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RESEARCH ARTICLE

INVESTIGATION OF THE EFFECTS OF GEOTHERMAL AND MINERAL WATER ON BARLEY (*Hordeum vulgare* L.) AND WHEAT (*Triticum aestivum* L.)

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ABSTRACT

In the present study, the usability of geothermal and mineral water in agricultural lands was investigated. Geothermal water, mineral water, and tap water with two wheat varieties and one barley variety were used, and six different water groups were formed with geothermal, mineral, and tap water by mixing them at a ratio of 50%. Field soil mixed with 750 g of animal manure was prepared in the growing containers, and then, 6 g of the wheat varieties and 5 g of the barley variety were planted in them. The germinated wheat and barley were irrigated periodically according to their water needs. Barley and wheat were harvested after 15 days. Chlorophyll size, electrolyte leakage, weight, and mineral element concentrations were determined in the harvested crops. The mineral element concentrations of the samples were analyzed in ICP-AES. Additionally, geothermal, mineral and normal water were applied to the soil for three months, and the change between the resulting soil and the starting soil was determined. The collected data were analyzed in the SPSS 22 Statistical Package Program.

Keywords: Barley, Geothermal water, Irrigation, Mineral element, Mineral water, Wheat

1. INTRODUCTION

Water is the most indispensable resource provided by nature. Water exists in nature in many ways, such as oceans, seas, rivers, and groundwater. Due to the increase in world population, intensive agricultural activities and water use in domestic and industrial areas have significantly increased the demand for freshwater [1, 2, 3]. Because of these demands, utilizable freshwater resources are gradually decreasing [4, 5, 6]. Especially, the haphazard use of groundwater for irrigation and its widespread exploitation seem to cause problems in the long run [7, 8, 9]. Insufficient water resources and deteriorating water quality lead to severe concerns for industry, agriculture, and the environment in many parts of the world [10]. The existing total water of the world consists of 97.4% saltwater and 2.6% freshwater. The reclamation and recovery of wastewater, including reuse and recycling, have recently been seen as one of the possible tools that contribute to the better management of water resources [11, 12]. With the race to increase agricultural productivity, irrigation will become more dependent on substandard water resources. Therefore, investigating the effects of irrigation water quality on yield has considerable significance. This approach is extremely critical for maintaining proper food and soil quality as well as providing sufficient crop production for the increasing need [13].

In recent years, the increasing water limitation due to the deterioration of water quality and quantity has started to become a significant problem. In many countries, a large part of urban wastewater is drained from rivers without being treated sufficiently or at all, and the water of these rivers is used for the irrigation of agricultural areas. Rapidly increasing population, rapid urbanization, industrialization, and the extensive use of fertilizers and pesticides in agricultural areas may cause rapid contamination in freshwater resources [14, 15, 16]. Although the distribution of usage areas of water changes, on average, 70% of the total freshwater is used for agriculture, 20% is used for industrial purposes, and 10% is used

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for domestic purposes worldwide. Based on these rates, clean water used for agricultural irrigation creates a large part of the total water used. Depending on the increasing population, it is predicted that by 2050, 70% more food will be produced, and consequently, the amount of water required for agricultural irrigation will increase [17,18]. Thus, it has become an increasingly commonplace practice to use treated wastewater for agricultural irrigation, especially in countries that have water shortages and want to eliminate the cost of wastewater treatment and utilize the rich nutrient resources in wastewater [13, 19].

The use of thermal resources is a very old. The systematic use and development of these resources, which are thought to be used for health and religious purposes in antiquity, coincide with the Roman period. Türkiye is rich in geothermal resources due to the large footprint of active volcanic and tectonic areas. Hence, Türkiye has a significant potential for geothermal tourism. The estimated total number of geothermal resource sites is 1300, and the number of medicinal water sources is over 2000 in Türkiye. Thus, Türkiye is in the top five in the distribution of geothermal resources worldwide [20, 21].

Geothermal water has been used in the tourism sector in many parts of the world, while mineral water is mostly used as drinking water. In this study, the usability of geothermal and mineral water in agricultural areas was investigated.

2. MATERIAL AND METHODS

Geothermal water in Erzincan is among the therapeutic water resources with superior properties such as a temperature of approximately 34° and 660 mg of free carbon dioxide gas per liter. This geothermal water is currently used in geothermal tourism. Mineral water is also located close to the region where geothermal water comes out. It is used for drinking and is always open to the public (Figure 1).

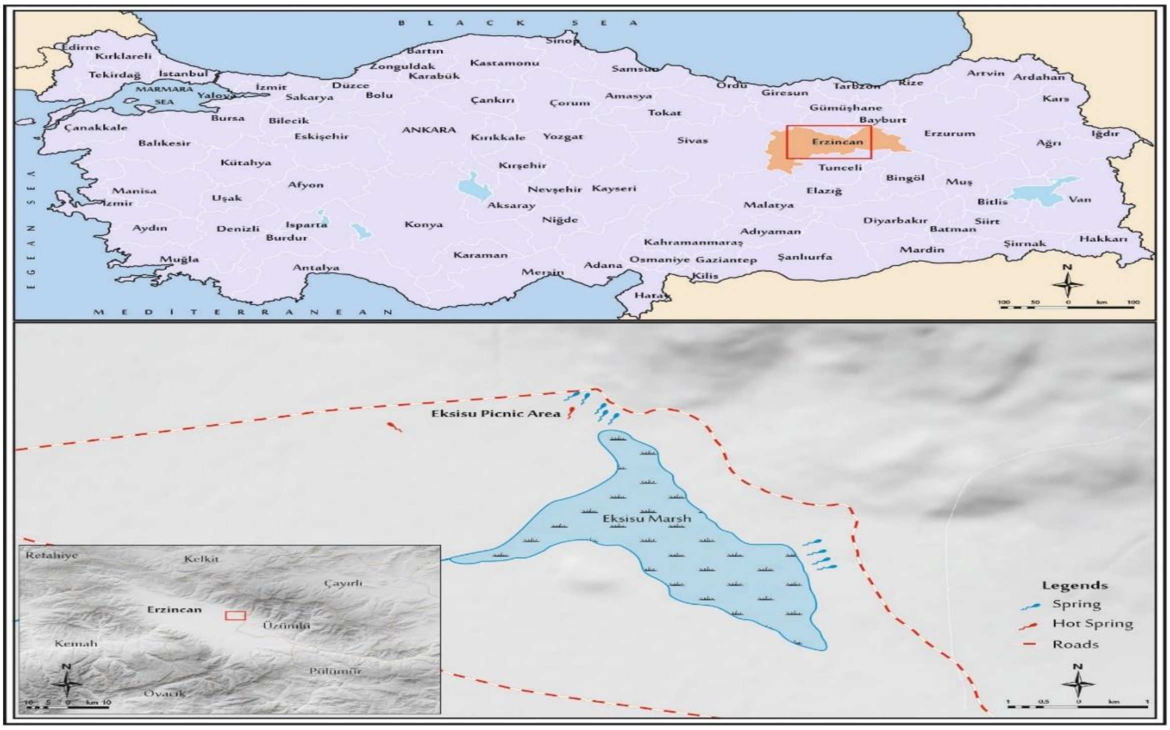

Figure 1. Area of geothermal ve mineral water

The geothermal and mineral water and tap water located within the borders of Erzincan and two wheat (Forblanc, Esperia) and one barley (Akhisar 98) varieties were used in this study. The Forblanc wheat variety is of medium height, and its ears are awn. It has resistance to drought, cold stress, and lying. The

Esperia wheat variety is approximately 80-85 cm in height. Its grain color is red, and its grain structure is hard. It has a winter development nature; its stem is strong, it does not bend easily, and its performance is high in irrigated areas. The Akhisar 98 barley variety is 85-90 cm in height; it is a summer, six-row barley variety. It has medium sensitivity to drought stress and is very productive [22, 23, 24]. In this study, six different water groups were formed using geothermal, mineral, and tap water by mixing them at a ratio of 50%. Additionally, field soil mixed with 750 g of animal manure was prepared in the growing containers, and then, 6 g of the wheat varieties and 5 g of the barley variety were planted in them. The geothermal water was cooled to a suitable temperature before using it for the irrigation of plants. After germination, the plants were irrigated according to the water needs of wheat and barley and the field capacity. Next, barley and wheat were harvested for analyses after an average of 15 days. Chlorophyll size, electrolyte leakage, weight, and mineral element concentrations were determined in the harvested plants. Apart from these analyses, geothermal water, mineral water and tap water were applied to the soil for three months, some properties (e.g., organic matter and salinity) and element concentrations in the resulting soil were determined, and these properties were compared to those of the same soil where no water application was made. Moreover, the water that was used to irrigate the soil was analyzed.

The electrolyte leakage of fresh leaves was determined according to the method reported by [25] 4 mL of distilled water was added to six replicate test tubes containing 0.1 g of fresh leaves and incubated at 4 °C for 24 h. An electrical conductivity meter was used to measure the number of ions present in water.

The Lichtenthaler and Buschmann (2001) method was used to estimate total chlorophyll and carotenoid content in fresh leaves. Fresh leaf tissue (0.5 g) was ground using a mortar and pestle, which contained 5 mL acetone (80%). The absorbance of the corresponding extract was measured at 662 and 645 nm (chlorophyll) and 440 nm (carotenoids). Photosynthetic pigments are expressed as mg/g FW [26].

Samples were dried at 65°C for 24 h, ground, and dried again at 65°C for 12 h. These dried samples were used for the analysis. Needle samples (0.5 g) were prepared using a precision scale and then put into Teflon cells. Eight milliliters of HNO_3 (65%) were added to the ground samples, while 5 mL HNO_3 (65%), 3 ml HCI (37%), and 2 mL HF (48%) were added to the ground soil samples. The samples were put into a microwave oven (Berghof-MWS2). The temperature of the microwave contents was gradually increased to 175°C and held constant for 20 min. The samples and chemicals were filtered with Whatman filters into 50 mL sterile tubes and diluted to 50 mL with ultra-pure water for the ICP-OES analysis. Before the spectroscopic analysis, standards were prepared using a 1,000 ppm multi-element solution. The ICP-OES measurements were made after the calibration using the standards [26].

The data obtained in the study were statistically evaluated. A value of $p \leq 0.05$ was accepted as significant in statistical calculations and comparisons. With SPSS 22 Package Statistical Program, the data were analyzed by ANOVA test at 95% confidence interval and the differences between samples in multiple comparisons were determined by Tukey's B and S-N-K [26].

3. RESULTS AND DISCUSSION

In this study, many parameters were examined, and significant results were obtained (Table 1.). First of all, according to the analysis of the three different types of water, it was determined that the geothermal water had a quite high turbidity at 55.6 NTU, and its conductivity was very high at 7100 µS/cm. On the other hand, the turbidity (0-1 NTU) and conductivity (0-2500 µS/cm) values of the tap and mineral water were within normal ranges. When the pH values of the water were examined, it was seen that the mineral water (5.5) was more acidic, while the other water types were within normal pH ranges (6.5-9.5). Afterwards, due to the application of different irrigation water types (geothermal, mineral, tap) in the soil for three months, the amount of organic matter increased in all three irrigation groups, and differences were observed in other parameters. Changes in the concentrations of elements in the soil were also seen. The concentration of the elements in the soil irrigated with three different types of water was determined differently than in the non-irrigated soil. Therefore, it was seen that the water used in the study changed the element concentrations of the soil. The data obtained on the differences in element concentrations based on different water treatments are shown in (Table 2).

Table 1. Chemical properties of different waters.

Parametres	Geothermal Water		Mineral Water		Normal Water		Control	
Ph	8,23	Strong Alkaline	7,85	Light Alkaline	8,01	Strong Alkaline	8,03	Strong Alkaline
Ec(Micromhos)	3,22		1,46		1,74		0,91	
Soil Texture	70,00	Clayey-Loamy	68,00	Clayey-Loamy	72,00	Clayey	55,00	Clayey-Loamy
Organic Substance	5,53	High	4,98	High	5,26	High	0,83	Very little
Lime	10,93	Limy	12,10	Limy	10,93	Limy	14,83	Limy
Salt	0,14	Saltless	0,06	Saltless	0,08	Saltless	0,03	Saltless

Table 2. Element concentration in the soil applied to different waters (mg / kg DW).

Element	Al	B	Cu	Fe	Mn	Zn
Geothermal Water	3143,9 ± 57,5[b]	49,8 ± 0,4[a]	58,2 ± 0,4[a]	51258,6 ± 325,1[b]	613,7 ± 4,3[a]	65,1 ± 0,6[a]
Mineral Water	3076,1 ± 41,6[b]	27,8 ± 0,6[c]	53,9 ± 0,5[b]	50732,1 ± 316,2[b]	609,0 ± 2,5[a]	64,6 ± 1,5[a]
Normal Water	3237,7 ± 50,9[b]	32,8 ± 0,3[b]	56,8 ± 0,9[a]	51924,5 ± 479,8[b]	616,1 ± 5,5[a]	64,0 ± 0,7[a]
Control	3550,3 ± 70,7[a]	27,5 ± 0,1[c]	55,8 ± 0,5[b]	53947,7 ± 570,2[a]	588,8 ± 3,8[b]	53,5 ± 0,4[b]

Element	Na	Mg	K	Ca	P
Geothermal Water	1057,4 ± 23,1[a]	78100,1 ± 652,1[a]	3233,0 ± 74,9[a]	43822,4 ± 333,7[b]	644,1 ± 3,8[a]
Mineral Water	337,5 ± 12,5[d]	75350,5 ± 505,9[b]	2888,6 ± 59,5[a]	44696,7 ± 296,8[b]	614,1 ± 6,7[a]
Normal Water	431,8 ± 10,7[c]	78401,6 ± 833,4[a]	3358,6 ± 66,4[a]	44944,3 ± 457,2[b]	635,2 ± 7,9[a]
Control	742,7 ± 20,7[b]	78233,1 ± 899,8[a]	2352,4 ± 18,1[a]	63662,2 ± 959,2[a]	254,4 ± 6,1[b]

After applying irrigation water, in the wheat varieties, the concentrations of elements varied in different ranges as: Cu (11.7 ± 1.4-23 ± 0.2 mg/kg DW), Mn (33.6 ± 1.8-45.8 ± 3.9 mg/kg DW) and Zn (23, 5 ± 0.8-39.9 ± 1.3 mg/kg DW), whereas these ranges for the barley variety were as follows: Cu (20.3 ± 0.2-26.5 ± 0.2 mg/kg DW) in barley variety, Mn (31.3 ± 0.6-53.9 ± 2 mg/kg DW) and Zn (33.2 ± 0.7-54.6 ± 0.5 mg/kg DW). It was observed that these values were close to those of the irrigation water. On the other hand the B (27.7 ± 0.2 and 24.0 ± 2.1 mg/kg DW), Fe (199.5 ± 13.1 and 780.1 ± 144.8 mg/kg DW) Na (1027, 6 ± 4.1 and 2049.6 ± 231.6 mg/kg DW) concentrations in the wheat varieties and the Na (9334.5 ± 68.3 mg/kg DW) and B (18.7 ± 0.2 mg/kg DW) concentrations in the barley variety were higher in the samples irrigated with geothermal waters compared to those irrigated with the other water types. According to these results, considerable differences were generally observed between the concentrations of elements due to the application of different types of water (Tables 3-5). Additionally, the chlorophyll levels of the plants differed based on the type of water that was applied. Among the wheat samples, chlorophyll a (5.97-10.56 mg g^{-1} FW), chlorophyll b (2.58-5.18 mg g^{-1} FW), total chlorophyll (8.56-15.61 mg g^{-1} FW) and carotenoid (0.92-2.01 mg g^{-1} FW) levels were higher in the samples where tap water and mineral water were used for irrigation together than those where geothermal water was used, while these values among the barley samples were higher in the samples where tap water was applied.

Table 3. Element concentration in the barley applied to different waters (mg / kg DW) (*p < 0.05, **p < 0.01, ***p < 0.001 significant).

Barley (Akhisar 98)	Al	B	Cu	Fe	Mn	Zn
Geothermal Water	27,1 ± $2,1^{b}$	18,7 ± $0,2^{e}$	26,5 ± $0,2^{d}$	143,6 ± $6,5^{b}$	44,7 ± $0,4^{c}$	54,6 ± $0,5^{e}$
Mineral Water	49,6 ± $5,3^{d}$	10,9 ± $0,4^{d}$	23,4 ± $0,4^{c}$	201,3 ± $15,9^{d}$	53,9 ± $2,0^{e}$	51,3 ± $1,1^{d}$
Normal Water	134,4 ± $0,6^{e}$	9,7 ± $0,1^{c}$	21,5 ± $0,3^{b}$	370,8 ± $9,8^{e}$	49,1 ± $0,1^{d}$	46,4 ± $0,5^{c}$
Geothermal+Normal	40,1 ± $1,7^{c}$	10,5 ± $0,1^{d}$	21,7 ± $0,3^{b}$	175,6 ± $5,2^{c}$	38,2 ± $0,3^{b}$	40,6 ± $0,4^{b}$
Mineral+Normal	7,2 ± $0,2^{a}$	7,7 ± $0,1^{b}$	20,8 ± $0,2^{ab}$	85,8 ± $2,8^{a}$	40,6 ± $0,6^{b}$	39,9 ± $0,8^{b}$
Mineral+Geothermal	7,0 ± $0,4^{a}$	7,0 ± $0,0^{a}$	20,3 ± $0,2^{a}$	83,7 ± $1,9^{a}$	31,3 ± $0,6^{a}$	33,2 ± $0,7^{a}$
Significant	***	***	***	***	***	***

	Na	Mg	K	Ca	P
Geothermal Water	9334,5 ± $68,3^{e}$	3876,2 ± $7,1^{de}$	73214,1 ± $530,2^{e}$	2363,8 ± $16,6^{c}$	9148,1 ± $62,5^{c}$
Mineral Water	2062,8 ± $62,4^{b}$	4068,5 ± $154,0^{e}$	57853,9 ± $1155,4^{c}$	2420,3 ± $93,6^{c}$	11374,8 ± $177,1^{f}$
Normal Water	1540,1 ± $14,4^{a}$	3781,1 ± $21,0^{d}$	53731,1 ± $262,6^{b}$	2149,5 ± $25,4^{b}$	10441,1 ± $124,7^{e}$
Geothermal+Normal	4661,1 ± $72,8^{d}$	3213,8 ± $61,5^{c}$	61581,8 ± $757,5^{d}$	2119,4 ± $43,3^{b}$	8134,1 ± $89,4^{b}$
Mineral+Normal	1467,4 ± $12,0^{a}$	2908,1 ± $80,4^{b}$	48344,6 ± $464,2^{a}$	1652,5 ± $48,4^{a}$	9677,7 ± $140,2^{d}$
Mineral+Geothermal	4323,0 ± $48,9^{c}$	2512,7 ± $59,9^{a}$	54164,1 ± $840,1^{b}$	1667,8 ± $35,3^{a}$	6256,0 ± $147,9^{a}$
Significant	***	***	***	***	***

Table 4. Element concentration in the wheat applied to different waters (mg / kg DW). (*p < 0.05, **p < 0.01,

Wheat (Forblanc)	Al	B	Cu	Fe	Mn	Zn
Geothermal Water	48,9 ± $0,5^{a}$	27,7 ± $0,2^{a}$	17,6 ± $0,1^{ab}$	199,5 ± $13,1^{a}$	42,2 ± $0,8^{a}$	24,1 ± $0,4^{ab}$
Mineral Water	13,8 ± $0,7^{b}$	2,8 ± $0,1^{d}$	17,5 ± $0,2^{ab}$	67,0 ± $3,7^{cd}$	36,0 ± $1,2^{c}$	23,5 ± $0,8^{b}$
Normal Water	13,5 ± $0,7^{b}$	3,2 ± $0,2^{d}$	18,1 ± $0,1^{a}$	90,6 ± $2,5^{b}$	38,9 ± $0,7^{b}$	25,9 ± $0,4^{a}$
Geothermal+Normal	7,6 ± $0,2^{c}$	20,1 ± 0,2b	16,5 ± $0,1^{b}$	71,2 ± $0,6^{bc}$	42,0 ± $0,3^{a}$	25,6 ± $0,4^{a}$
Mineral+Normal	2,7 ± $0,2^{d}$	3,1 ± $0,1^{d}$	16,9 ± $0,2^{b}$	55,3 ± $1,3^{d}$	39,4 ± $0,6^{b}$	24,9 ± $0,4^{ab}$
Mineral+Geothermal	12,6 ± $1,7^{b}$	11,4 ± $0,5^{c}$	18,4 ± $0,7^{a}$	82,8 ± $3,6^{bc}$	40,5 ± $0,6^{ab}$	25,4 ± $0,5^{a}$
Significant	***	***	***	***	***	**

	Na	Mg	K	Ca	P
Geothermal Water	1027,6 ± $4,1^{a}$	2483,4 ± $85,2^{b}$	51778,9 ± $536,8^{a}$	1483,1 ± $48,0^{a}$	6106,5 ± $110,2^{d}$
Mineral Water	163,7 ± $6,2^{e}$	2163,1 ± $84,8^{d}$	45137,0 ± $1373,8^{b}$	1275,2 ± $73,4^{b}$	8262,1 ± $269,1^{bc}$
Normal Water	144,6 ± $2,1^{f}$	2334,2 ± $52,2^{cd}$	50755,8 ± $909,1^{a}$	1537,1 ± $48,0^{a}$	8396,5 ± $205,3^{bc}$
Geothermal+Normal	782,6 ± $8,3^{b}$	2446,7 ± $36,9^{ab}$	50263,8 ± $314,0^{a}$	1523,9 ± $31,1^{a}$	8696,4 ± $101,2^{ab}$
Mineral+Normal	185,7 ± $3,1^{d}$	2512,4 ± $44,2^{a}$	46274,3 ± $775,6^{b}$	1557,0 ± $33,9^{a}$	9155,3 ± $150,2^{a}$
Mineral+Geothermal	720,1 ± $10,3^{c}$	2519,0 ± $45,0^{a}$	49020,3 ± $781,6^{a}$	1510,9 ± $41,7^{a}$	7882,9 ± $96,4^{c}$
Significant	***	***	***	***	***

***p < 0.001 significant).

Table 5. Element concentration in the wheat applied to different waters (mg / kg DW). (*p < 0.05, **p < 0.01, ***p < 0.001 significant).

Wheat (Esperia)	**Al**	**B**	**Cu**	**Fe**	**Mn**	**Zn**
Geothermal Water	26,8 ± 2,6^{c}	24,0 ± 2,1^{a}	18,7 ± 0,6^{b}	780,1 ± 144,8^{a}	33,6 ± 1,8^{b}	28,3 ± 2,1^{b}
Mineral Water	146,1 ± 2,8^{a}	3,1 ± 0,7^{c}	23,4 ± 1,5^{a}	461,0 ± 14,4^{c}	36,5 ± 1,3^{ab}	28,7 ± 1,4^{b}
Normal Water	57,3 ± 7,0^{b}	7,0 ± 0,4^{c}	20,0 ± 0,6^{ab}	214,0 ± 18,0^{d}	45,8 ± 3,9^{a}	39,9 ± 1,3^{a}
Geothermal+Normal	58,6 ± 5,4^{b}	12,9 ± 0,8^{b}	11,7 ± 1,4^{c}	600,8 ± 3,1^{b}	40,4 ± 0,8^{a}	24,0 ± 1,9^{c}
Mineral+Normal	28,5 ± 6,5^{c}	14,0 ± 3,7^{b}	21,3 ± 0,5^{ab}	147,6 ± 20,7^{d}	43,0 ± 2,6^{a}	39,6 ± 1,5^{a}
Mineral+Geothermal	13,8 ± 0,6^{c}	21,0 ± 0,2^{a}	23,0 ± 0,2^{a}	85,7 ± 2,1^{d}	37,1 ± 0,9^{ab}	32,8 ± 0,9^{b}
Significant	***	***	***	***	***	**

	Na	**Mg**	**K**	**Ca**	**P**
Geothermal Water	2049,6 ± 231,6^{a}	4630,0 ± 494,5	55030,0 ± 1199,5^{d}	2445,4 ± 428,0^{ab}	8090,6 ± 344,1^{c}
Mineral Water	399,4 ± 32,6^{cd}	3438,7 ± 228,6	60917,1 ± 2564,2^{c}	1955,9 ± 84,2^{ab}	10383,5 ± 303,6^{b}
Normal Water	327,2 ± 11,3^{d}	4463,5 ± 274,2	69301,7 ± 1819,4^{b}	2591,1 ± 165,7^{ab}	14337,2 ± 455,3^{a}
Geothermal+Normal	319,6 ± 5,5^{d}	4433,9 ± 97,7	10041,4 ± 1612,3^{e}	1698,3 ± 258,5^{c}	6352,2 ± 983,1^{d}
Mineral+Normal	647,7 ± 161,3^{c}	4298,5 ± 207,1	74905,3 ± 2728,2^{a}	2849,1 ± 395,8^{a}	13746,2 ± 297,4^{a}
Mineral+Geothermal	1065,5 ± 15,3^{b}	3182,2 ± 113,9	76873,8 ± 1105,2^{a}	1828,0 ± 79,0^{b}	10573,6 ± 187,8^{b}
Significant	***	***	***	***	***

The findings showed that the lowest chlorophyll concentrations in the samples were in the Forblanc wheat variety treated with geothermal water, the Esperia wheat variety treated with mineral water, and the barley variety treated with mineral and geothermal water irrigation. Additionally, there were no significant differences in the chlorophyll and carotenoid analysis results among the irrigation methods applied in the Esperia variety, while there were significant differences in the Forblanc wheat variety and the barley variety. There were differences regarding the weights of the plants after harvesting depending on the water applied, and the weights of the plants irrigated with geothermal water were higher than the weights of others. According to the electrolyte leakage analysis results, there were generally high concentrations in the samples in which mineral water and geothermal water were used together (Figure 2 and 3).

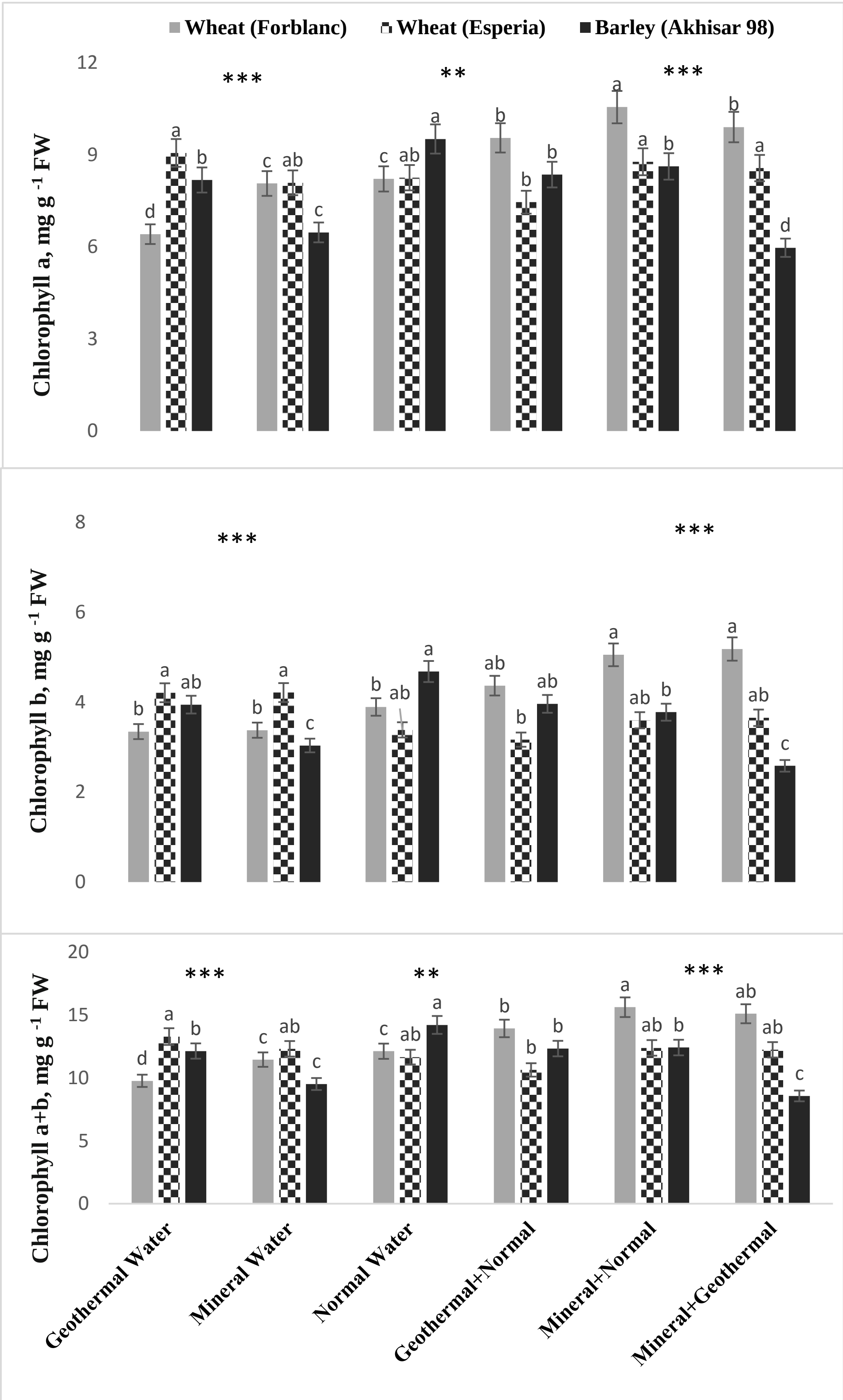

Figure 2. Chlorophyll a, Chlorophyll b, Chlorophyll a+b concentration in wheat and barley using different water

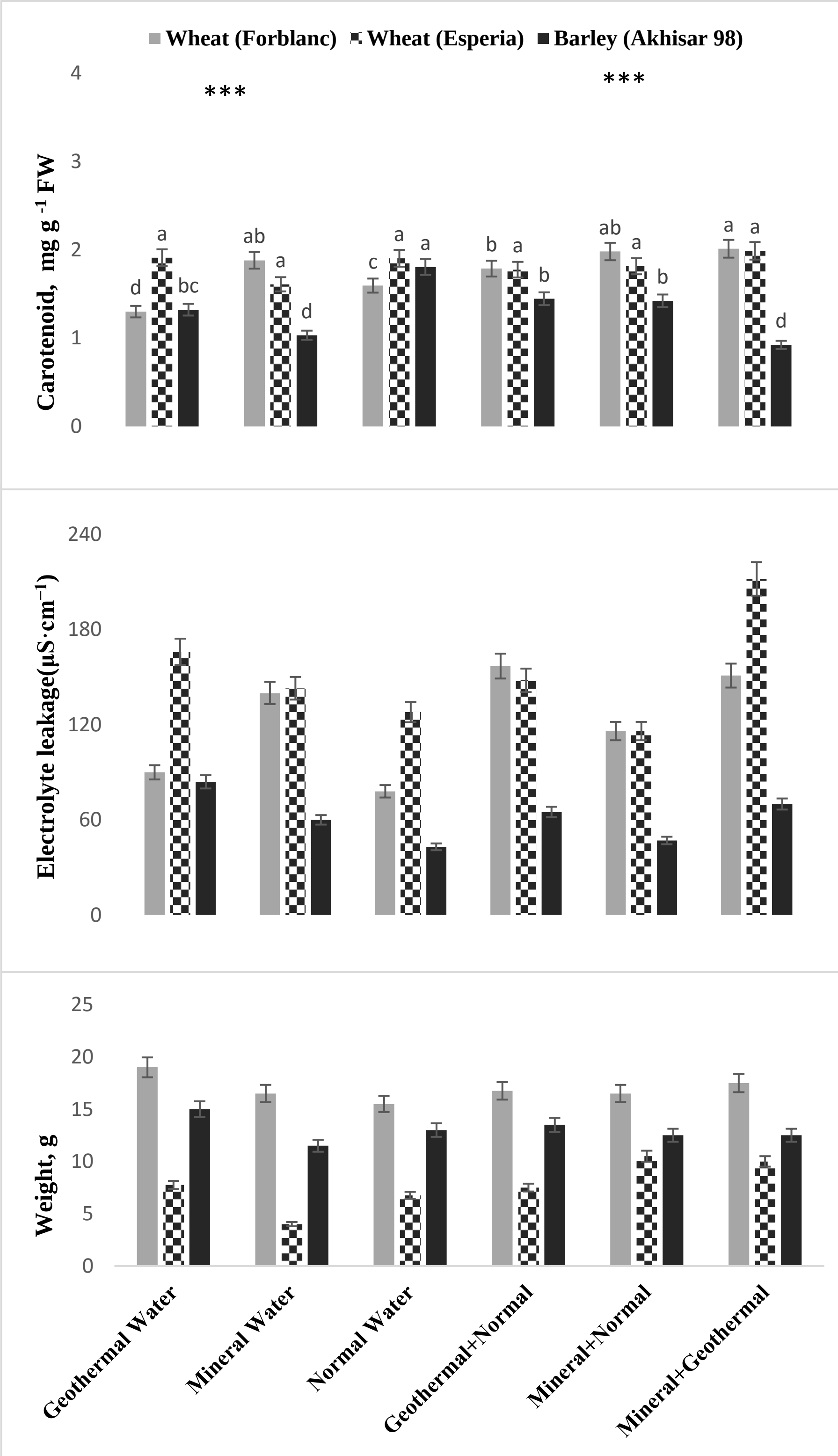

Figure 3. Carotenoid, Electrolyte leakage, Weight concentration in wheat and barley using different water

4. CONCLUSION

In general, geothermal waters are used for energy and therapeutic purposes. On the other hand, mineral waters are mostly used as drinking water. To our knowledge, there is no research on the use of geothermal and mineral waters in plant growing. Studies on groundwater quality for drinking and irrigation purposes have been conducted by many authors [28-32]. The data of this study showed that there were no noticeable differences between the experimental groups that may significantly affect the growth of plants. Türkiye has much thermal water with very different properties about contents, which come to the earth's surface. To investigate the effects of agricultural irrigation, long-term trial studies with different plants and soils should be conducted by determining the contents of these waters. Geothermal and mineral water resources that can be used should be determined in terms of their chemical properties. However, geothermal water can be used as well if it is pre-treated with appropriate methods. More comprehensive studies should be conducted to use such water in the irrigation of plants in case of future water deficiencies regarding this type of water, which is wasted to a substantial extent today. The effects of geothermal and mineral water on the product quality of crops should be examined in depth, and attention should be paid to studies on its use, especially in greenhouse cultivation work with this water.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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