4 (100 mg/l)	22.34	52.62	140.79	69.78
	K_2SO_4 (200 mg/l)	21.18	44.90	118.92	71.58
LSD at 5%		0.20	4.01	4.67	4.67

with 3% kaolin. The highest CAT activity was observed in plants treated with K_2SO_4 (200 mg/l) particularly at 60% WHC and kaolin 6% at 40% WHC as well.

Minerals nutrition contents

The decrease of WHC to 60% and 40% in the soil induced significant increases in N percentage, K percentage ,and Ca percentage as compared to 80% of WHC. However, P and Na showed a significant increase particularly at 60% of WHC and then decrease at 40% of WHC as compared to 80% of WHC (Table 6). Foliar spray at different concentrations of kaolin and K_2SO_4 to wheat plants under various levels of WHC caused a significant increase in the N, K, and Ca percentage as compared with the corresponding WHC levels (Table 6), while P and Na contents induced variable changes at different WHC levels.

Yield components

The results in Table 7 showed the influence of different concentrations of kaolin and K_2SO_4 on yield parameters of wheat plants under various water holding capacity levels. Exposure of plants to 60% and 40% of WHC leads to a significant decrease in all yield parameters studied as compared to 80% of WHC except the plant height. Treatment of wheat plants with different concentrations of kaolin and K_2SO_4 increased all yield parameters under different water levels as compared with the corresponding controls of WHC. The maximum increases in grain weight/spike and weight of 1000 grains were obtained by using 200 mg/l K_2SO_4 as compared to the corresponding controls at WHC levels. The percentages of increase were 60%, 42%, and 36% in grain weight/spike and 20%, 25%, and 16% weight of 1000 grains at 80%, 60%, and 40% WHC, respectively, as compared with the corresponding controls at WHC levels.

Table 6 Effect of different concentrations of kaolin or K_2SO_4 under different levels of water holding capacity on N, P, K, Na, and Ca percentage of wheat plants after 75 days from sowing (combined analysis of two seasons)

WHC (%)	Treatment	N %	P %	K %	Na %	Ca %
80%	Control	2.594	0.277	0.460	0.105	0.297
	Kaolin 3%	2.991	0.284	0.656	0.232	0.566
	Kaolin 6%	3.296	0.335	0.632	0.118	0.542
	K_2SO_4 (100 mg/l)	3.418	0.284	0.712	0.334	0.481
	K_2SO_4 (200 mg/l)	3.296	0.292	0.696	0.118	0.301
60%	Control	3.010	0.285	0.604	0.188	0.376
	Kaolin 3%	3.991	0.239	0.708	0.139	0.470
	Kaolin 6%	3.662	0.299	0.652	0.121	0.397
	K_2SO_4 (100 mg/l)	3.510	0.250	0.637	0.146	0.470
	K_2SO_4 (200 mg/l)	3.552	0.276	0.648	0.117	0.393
40%	Control	3.115	0.243	0.652	0.086	0.373
	Kaolin 3%	3.205	0.216	1.268	0.141	0.446
	Kaolin 6%	3.906	0.207	0.696	0.130	0.446
	K_2SO_4 (100 mg/l)	3.784	0.267	0.658	0.117	0.395
	K_2SO_4 (200 mg/l)	3.662	0.205	0.660	0.112	0.434
LSD at 5%		0.005	0.022	0.006	0.037	0.007

Carbohydrate percentage and protein percentage of grain yield

The reduction of WHC to 60% and 40% in the soil induced significant decreases in the percentage of carbohydrates percentage and protein percentage in the yielded grains as compared to 80% of water holding capacity. Foliar spray of different concentrations of kaolin and K_2SO_4 to wheat plants under the different levels of WHC caused an increase in the carbohydrate percentage and protein percentage as compared with the corresponding WHC levels (Table 8).

Mineral nutrients in grain yield

The decrease of WHC to 60% and 40% in the soil induced significant increases in N, K^+, and Ca^{2+} % in 60% WHC and then decreases at 40% WHC as compared to 80% of water holding capacity. Foliar spray of different concentrations of kaolin and K_2SO_4 under different levels of WHC caused a significant increase in the percentage of N, K^+, and Ca as compared with the corresponding WHC levels (Table 8**)**, while phosphorus induced a non-significant change.

Discussion

Plant growth

The exposure of plants to 60% and 40% WHC led to a marked decrease in all morphological parameter. The reduction in the growth parameters may be attributed to losses of tissue water which inhibited cell division and enlargement, or possibly to a decrease in the activity of meristematic tissues responsible for elongation (Siddique et al. 1999; El Sebai et al. 2016). Moreover, total FW and DW decreased due to the exposure to low levels of drought which might have resulted from a reduction in chlorophyll content and consequently, photosynthetic efficiency (Bakry et al. 2012).

The data in Table 2 illustrated that foliar application of different concentrations of kaolin and K_2SO_4 induced significant increases on growth criteria. Whereas, kaolin led to the reduction in the transpiration rate that led to keep higher water content in the plant tissues and hence might favor the plant metabolism, the physiological processes, photosynthetic rate, carbohydrate metabolism, and many other important functions that directly affect plant growth. In this respect, studies conducted on tomato and potato showed that kaolin application

Table 7 Effect of different concentrations of kaolin or K_2SO_4 under different levels of water holding capacity on yield components of wheat plants (combined analysis of two seasons)

WHC (%)	Treatment	Plant height (cm)	Spike length (cm)	Spike wt. (g)	Spikelet no. /spike	Grain no./spike	Grain wt. (g)/spike	Weight of 1000 grains (g)
80%	Control	63.51	10.33	1.82	14.00	36.50	1.415	39.62
	Kaolin 3%	64.62	11.67	2.04	16.33	39.33	1.543	39.81
	Kaolin 6%	66.03	12.33	2.15	15.67	43.50	1.950	44.23
	K_2SO_4 (100 mg/l)	70.14	12.33	2.48	16.33	45.67	2.099	45.15
	K_2SO_4 (200 mg/l)	69.00	12.00	2.43	15.33	49.33	2.271	47.68
60%	Control	58.33	10.00	1.79	14.00	33.50	1.311	38.43
	Kaolin 3%	61.88	13.00	2.33	15.67	38.40	1.576	41. 36
	Kaolin 6%	62.60	13.33	2.45	15.00	44.50	1.843	42.83
	K_2SO_4 (100 mg/l)	61.00	12.33	2.26	14.33	41.00	1.855	44.99
	K_2SO_4 (200 mg/l)	61.33	12.67	2.73	14.33	40.33	1.896	48.00
40%	Control	57.00	9.33	1.64	14.00	26.67	1.149	35.94
	Kaolin 3%	59.33	10.33	2.00	14.33	29.67	1.289	39.32
	Kaolin 6%	58.07	13.00	1.91	13.67	32.33	1.297	40.66
	K_2SO_4 (100 mg/l)	59.00	12.33	1.95	14.33	36.67	1.554	41.20
	K_2SO_4 (200 mg/l)	59.67	12.00	1.98	14.00	34.33	1.559	41.59
LSD at 5%		2.39	0.36	0.15	0.67	3.28	0.008	0.23

gradually decreases plant stress, which is vital for plant growth and quality of yield Cantore et al. (2009). Moreover, Segura-Monroy et al. (2015) observed that kaolin enhanced the plant height, and plant dry weight, of *Physalisperuviana* L. seedlings. Khalil (2006) reported that all anti-transpirants (film-forming, stomata, and reflecting) significantly increased all growth parameters of sesame (*Sesamum indicum*) plants compared with the control treatment.

Potassium is required for the plant growth; it plays an essential function in enzyme activities, stomatal opening and closing mechanism, and photosynthesis (Golldack et al. 2003). Abdelaziz and Abdeldaym (2018) demonstrated that foliar potassium rates resulted in significant increases in

Table 8 Effect of different concentrations of kaolin or K_2SO_4 under different levels of water holding capacity on carbohydrate percentage, protein percentage, and elements (N, P, K, and Ca %) of wheat grains (combined analysis of two seasons)

WHC (%)	Treatment	Carbohydrates %	Protein %	N %	P %	K %	Ca %
80%	Control	52.76	12.11	1.94	0.38	0.42	0.017
	Kaolin 3%	58.93	13.96	2.23	0.39	0.47	0.023
	Kaolin 6%	55.27	14.13	2.26	0.41	0.42	0.026
	K_2SO_4 (100 mg/l)	56.88	14.39	2.30	0.41	0.42	0.069
	K_2SO_4 (200 mg/l)	57.66	15.01	2.40	0.44	0.48	0.021
60%	Control	46.19	12.47	2.00	0.40	0.46	0.023
	Kaolin 3%	48.50	14.26	2.28	0.40	0.48	0.023
	Kaolin 6%	54.34	13.74	2.20	0.40	0.48	0.028
	K_2SO_4 (100 mg/l)	52.68	14.31	2.29	0.45	0.47	0.046
	K_2SO_4 (200 mg/l)	50.77	14.26	2.28	0.41	0.46	0.048
40%	Control	43.49	12.03	1.93	0.37	0.41	0.012
	Kaolin 3%	47.66	12.91	2.07	0.41	0.42	0.020
	Kaolin 6%	46.89	13.52	2.16	0.38	0.44	0.016
	K_2SO_4 (100 mg/l)	47.98	13.21	2.11	0.38	0.48	0.017
	K_2SO_4 (200 mg/l)	47.23	14.48	2.32	0.40	0.47	0.015
LSD at 5%		1.45	1.45	0.13	n.s	0.05	0.003

cucumber growth. Potassium plays a vital role in improving the photosynthetic capacity, water used efficiency, participatory in the biosynthesis of metabolic compounds, and improving in plant growth.

Stomata opening area

Leaf stomatal area was negatively affected by drought and the different treatments used that is reliable with the results of wheat leaves (Table 2). Several studies showed that drought induced a decrease in stomatal size (Martinez et al. 2007; Xu and Zhou 2008) indicating that such a phenomenon may increase the adaptation of plants to drought. Plant response to drought stress is the decrease in leaf area and plant growth that lets plants to lowering their transpiration, in consequences increasing water use efficiencies and raising interspecies competition ability under drought (Aguirrezabal et al. 2006).

Anti-transpirants were classified according to their action role: metabolic materials which are chemical compounds such as K_2SO_4 that prevents stomatal opening completely by stimulating the guard cells around the stomata pore. So, it leads to the inhibition of the loss of water vapor from plant leaves (Anjum et al. 2011). MacRobbie (2006) demonstrated that potassium accumulating in guard cells in large quantity mainly in vacuole leads to stomata opening. Accumulation of K^+ into the vacuole against the electrochemical gradient is necessary to generate sufficient turgor for stomatal opening.

Kaolin may be used as a foliar anti-transpirant in a form of water emulsion; it forms a thin film on leaves, which polymerizes under the effect of sunlight, reaching high resistance and elasticity. Such film reduces the escape of water from the plant by decreasing stomatal conductance, decreasing transpiration losses, improving plant water status, and decreasing wilting and leaf abscission. It is considered as a safe substance for the environment (Faralli et al. 2016).

Photosynthetic pigments

Treatment of wheat plants with different concentrations of kaolin and K_2SO_4 significantly increased photosynthetic pigments under different water levels as compared with the corresponding WHC (Table 3). The water stress that affects plant development has a negative response to photosynthesis (Abd Allah et al. 2016). Drought stress disrupts the photosynthetic pigments producing irreversible damage to the photosynthetic apparatus, decreasing gas exchange, leading to a decrease in plant growth and productivity (Anjum et al. 2011). The inhibition in chlorophyll content in most stressed plants might be due to the disorganization of thylakoid membranes, with more degradation than a synthesis of chlorophyll through the formation of proteolytic enzymes, like chlorophyllase, that is responsible for degrading chlorophyll and damaging the photosynthetic apparatus (Rong-Hua et al. 2006). Ripley et al. (2007) found that water stress might reduce photosynthetic assimilation by both stomatal and metabolic limitations.

Foliar application of kaolin evaluates its ability to decrease the negative effects of water stress and to improve the physiology and productivity of plants and alleviates the adverse effects of water stress on photosynthesis in almond trees or walnut trees (Rosati et al. 2006). Denaxa et al. (2012) found that kaolin improved the photosynthetic rate under water-deficit conditions by increasing photosynthesis levels in olive plants. Moreover, Lombardini et al. (2005) observed a positive effect on the chlorophyll index after treatment with kaolin. This increment in chlorophyll content might be because of the reality that leaves not treated with kaolin could show a lower light reflectance, indicating an increased degradation of the photosynthetic pigments (Dinis et al. 2016). Recently, it has been found that kaolin treatment in a grapevine plant increased photochemical reflectance and photosynthetic pigments (Dinis et al. 2018).

Treatment of wheat plants with different concentrations of K_2SO_4 significantly increased photosynthetic pigments under different water levels. Asgharipour and Heidari (2011) found that treatment with K_2SO_4 increased significantly the chlorophyll content with an increase in K supply and increase in the frequency of irrigation. In addition, K plays an important role in the formation of photosynthetic pigment by preventing decomposition of newly formed Chl and δ-aminolevulinic acid (ALA) synthase formation (Tanaka and Tsuji 1980). These results indicate that the application of K+ is connected with the tolerance of wheat plants to water stress by enhancing the biosynthesis of photosynthetic pigments.

Carbohydrates, proline, and free amino acid

The data in (Table 4) also demonstrated that the application of potassium sulfate had a significant effect on carbohydrate accumulation in wheat plants under water stress. It has been reported that the total soluble carbohydrates increased under drought stress, which played an important role in osmotic adjustment, carbon storage, and radical scavenging in two linseed varieties (Bakry et al. 2012). Cherel (2004) demonstrated that K played an important role in the balancing of membrane potential and turgor, activating enzymes, and regulating osmotic pressure and stomata movement. Furthermore, K improves the solute accumulation, reducing the osmotic potential, and preserves the cell turgor even under water-limited conditions Marschner (2012).

In addition, Abd Allah et al. (2016) and El Bassiouny et al. (2018) reported the accumulation of proline in plant tissues because of various abiotic stresses which might play an important part against oxidative damages caused by reactive oxygen spices (ROS) owing to its action as a single oxygen quencher.

Treatment of wheat leaves with kaolin caused a marked decrease in proline accumulation as compared with the corresponding control plants. The decrease in proline content by anti-transpirant treatments is likely to be due to a direct increase of mRNA protein synthesis (Shanan and Shalaby 2011). Kaolin-treated plants showed lower contents of proline (Dinis et al. 2016), which supports the thought that this particle film is a protecting factor for wheat growing under drought and high-temperature conditions. On the other hand, foliar application with anti-transpirant kaolin positively affected proline of the tested plants compared with control treatment (El Mantawy and El Bialy 2018). Dayer et al. (2013) reported that the application of kaolin gradually increases the accumulation of carbohydrates reserved in the perennial tissue. Ibrahim and Selim (2010) suggested that a foliar spray with kaolin reduced the transpiration rate, which in turn maintained higher water content in plant tissues, possibly favoring plant metabolism, physiological processes, photosynthetic rate, carbohydrate metabolism, and many other important functions that directly affect plant growth. Recently, kaolin treatment in grapevine plant increased soluble proteins, soluble sugars, and starch concentrations (Dinis et al. 2018).

Lipid peroxidation

Results revealed that wheat plant exposed to 60% and 40% of WHC showed a gradual and significant increase in malondialdehyde (MDA) compared to a control plant at 80% of WHC (Table 5). This may be due to the proline accumulation and antioxidant enzymes activity (Tables 4 and 5) which has an adaptive significance, as they detoxify the oxygen free radicals and so decreasing the oxidative stress-related membrane failure under water stress. At the same time, potassium plays a key role in lowering ROS production by decreasing the activity of NAD (P) H oxidases and preserving photosynthetic electron transport (Cakmak 2005).

The effects of kaolin application on lipid peroxidation in the wheat leaf are shown in (Table 5). Kaolin exhibited low values for MDA content as compared with the corresponding control at WHC percentage. The application of kaolin induced the activation in the antioxidant systems to decrease the lipid peroxidation compared to the control. It is recognized that lipid peroxidation could produce cellular damage by reacting with other lipids, proteins, and nucleic acids and prevent membrane injury in some plants (Beis and Patakas 2012; El Bassiouny et al. 2018). In addition, kaolin treatment decreased lipid peroxidation reactive substances in grapevine plant (Dinis et al. 2018).

Antioxidant enzymes

Drought stress can promote ROS production which induced the degradation of proteins and membranes, decreasing photosynthesis and plant growth (El Bassiouny et al. 2018). POX and CAT convert H_2O_2 into water and molecular oxygen, which are harmless to plants (Moller et al. 2007). These results were in good harmony with the results obtained by Bernardo et al. (2017). Kaolin particle film could induce SOD and CAT activities under stress. POX, APX, and CAT considerably increased SOD activity under salt stress to convert O_2^- to H_2O_2 that is consequently detoxified (Singh et al. 2012). Moreover, berries treated with kaolin have been correlated with a lowering of ROS, supporting the alleviation of adverse abiotic climatic stresses (Dinis et al. 2016).

There was an increment in CAT activity with increasing K levels. The increasing rates adversely affected the activities of SOD in wheat plants (Marques et al. 2014) and in eggplants.

Minerals nutrition

The results in Table 6 demonstrated that foliar spray at different concentrations of kaolin and K_2SO_4 on wheat plants under various levels of WHC caused a significant increase in the N, K, and Ca contents as compared with the corresponding WHC levels, while P was gradually decreased.

Bafeel and Moftah (2008) suggested that foliar spray with kaolin could lead to a reduction in the transpiration rate, which in turn maintained higher water content in the plant tissues and increased the mobility of nutrient to plants.

Potassium application significantly influenced the leaf potassium and sodium concentration in wheat plants (Table 6). The reduction in sodium content could be attributed to potassium competition with sodium for binding sites on the plasma membrane that repressed Na absorption (Al-Uqaili 2003). Application of potassium sulfate gradually increases the uptake of essential nutrients, N, P, K and Ca, that could increase metabolic activities, which enhanced growth and productivity (Ashraf et al. 2015). Hussain et al. (2013) stated that potassium is an essential nutrient element for plant growth.

Yield components

The results in Table 7 showed the influence of different concentrations of kaolin and K_2SO_4 on yield parameters of wheat plants subjected to different levels of WHC. It could be suggested that using anti-transpirant causes a covering layer on the surface foliage that decreased the transpiration rate. Furthermore, it keeps more water in plant tissues that would reflect a favorable effect on plant metabolism and photosynthetic rate and increased outward transportation of photosynthesis from the foliage of the tomato fruits, which is important for the best plant growth, yield, and quality (Cantore et al. 2009).

Kaolin application particularly under water stress conditions induced an increase in the yield of different crops (Coniberti et al. 2013). They included that both film-forming and stomata-closing compounds are capable to increase the leaf resistance to water vapor loss improving plant water use to assimilate carbon and production of biomass or yield (Tambussi and Bort 2007). Mohadeseh et al. (2013) reported that the sprayed kaolin at concentrations of 3.75% gradually increased the grain yield of wheat. Kaolin treatment of 1.25% gave the highest biological yield.

Ashraf et al. (2011) found that the application of K_2SO_4 stimulates wheat grain yield by improving growth conditions. Armita et al. (2017) observed the significant increases in yield components of tomato due to potassium fertilization. Also, Elayan et al. (2018) demonstrated that foliar potassium enhanced the plants' growth and the seed yield/fed of cotton plants.

Carbohydrate percentage and protein percentage of the grain yield

Foliar spray of different concentrations of kaolin and K_2SO_4 to wheat plants under the different levels of WHC caused increases in carbohydrate percentage and protein percentage as compared with the corresponding WHC levels (Table 8). Ibrahim and Selim (2010) suggested that foliar spray with kaolin reduced the transpiration rate, which in turn maintained higher water content in plant tissues, possibly favoring plant metabolism, physiological processes, photosynthetic rate, carbohydrate metabolism, and many other important functions that directly affect plant growth. Bernardo et al. (2017) suggested that kaolin may cause the global DNA de-methylation and consequently the regulation of transcriptional changes on genes associated to the DNA methylation/demethylation and lead to the formation of protein.

Potassium sulfate has a central role in the production of many important proteins which are necessary to report stress resistance in plants (Lee et al. 2009). The increase in yield and its components was due to the role of K for enhancing different enzyme activation, photosynthesis, protein synthesis, osmoregulation, energy transfer, stomatal movement, cation-anion balance, and stress resistance (Wang et al. 2013).

Mineral nutrients of the grain yield

Foliar spray of different concentrations of kaolin and K_2SO_4 under different levels of WHC caused a significant increase in N percentage, K percentage, and Ca percentage as compared with the corresponding WHC levels (Table 8). Decreasing soil moisture may decrease nutrient mobility and its availability. Erdal et al. (2007) obtained similar results on tomato. The data in Table 8 indicate that there is a significant increment percentage of N, P, K, and Ca concentrations compared with the untreated plants. The obtained results are consistent with the most previous investigations, which pointed out the same direct correlation between anti-transpirant materials and some element nutrient to tissues of soya bean (Yadav and Dashora 2003).

Kausar et al. (2016) reported that the nutrient uptake and accumulation such as Ca, Mg, K, and P were gradually increased by K application particularly under saline environments in both wheat genotypes. Abd El-Samad et al. (2018) found that the potassium application that increased significantly gained the highest percentage values of total soluble solids (TSS), protein, N, P, and K of bean plants.

Conclusion

This paper summarizes that kaolin and potassium sulfate ameliorated the adverse effects of water stress, enhanced wheat plant growth by affecting biosynthesis of the plant's bioactive compounds like compatible solute (total soluble sugars, proline, total free amino acid) and antioxidant enzyme activities (superoxide dismutase, catalase, peroxidase,), and decreased lipid peroxidation. Moreover, foliar application of kaolin or K_2SO_4 on wheat plants gave higher nutritional value, macronutrients (N, P, K, Ca), and carbohydrate and protein percentage in seed yield. Interestingly, the present study recommended that kaolin may ameliorate plant physiology and consequently led to a higher yield production, and it could be a safe substance for the environment. Potassium is a necessary nutrient and its ability controls some biochemical and physiological responses in plants.

Abbreviation

CAT: Catalase; POX: Peroxidase; K_2SO_4: Potassium sulfate; ROS: Reactive oxygen species; SOD: Superoxide dismutase; WHC: Water holding capacity

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Authors' contributions

MMSA, HMSE, and MAS designed the study, contributed to farming the plants, performed the experiment, are responsible for all the physiological and biochemical analysis, and also wrote and reviewed the manuscript. All authors read and approved the final manuscript.

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Author details
[1]Botany Department, Agriculture and Biology Division, National Research Centre, 33 El Bohouth St. Dokki, P.O. Box 12622, Giza, Egypt. [2]Plant Nutrition Department, Agriculture and Biology Division, National Research Centre, 33 El Bohouth St, Dokki, P.O. 12622, Giza, Egypt.

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