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Investigation of the Effects of Different Humic Acid Applications on Seedling Development of Rapeseed (*Brassica napus* L.) Under Salt Stress

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Abstract

Salt stress negatively impacts plant development in various ways. Some of these adverse effects manifest as impaired root and seedling growth and a decrease in chlorophyll content. However, fertilization can mitigate this damage. In recent years, many organic fertilizers, such as humic acid, have become preferred over chemical fertilizers. This study was designed to investigate the effects of applying humic acid at different doses on the seedling development of rapeseed (*Brassica napus* L.) under salt stress conditions in laboratory conditions. In the study, rapeseed (Süzer) was subjected to four different salt doses (0 (control), 75 mM, 150 mM, 225 mM) along with six different humic acid doses (0 (control), 2 kg da^{-1}, 4 kg da^{-1}, 6 kg da^{-1}, 8 kg da^{-1}, 10 kg da^{-1}) applied from the soil. The research was conducted in a factorial experimental design with three replications. As a result of the study, it was observed that increasing salt doses led to decreases in chlorophyll content, plant height, stem thickness, root length, root thickness, as well as fresh and dry weights of the plants. Furthermore, increased doses of applied humic acid were noted to have a positive effect. It was determined that the highest salt dose (225 mM) had the most significant adverse effect on the seedling development of the plants. However, it was found that the 4th and 5th applications of humic acid (6 kg da^{-1} and 8 kg da^{-1}) were more effective in reducing the effects of salt stress. The protective effects of humic acids on plants under salt stress are noteworthy. Research indicates that humic acids support plant growth and development under salty conditions and alleviate the negative effects of salt.

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1. Introduction

Rapeseed (*Brassica napus* L.) is one of the important oilseed crops grown in Turkey. Its early harvest provides raw material during the low capacity period of oil mills and fodder factories, allowing them to increase their operating capacities. Also suitable for second crop cultivation in suitable regions (Başalma, 2004). Rapeseed has both winter and summer forms and contains 38-50% oil and 16-24% protein in its seeds. Short vegetation period, high seed and oil yield (342 kg da^{-1}), the possibility of mechanization of all cultivation stages from sowing to harvest, and preventing the dominance of weeds by developing early are advantages that make rapeseed an important oil crop (Arslan et al., 2007; Tunçtürk, 2008).

However, salinity is a problem that is widely observed and negatively affects plant production in Turkey (Gürsoy, 2024). Salt stress is a major abiotic stress factor that plants are constantly exposed to throughout their lives (Omidi et al., 2022). Salt stress, which has a negative effect on plant growth and development, varies especially according to the type of salt, the level of stress, the duration of exposure, the type and developmental stages of the stressed plant (Kereçin and Öztürk, 2024). Salinity, arid and semi-arid regions makes it difficult to plant production and causes yield losses (Yılmaz et al., 2011; Gürsoy, 2020; Gürsoy, 2022). Salt stress leads to a decrease in water in the soil through osmotic stress and results in excessive ion uptake (especially Na^+ and Cl^-) (Abogadallah, 2010). Additionally, the increase in sodium ions (Na^+) in plant cells triggers the formation of reactive oxygen species (ROS). This leads to lipid peroxidation, membrane damage, nutrient imbalances, reduced photosynthetic activities, and enzymatic-metabolic disorders, ultimately resulting in plant death (Julkowska and Testerink, 2015; Khan et al., 2019). All of these factors negatively affect plant growth, leading to loss of yield and quality. Salt primarily increases osmotic pressure and causes ion stress, inhibiting protein synthesis and chlorophyll formation at the cellular level, while also increasing the synthesis of reactive oxygen species that disrupt membrane functions. Furthermore, it hinders the uptake of certain plant nutrients, disrupts the continuity of photosynthesis, and causes metabolic toxicity, thus inhibiting plant development (Çulha and Çakırlar, 2011).

In recent years, the use of organic fertilizers in plant production has increased. The main reason for this is that incorrect fertilization practices over the years have led to soil salinization (Çebi et al., 2018). Salinity negatively affects canola production and causes yield loss. Besides its important role in human nutrition, canola is also used in the biofuel, cosmetic, health, and livestock sectors. Moreover, it is considered an alternative crop to help reduce the country's oil deficit (Uyanık et al., 2014). With the significant increase in canola cultivation areas and production in recent years, it has become necessary to determine the salt tolerance of canola.

Although various strategies exist to combat salinity, in recent years, plant growth regulators have begun to be used to reduce salt stress in plants and minimize the damage caused by salinity (Kaydan and Yağmur, 2006). Humic substances are naturally occurring, heterogenous materials ranging from yellow to black in color, with high molecular weight and resistance to degradation (Akıncı, 2011). They exhibit buffer solution properties over a wide pH range in the soil and make micro-nutrients more accessible to plants (Karaman et al., 2012). Humic acid applications increase soil aeration and water retention capacity, support the development and proliferation of soil microorganisms, and enhance plant resistance to stress conditions, diseases, and pests (İçel, 2005).

This study aims to examine the effects of humic acid applied at different doses on the seedling growth of canola plants under salt stress.

2. Material and Methods

The study was carried out in the climate cabinet of the Field Crops Laboratory of Siirt University Faculty of Agriculture. To the rapeseed plant (Suzer), 4 different salt doses (0 (control), 75 mM, 150 mM, 225 mM) and 6 different humic acid doses (0 (control), 2 kg da^{-1}, 4 kg da^{-1}, 6 kg da^{-1}, 8 kg da^{-1}, 10 kg da^{-1}) was applied through the soil. The experiment was set up in 72 pots with 3 replications in a factorial experimental design in randomized plots. 5 seeds were planted in each pot and thinning was done to leave 1 plant after germination and the applications were made to reach field capacity by taking into account the water given.

Rapeseed (Süzer) variety obtained from the Thrace Agricultural Research Institute was used as plant material in the study.

2.1. Humic acid content

Organic matter (55%), total (humic + fulvic) acid (65%), water-soluble potassium oxide (10%), maximum moisture (20%) and pH range (8-10). In the study, which was carried out as a pot trial, peat/perlite (3/1) mixture was filled into 1-liter plastic pots. Applications were started after 100% emergence was achieved.

2.2. Climate chamber features

It has features where the temperature can be adjusted between –20 °C and +40 °C, the light intensity is 400 µmol m^{-2} s^{-1}, and the photoperiod (day $night^{-1}$) and humidity conditions can be adjusted as desired. For rapeseed cultivation, it was set to have an average temperature of 20±2 ºC, 70% humidity and 16 hours of light and 8 hours of dark environment.

2.3. Statistical analysis

The data obtained within the scope of the research were subjected to analysis of variance using a factorial experimental design in randomized plots. Tukey's Honestly Significant Difference (HSD) test was employed for grouping the means. Statistical calculations were performed using the JMP program.

3. Results and Discussion

In terms of SPAD, a significant difference was found with respect to humic acid and salt application direction, but the interaction between salt and humic acid was insignificant. The highest SPAD was obtained from the control (46.58) application in terms of salt application direction, and the lowest was obtained from the 225 mM (36.41) salt application. In terms of humic acid application dose, the highest SPAD was obtained from the 6 kg da^{-1} application with 45.18, and the lowest was obtained from the control and 10 kg da^{-1} applications with 39.26 and 39.31, respectively (Table 1).

Table 1. Averages for the SPAD values of canola plants regarding different salt doses, humic acid doses, and their interactions

Humic Acid Doses	Salt Concentrations				
	0	**75**	**150**	**225**	**Mean**
0 kg da^{-1}	41.70	41.00	40.33	34.00	**39.26 c**
2 kg da^{-1}	45.33	43.67	41.67	37.00	**41.92 bc**
4 kg da^{-1}	49.34	46.01	43.43	37.00	**43.94 ab**
6 kg da^{-1}	52.01	48.05	42.33	38.33	**45.18 a**
8 kg da^{-1}	46.34	44.02	40.50	37.00	**41.97 bc**
10 kg da^{-1}	44.73	41.33	36.02	35.13	**39.31 c**
Mean	**46.58 a**	**44.01 b**	**40.71 c**	**36.41 d**	**41.93**
LSD Salt					**2.62****
LSD Humic Acid					**3.05****
LSD Salt x Humic Acid interaction					**-**
CV					**8.86**

**: p<0.01

In terms of plant height, a significant difference was found with respect to humic acid and salt application direction, but the interaction between salt and humic acid was insignificant. The highest plant height was obtained from the control application in terms of salt application direction, and the lowest was obtained from the 150 mM salt application. In terms of humic acid application dose, the highest plant height was obtained from the 4 kg da^{-1} application with 110.33 mm, and the lowest was obtained from the 10 kg da^{-1} application with 87.51 mm (Table 2).

Table 2. Averages for the plant height of rapeseed plants regarding different salt doses, humic acid doses, and their interactions

Humic Acid Doses	Salt Concentrations				
	0	75	150	225	Mean
0 kg da^{-1}	98.65	89.76	94.38	84.09	**91.72 bc**
2 kg da^{-1}	121.27	107.67	86.61	97.56	**103.28 abc**
4 kg da^{-1}	118.81	116.30	101.20	105.03	**110.33 a**
6 kg da^{-1}	119.63	105.26	101.46	100.60	**106.74 ab**
8 kg da^{-1}	103.83	101.62	81.10	89.21	**93.94 bc**
10 kg da^{-1}	95.12	88.05	86.53	80.33	**87.51 c**
Mean	**109.55 a**	**101.44 ab**	**91.88 b**	**92.80 b**	**98.92**
LSD Salt					**12.98***
LSD Humic Acid					**15.9***
LSD Salt x Humic Acid interaction					**-**
CV					**19.59**

*: $p<0.05$

In terms of stem thickness, a significant difference was found regarding humic acid, salt application, and their interaction. The highest stem thickness was obtained from the control application (1.41 mm) in terms of salt application, and the lowest was obtained from the 225 mM salt application (0.86 mm). In terms of humic acid application dose, the highest stem thickness was obtained from the 4 kg da^{-1} (1.24 mm) and 6 kg da^{-1} (1.28 mm) applications, and the lowest was obtained from the control (1.02 mm) and 10 kg da^{-1} (1.03 mm) applications (Table 3).

Table 3. Averages for the stem thickness of rapeseed plants regarding different salt doses, humic acid doses, and their interactions

Humic Acid Doses	Salt Concentrations				
	0	75	150	225	Mean
0 kg da^{-1}	1.13 f-ı	1.10 g-ı	1.04 ı	0.81 k	**1.02 c**
2 kg da^{-1}	1.45 b	1.17 f-h	1.05 ı	0.89 jk	**1.14 b**
4 kg da^{-1}	1.69 a	1.19 e-g	1.18 f-g	0.91	**1.24 a**
6 kg da^{-1}	1.61 a	1.28 de	1.35 cd	0.86 jk	**1.28 a**
8 kg da^{-1}	1.38 bc	1.20 ef	1.20 ef	0.86 jk	**1.16 b**
10 kg da^{-1}	1.17 f-h	1.06 ı	1.09 hı	0.80 k	**1.03 c**
Mean	**1.41 a**	**1.17 b**	**1.15 b**	**0.86 c**	**1.15**
LSD Salt					**0.037****
LSD Humic Acid					**0.045****
LSD Salt x Humic Acid interaction					**0.09****
CV					**4.87**

**: $p<0.01$

In terms of leaf count, the difference was insignificant with respect to humic acid, salt application, and their interaction (Table 4). In terms of root length, a significant difference was found with respect to salt and humic acid application direction. However, the interaction between salt and humic acid was insignificant. The highest root length was obtained from the control application (21.15 mm) in terms of salt application direction, and the lowest was obtained from the 225 mM salt application (15.19 mm). In terms of humic acid application dose, the highest root lengths were obtained from the 4 kg da^{-1} (18.97 mm) and 6 kg da^{-1} (18.83 mm) applications, and the lowest were obtained from the 10 kg da^{-1} (17.43 mm) and control (17.83 mm) applications, respectively (Table 5).

Table 4. Averages for the leaf count of rapeseed plants regarding different salt doses, humic acid doses, and their interactions

Humic Acid Doses	Salt Concentrations				
	0	**75**	**150**	**225**	**Mean**
0 kg da^{-1}	2.00	3.00	2.67	2.67	**2.58**
2 kg da^{-1}	1.67	2.00	2.33	2.33	**2.08**
4 kg da^{-1}	2.33	2.67	2.33	2.33	**2.42**
6 kg da^{-1}	2.33	2.00	2.33	2.00	**2.17**
8 kg da^{-1}	3.00	2.00	2.00	3.33	**2.58**
10 kg da^{-1}	2.33	2.00	2.33	2.00	**2.17**
Mean	**2.28**	**2.28**	**2.33**	**2.44**	**2.33**
LSD Salt					**-**
LSD Humic Acid					**-**
LSD Salt x Humic Acid interaction					**-**
CV					**24**

Table 5. Averages for the root length of rapeseed plants regarding different salt doses, humic acid doses, and their interactions

Humic Acid Doses	Salt Concentrations				
	0	**75**	**150**	**225**	**Mean**
0 kg da^{-1}	20.33	18.00	18.33	14.67	**17.83 c**
2 kg da^{-1}	20.67	17.33	18.33	15.67	**18.00 bc**
4 kg da^{-1}	22.13	18.67	18.67	15.83	**18.83 a**
6 kg da^{-1}	21.87	19.33	19.00	15.67	**18.97 a**
8 kg da^{-1}	21.50	19.67	18.00	15.00	**18.54 ab**
10 kg da^{-1}	20.40	17.67	17.33	14.33	**17.43 c**
Mean	**21.15 a**	**18.44 b**	**18.28 b**	**15.19 c**	**18.27**
LSD Mean					**0.56****
LSD Humic Acid					**0.69***
LSD Salt x Humic Acid interaction					**-**
CV					**4.76**

**: p<0.01, *: p<0.05

In terms of root thickness, a significant difference was found regarding salt, humic acid, and their interaction. The highest root thickness was obtained from the control application (1.59 mm) in terms of salt application, and the lowest was obtained from the 225 mM salt application (1.01 mm). In terms of humic acid application dose, the highest root thicknesses were obtained from the 8 kg da^{-1} applications (1.44 mm), and the lowest were obtained from the 2 kg da^{-1} and control applications (1.26 mm) respectively (Table 6).

Table 6. Averages for the root thickness of rapeseed plants regarding different salt doses, humic acid doses, and their interactions

Humic Acid Doses	Salt Concentrations				
	0	**75**	**150**	**225**	**Mean**
0 kg da^{-1}	1.51 cd	1.35 e-h	1.25 ıj	0.94 l	**1.26 c**
2 kg da^{-1}	1.57 c	1.27 g-j	1.21 j	1.00 kl	**1.26 c**
4 kg da^{-1}	1.69 b	1.32 g-ı	1.26 h-j	1.01 kl	**1.32 b**
6 kg da^{-1}	1.53 c	1.43 d-f	1.33 f-ı	1.09 k	**1.35 b**
8 kg da^{-1}	1.72 a	1.52 cd	1.36 e-g	1.05 k	**1.44 a**
10 kg da^{-1}	1.55 c	1.43 de	1.31 g-ı	0.99 kl	**1.32 b**
Mean	**1.59 a**	**1.39 b**	**1.29 c**	**1.01 d**	**1.32**
LSD Salt					**0.04****
LSD Humic Acid					**0.05****
LSD Salt x Humic Acid interaction					**0.099***
CV					**4.56**

**: p<0.01, *: p<0.05

In terms of plant fresh weight, a significant difference was found with respect to salt application. However, the differences with respect to humic acid application and the interaction between salt and humic acid were insignificant. The highest plant fresh weight was obtained from the control application (1.47 g) in terms of salt application, and the lowest was obtained from the 225 mM salt application (0.92 g) (Table 7).

Table 7. Averages for the plant fresh weight of rapeseed plants regarding different salt doses, humic acid doses, and their interactions

Humic Acid Doses	Salt Concentrations				
	0	**75**	**150**	**225**	**Mean**
0 kg da^{-1}	1.17	1.13	1.08	0.96	**1.09**
2 kg da^{-1}	1.17	1.13	1.08	0.91	**1.07**
4 kg da^{-1}	1.63	1.20	1.07	0.94	**1.21**
6 kg da^{-1}	1.54	1.25	1.01	0.91	**1.18**
8 kg da^{-1}	1.48	1.28	0.96	0.86	**1.15**
10 kg da^{-1}	1.83	1.20	1.01	0.91	**1.24**
Mean	**1.47 a**	**1.20 b**	**1.04 c**	**0.92 c**	**1.16**
LSD Salt					**0.14****
LSD Humic Acid					-
LSD Salt x Humic Acid interaction					-
CV					**18.2**

**: p<0.01

In terms of plant dry weight, a significant difference was found regarding salt, humic acid, and their interaction. The highest plant dry weight was obtained from the control application (0.51 g) in terms of salt application, and the lowest was obtained from the 225 mM salt application (0.26 g). In terms of humic acid application dose, the highest plant dry weights were obtained from the control (0.40 g), 2 kg da^{-1} (0.39 g), 4 kg da^{-1} (0.39 g), and 6 kg da^{-1} (0.39 g) applications, and the lowest were obtained from the 8 kg da^{-1} (0.36 g) and 10 kg da^{-1} (0.36 g) applications respectively (Table 8).

Table 8. Averages for the plant dry weight of rapeseed plants regarding different salt doses, humic acid doses, and their interactions

Humic Acid Doses	Salt concentrations				
	0	75	150	225	Mean
0 kg da^{-1}	0.50 ab	0.47 bc	0.37 ef	0.27 h	**0.40 a**
2 kg da^{-1}	0.46 c	0.48 bc	0.34 fg	0.27 h	**0.39 a**
4 kg da^{-1}	0.53 a	0.43 d	0.34 fg	0.26 hı	**0.39 a**
6 kg da^{-1}	0.53 a	0.47 c	0.33 g	0.24 hı	**0.39 a**
8 kg da^{-1}	0.50 ab	0.37 ef	0.32 g	0.25 hı	**0.36 b**
10 kg da^{-1}	0.52 a	0.38 e	0.32 g	0.24 ı	**0.36 b**
Mean	**0.51 a**	**0.43 b**	**0.34 c**	**0.26 d**	**0.38**
LSD Salt					**0.001****
LSD Humic Acid					**0.015****
LSD Salt x Humic Acid interaction					**0.031****
CV					**4.95**

**: p<0.01

Table 9. Averages of the effects of salt dose, humic acid dose and salt x humic acid interaction on rapeseed growth

Salt Concentrations		SPAD	Plant height (mm)	Body thickness (mm)	Number of leaves (pcs)	Root length (mm)	Root thickness (mm)	Plant fresh weight (g)	Dry weight of plant (g)
Control		**46.58 a**	**109.55 a**	**1.41 a**	2.28	**21.15 a**	**1.59 a**	**1.47 a**	**0.51 a**
75 mM Salt		44.01 b	**101.44 ab**	1.17 b	2.28	18.44 b	1.39 b	1.20 b	0.43 b
150 mM Salt		40.71 c	91.88 b	1.15 b	2.33	18.28 b	1.29 c	1.04 c	0.34 c
225 mM Salt		36.41 d	92.80 b	0.86 c	2.44	15.19 c	1.01 d	0.92 c	0.26 d
LSD Salt		**	**	**	-	*	**	**	**
Humic Acid Doses		**SPAD**	**Plant height (mm)**	**Body thickness (mm)**	**Number of leaves (pcs)**	**Root length (mm)**	**Root thickness (mm)**	**Plant fresh weight (g)**	**dry weight of plant (g)**
Control		39.26 c	91.72 bc	1.02 c	2.58	17.83 c	1.26 c	1.09	0.40 a
2 kg da^{-1}		41.92 bc	**103.28 a-c**	1.14 b	2.08	18.00 bc	1.26 c	1.07	**0.39 a**
4 kg da^{-1}		**43.94 ab**	**110.33 a**	**1.24 a**	2.42	**18.83 a**	1.32 b	1.21	**0.39 a**
6 kg da^{-1}		**45.18 a**	106.74 ab	**1.28 a**	2.17	**18.97 a**	1.35 b	1.18	**0.39 a**
8 kg da^{-1}		41.97 bc	93.94 bc	1.16 b	2.58	**18.54 ab**	**1.44 a**	1.15	0.36 b
10 kg da^{-1}		39.31 c	87.51 c	1.03 c	2.17	17.43 c	1.32 b	1.24	0.36 b
LSD Humic Acid		**	*	**	-	*	**	-	**
Salt x Humic Acid		**SPAD**	**Plant height (mm)**	**Body thickness (mm)**	**Number of leaves (pcs)**	**Root length (mm)**	**Root thickness (mm)**	**Plant fresh weight (g)**	**dry weight of plant (g)**
Control	**Control**	41.70	98.65	1.13 f-ı	2.00	20.33	1.51 cd	1.17	0.50 ab
Control	**2 kg da^{-1}**	45.33	121.27	1.45 b	1.67	20.67	1.57 c	1.17	0.46 c
Control	**4 kg da^{-1}**	49.34	118.81	**1.69 a**	2.33	22.13	1.69 b	1.63	0.53 a
Control	**6 kg da^{-1}**	52.01	119.63	**1.61 a**	2.33	21.87	1.53 c	1.54	0.53 a
Control	**8 kg da^{-1}**	46.34	103.83	1.38 bc	3.00	21.50	**1.72 a**	1.48	0.50 ab
Control	**10 kg da^{-1}**	44.73	95.12	1.17 f-h	2.33	20.40	1.55 c	1.83	0.52 a
75 mM	**Control**	41.00	89.76	1.10 g-ı	3.00	18.00	1.35 e-h	1.13	0.47 bc
75 mM	**2 kg da^{-1}**	43.67	107.67	1.17 f-h	2.00	17.33	1.27 g-j	1.13	0.48 bc
75 mM	**4 kg da^{-1}**	46.01	116.30	1.19 e-g	2.67	18.67	1.32 g-ı	1.20	0.43 d
75 mM	**6 kg da^{-1}**	48.05	105.26	1.28 de	2.00	19.33	1.43 d-f	1.25	0.47 c
75 mM	**8 kg da^{-1}**	44.02	101.62	1.20 ef	2.00	19.67	1.52 cd	1.28	0.37 ef
75 mM	**10 kg da^{-1}**	41.33	88.05	1.06 ı	2.00	17.67	1.43 de	1.20	0.38 e
150 mM	**Control**	40.33	94.38	1.04 ı	2.67	18.33	1.25 ıj	1.08	0.37 ef
150 mM	**2 kg da^{-1}**	41.67	86.61	1.05 ı	2.33	18.33	1.21 j	1.08	0.34 fg
150 mM	**4 kg da^{-1}**	43.43	101.20	1.18 f-g	2.33	18.67	1.26 h-j	1.07	0.34 fg
150 mM	**6 kg da^{-1}**	42.33	101.46	1.35 cd	2.33	19.00	1.33 f-ı	1.01	0.33 g
150 mM	**8 kg da^{-1}**	40.50	81.10	1.20 ef	2.00	18.00	1.36 e-g	0.96	0.32 g
150 mM	**10 kg da^{-1}**	36.02	86.53	1.09 hı	2.33	17.33	1.31 g-ı	1.01	0.32 g
225 mM	**Control**	34.00	84.09	0.81 k	2.67	14.67	0.94 l	0.96	0.27 h
225 mM	**2 kg da^{-1}**	37.00	97.56	0.89 jk	2.33	15.67	1.00 kl	0.91	0.27 h
225 mM	**4 kg da^{-1}**	37.00	105.03	0.91	2.33	15.83	1.01 kl	0.94	0.26 hı
225 mM	**6 kg da^{-1}**	38.33	100.60	0.86 jk	2.00	15.67	1.09 k	0.91	0.24 hı
225 mM	**8 kg da^{-1}**	37.00	89.21	0.86 jk	3.33	15.00	1.05 k	0.86	0.25 hı
225 mM	**10 kg da^{-1}**	35.13	80.33	0.80 k	2.00	14.33	0.99 kl	0.91	0.24 ı
Mean LSD salt x humic asid		-	-	**	-	-	*	-	**

**: p<0.01. *:p<0.05

Salt stress can cause problems such as reduced growth and yield in many plants. In this context, humic acids stand out among the organic compounds used to support plant health and yield. Humic acids positively affect plant growth by improving the utilization of nutrients in the soil. Additionally, they increase the plants resistance to stress conditions. In this study, different doses of humic acid were applied to canola plants grown under salt stress and seedling development was examined. The results showed that humic acid applications positively affected seedling development in canola plants grown under salt stress. These findings reveal that humic acids increase the adaptation of canola plants to salt stress. Therefore, humic acid applications to canola plants grown under salt stress can be an effective method to support plant growth and increase yield. Different studies describe the effects of salt stress on the growth and development of plants. Korkmaz et al. (2020) study examined the effects of gibberellic and salicylic acid applications on canola plants under salt stress and showed that gibberellic acid application partially reduced the negative impact of salt stress. It has been stated that the application of humic and fulvic acids with potassium in leonardite caused an increase in yield and yield components of the spring canola variety Heros (Gürsoy and Kolsarıcı, 2017). Similarly, humic acid and calcium nitrate applications to pepper plants under saline conditions caused increases in growth parameters, photosynthetic pigments, and mineral content (Akladious and Mohamed, 2018). Finally, a study on the application of humic acid to enhance salt tolerance in soybeans showed that it reduced the damaging effects of salt on leaf area, plant height, fresh and dry mass of the above-ground part, stem length, chlorophyll content, and macro and microelement contents (Matuszak et al., 2017). The data reported by Bozcuk (2000) emphasize that the presence of Al ions increases the uptake of Fe, Mn, and K, which in turn supports chlorophyll synthesis; this is essential for the healthy growth of plants. Meganid et al. (2015) statistically demonstrated the effect of humic acid on increasing root length in their studies conducted under salt stress; Jarosova et al. (2016) indicated that the negative effects of NaCl application could be mitigated with humic acid treatment. In the study by Tuçtürk et al. (2020), it was observed that increasing doses of humic acid led to positive changes in physiological and biochemical parameters. When all these studies are considered together, they clearly reveal the potential of humic acid to enhance plant performance under stress conditions. The positive effects of humic acid (HA) application on various parameters under salt stress have been highlighted. The similarities in findings from different studies indicate that humic acid plays a significant role in plant development and its ability to tolerate stress. In light of these findings, it can be stated that humic acid has potential as a protective agent against challenging conditions such as salt stress in agricultural applications. Continuing such research will contribute both to fundamental sciences and agricultural practices.

4. Conclusion

The study results showed that humic acid positively affects the growth and development of canola seedlings under salt stress. Humic acid application led to increases in root and stem length, biomass, and chlorophyll content of the seedlings. The highest salt dose applied (225 mM) had the most negative impact on the seedling development stage. However, the 4th and 5th humic acid applications (6 kg da^{-1} and 8 kg da^{-1}) were found to be more effective in mitigating the stress effects. Humic acids' protective effects on plants under salt stress are noteworthy. Research suggests that humic acid applications support plant growth and development under salt stress and mitigate the negative effects of salt. Therefore, humic acid applications could be an important tool for plant cultivation under salt stress conditions. However, more research is needed. Specifically, the effects of humic acid applications on different plant species and salt stress conditions should be studied. Moreover, the environmental and human health effects of humic acid applications should also be investigated.

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