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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Determining Effects of Foliar Zinc Fertilizer on the Growth of Some Potato Varieties under Greenhouse Conditions

Sera Koşullarında Bazı Patates Çeşitlerinin Büyümesi Üzerine Yaprak Çinko Gübrelerinin Etkilerinin Belirlenmesi

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Abstract

As known, potato (*Solanum tuberosum* L.) is a significantly important plant species of economic importance rich in minerals, vitamins, and total phenolics and consumed as a palatable food. Zinc or (Zn), a micronutrient, is essential for plant growth as it is an integral part of various biomolecules such as lipids and proteins in plant metabolism. Thus increasing crop yield and quality. Different doses of Zn-treatment by foliar spray were used in 10 potato cultivars, and they were treated with 4 different doses, such as Zn_0 (Control), Zn_1 (0.625 g l^{-1}), Zn_2 (1.250 g l^{-1}) and Zn_3 (2.500 g l^{-1}) application was made at the beginning of flowering and 20 days after flowering. According to the obtained results, statistical significance ($p < 0.05$) was seen among genotypes, zinc application(s), and their interaction. In addition, chlorophyll content (spad unit) varied between 33.67-52.60, and plant height (cm) ranged from 46.17-65.15. Similarly, the number of tubers per plant was between 6.10-8.95, the tuber yield per plant (g plant^{-1}) was between 82.70-205.20, and the mean tuber weight (g) varied from 19.56-22.93. Among the Zn treatments, the highest proportion of large tubers (> 20 g) was obtained with 2.500 g l^{-1} (Zn_3), the greatest amount of medium tubers 10.0-20.0g, and small tubers (< 10 g) was found with the Zn_0 dose. Under greenhouse conditions, the highest performance was recorded in the Agria variety when subjected to foliar application of zinc at a concentration of 2.500 g L^{-1}, indicating its superior response to Zn treatment among the tested varieties. The results obtained in our study indicate that foliar application of Zn in potatoes has the potential to enhance yield in crop production.

Keywords: Chlorophyll content, Correlations, Cluster heatmap, *Solanum tuberosum* L., Tuber yield, Zinc treatments

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Öz

Bilindiği üzere, patates (*Solanum tuberosum* L.), mineral, vitamin ve toplam fenolik bileşikler açısından zengin içeriği ve lezzetli bir gıda olarak tüketilmesi nedeniyle ekonomik açıdan büyük öneme sahip bir tarım ürünüdür. Çinko (Zn), bitki metabolizmasında lipitler ve proteinler gibi çeşitli biyomoleküllerin yapısal ve işlevsel bir bileşeni olarak bitki büyümesi için hayati öneme sahip bir mikro besin elementidir ve bu yolla verim ve kalite artışına katkı sağlar. 10 patates çeşidine yapraktan farklı dozlarda çinko (Zn) uygulaması yapılmıştır. Dört farklı doz kullanılmıştır: Zn_0 (kontrol), Zn_1 (0,625 g L^{-1}), Zn_2 (1,25 g L^{-1}) ve Zn_3 (2,50 g L^{-1}). Uygulamalar, çiçeklenme başlangıcında ve çiçeklenmeden 20 gün sonra olmak üzere iki kere yapılmıştır..Elde edilen sonuçlara göre, çeşitler, çinko uygulamaları ve bu iki faktörün etkileşimleri arasında istatistiksel olarak anlamlı farklar ($p < 0.05$) bulunmuştur. Klorofil içeriği (SPAD birimi) 33.67 ile 52.60 arasında değişmiş, bitki boyu ise 46.17 ile 65.15 cm arasında ölçülmüştür. Aynı şekilde, bitki başına yumru sayısı 6.10 ile 8.95 arasında, bitki başına yumru verimi 82.70 ile 205.20 g arasında ve ortalama yumru ağırlığı 19.56 ile 22.93 g arasında değişmiştir. Zn uygulamaları arasında, en yüksek oranda büyük yumru (> 20 g) Zn_3 (2.500 g L^{-1}) dozuyla elde edilirken, orta boy (10–20 g) ve küçük boy (< 10 g) yumruların en fazla olduğu grup kontrol (Zn_0) olmuştur. Sera koşullarında, yapraktan 2.500 g L^{-1} Zn uygulaması yapılan ‘Agria’ çeşidi en yüksek performansı göstermiştir ve bu da test edilen çeşitler arasında çinko uygulamasına en iyi yanıtı verdiğini ortaya koymaktadır. Bu sonuçlar, patateste yapraktan çinko uygulamasının ürün verimini artırma potansiyeline sahip olduğunu göstermektedir.

Anahtar Kelimeler: Klorofil içeriği, Korelasyon, Küme ısı haritası, *Solanum tuberosum* L., Yumru verimi, Zn uygulaması

1. Introduction

Potato (*Solanum tuberosum* L.) is a significantly important cultural plant grown in the world after corn (*Zea mays* L.), wheat (*Triticum* spp.), and rice (*Oryza sativa* L.) (Rusinovci et al., 2024). However, potatoes are cultivated in specific areas suitable for potato cultivation for table purposes, industrial processing, and the manufacture of alcohol, starch, etc. The breeders are in constant search to find the methodologies to improve the quality of potatoes. Many factors affect sustainable potato farming including deficiency of macro-elements and micronutrients like Zinc (Zn), Copper (Cu), Molybdenum (Mo), Manganese (Mn), Boron (B), Iron (Fe) etc, which affect the productivity, quantitative and qualitative yield (Dhaliwal et al., 2022).

On the other hand, potatoes are very sensitive to low levels of Zn deficiency (Demir and Çalışkan, 2017; Zhu et al., 2021). In a general assessment of soils in Turkey, it was reported that 81% of soils had pH values above 7.0 (Usta et al., 2018), and in another study, it was reported that 63% of soils had pH values above 7.5 (Saltali and Nedirli, 2021).

The high pH value of soil reduces the uptake of nutrients by plants and makes it difficult to take micronutrients from soil. It also slows down water storage in the soil (Gonzalez et al., 2023). Zn has a number of important physiological roles in plants, like biosynthesis of proteins, gene expression, and the detoxification of highly toxic oxygen-free radicals (İkinci and Aldanmaz, 2022). A lack of P, Fe, K, and Zn, uptake results in a high decrease in quality and production efficiency (Fageria et al., 2008). Zn is an essential plant nutrient and its deficiency limits crop production, which in turn affects the uptake of nutrients by plants (Mahmud et al., 2021). When considered in terms of human nutrition, Zn is critically important for many body functions and the regulation of > 300 biological enzymes (Duan et al., 2023). Its deficiency is responsible for the induction of many diseases in human beings, including stunting and malfunctions of many organs, recurrent infections, and infant deaths (Hussein et al., 2022). The Zn content in the soil is inversely proportional to soil pH. It is mentioned that as soil pH decreases, the amount of Zn is available (Laurent et al., 2020). These days, Turkish potato growing areas are showing multiple-nutrient deficiencies including Zn, adversely affecting the crop vigor, with the production of low-quality tubers, poor yield, and losses in trade. This is widely seen in regions with low rainfall, high pH and $CaCO_3$ content of the soils, with clayey structure, and low organic matter (Yahaya et al., 2023). The causes of the reduction in crop yield and quality due to excessive Zn deficiency. (Younas et. al., 2023). Controlled use of Zn fertilizers can meet Zn deficiency in potato crop (Gupta et al., 2023) and avoid its antagonistic effects with other mineral elements like P.

Mahmoud et al. (2019) reported that the potato plant is moderately sensitive to Zn deficiency in the soil and agreed on the positive role of Zn and its utility in stopping the spread of many diseases. Although there is no decrease in the yield of plants with 20 g kg^{-1} Zn, it is agreed and established that the potato tubers show abnormalities if their level falls below 10 g kg^{-1} Zn. A large part of the Central Anatolian region faces erratic rainfall, with 92% of soils showing a quite low amount of 0.5 g kg^{-1} available Zn (Singh et al., 2023). Fertilizers with combined many trace elements (Fe, Cu, Mn, Zn, etc.) are also recommended for overhead foliar treatments in potatoes (Çağlar and Cengiz, 2023). Alternative ways to apply zinc to zinc-deficient soils could be foliar spray or Zn-based encapsulation of seeds (Al Jabri et al., 2022) or foliar treatment of Zn. The two methods could be more advantageous to increase both tuber yield and quality of the end product compared to soil treatment of Zn (Phuphong et al., 2020) and ameliorate complicated soil interactions that limit root uptake of Zn (Mabesa et al., 2013).

Almost the half of the agricultural soils in Turkey are deficient in zinc (Ete Aydemir, 2024), and literature on the availability and role of Zn in the growth and development of potatoes in Central Anatolia or other regions is very limited Therefore, this study aimed to find effective Zn treatments in improving morpho-physiological levels of productivity, qualitative traits, and collect information about agronomic parameters of 10 different potato varieties under controlled greenhouse conditions.

2. Materials and Methods

This experiment was carried out in the experimental greenhouses of the Department of Field Crops, Faculty of Agriculture, Ankara University, from April 15 to August 15, 2023.

2.1 Plant Material and Growth Conditions

The cultivars used in this study were obtained from the Niğde Potato Research Institute, Türkiye, and are described in *Table 1*. The pots used in the experiment had dimensions of 30 × 26 cm. The seed tubers were planted in the pots using the hill planting method.The water-holding capacity of the soil was 30%. Each pot was irrigated with 1000 ml of water after every 3rd day. The temperature value was 24±2°C in the greenhouse, and the relative humidity was 50±2%. The photoperiod requirement was automatically controlled and maintained under light intensity of 45 µ Mol m^{-2} s^{-1}, for using 16 h light and 8 h dark fixed photoperiod.

Table 1. Used varieties in the study

Varieties	Origin	Maturity	Area of use
V1: Belmondo	Germany	Medium Earliness	Edible /Kitchen. Frying
V2: Soylu	Türkiye	Medium Earliness	Edible /Kitchen.
V3: Marabel	Austria	Medium Earliness	Frying and chips
V4: Agria	Germany	Medium Lateness	Edible /Kitchen. chips
V5: Russet Burbank	USA	Medium Earliness	Making French fries. chips
V6: Lady Olympia	The Netherland	Earliness	“ “ “ “
V7: Lady Claire	“ “	Medium Earliness	Making French fries
V8: Madeleine	“ “	Medium Earliness	Edible/kitchen
V9: Lady Rosetta	“ “	Medium Earliness	Chips
V10: Alegria	Peru & Mountains	Medium Earliness	Edible/Kitchen

The field soil used in the experiment was collected from the surface layer (0–30 cm) and was characterized as clay and loam soils with alkaline characteristics and low organic matter were used as soil substrates in the experiment (*Table 2*). The content of Zn in the soil used in the experiment was 0.54 g kg^{-1}, which means that it was very low in the soil. The reference values of Zinc in soil were determined as very low (< 2.0 g kg^{-1}), low (2.0-5.0 g kg^{-1}), medium (5.0-10.0 g kg^{-1}), sufficient (10.0-8.00 g kg^{-1}), and excessive (>80.0 g kg−1) (Sillanpaeae, 1990).

Table 2. Soil analysis results

CaCO3	**pH**	EC (dS m^{-1})	Organic matter	P (mg kg^{-1})	Si (mg kg^{-1})
74.1	7.88	0.38	1.5	1.55	40.7
K (mg kg^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	Zn (mg kg^{-1})	Fe (mg kg^{-1})	Cu (mg kg^{-1})
178	4900	500	0.54	4.39	1.75

*Source: Ankara University, Faculty of Agriculture, Department of Soil Science and Plant Nutrition, Soil Analysis results Ankara (Anonymous, 2024a).

Table 3. Quality control results of irrigation water used (mg^{-1})

Parameter	Al	Sb	As	Cu	Ba	Br	Density	Hg	Zn	Fe	Se
Value	28.57	<1	1.12	<0.01	<0.5	<5	0.36	<1	0.01	7.35	<1
Parameter	Fl	Cd	Ch	Cr	Pb	Mn	NO3-	NO2−	Ph	Color	SO_4^{2-}
Value	<0.1	<1	756.5	<1	<1	2.81	1.06	<0.05	7.61	<5	84.5

* Source: Management of Ankara Water and Sewage, 2024 (Anonymous, 2024b).

The experiment had 3 replications under controlled greenhouse conditions and used four different doses of Zn applied as a foliar spray including Zn_0 treatment used as control and mentioned as Zn_0. The foliar Zn spraying was applied at two stagesi.e. beginning of the flowering (around 45 days) and 20 days after flowering (around 75 days) (Kara, 2016).

Foliar Zn treatment, was applied using “Miramax Combi Plus” commercial micronutrient solution, which contained 5% Zn as $ZnSO_4$. The solution was prepared using deionized water.

1. Zn_0: Control (Spray with deionized water only)
2. Zn_1: Spray with deionized water containing 0.625 g l^{-1}Zn,
3. Zn_2: Spray with deionized water containing 1.250 g l^{-1} Zn

4. Zn_3: Spray with deionized water containing 2.500 g l^{-1} Zn

2.2. Studying and Measurement with Potato Plants

Chlorophyll contents (SPAD unit): Chlorophyll content was determined using a SPAD-502 Plus chlorophyll meter (Konica Minolta, Japan) on five leaves per pot, one week after zinc application following flowering, according to the method described by Ok and Şanlı (2024).

Plant height (cm): Each plant was measured with a meter precisely from the top of the soil level without damaging the plants.

Tubers $plant^{-1}$ in each pot were counted manually to define the number of tubers $plant^{-1}$.

Tuber weight (g $plant^{-1}$) was calculated as the total tuber weight of one plant.

Mean tuber weight (g): The total tuber weight obtained from a plant was found by proportioning the total number of tubers.

Size distribution of tubers (%): Tubers were divided into three different groups in grams: <10 g = small tuber, 10-20 g = medium tuber, and >20 g = large tubers. The number of tubers, the average weight of each classification group, and the percentage of the sums for single individuals were calculated separately.

2.3. Statistical Analysis

The data were evaluated using analysis of variance (ANOVA) based on a two-factorial experiment arranged in a completely randomized design with three replications. Potato varieties constituted the main factor, while zinc treatments were considered as the sub-factor. Significant differences among the means were determined using Duncan's multiple range test. Statistical analyses were performed using JMP version 17.0 (SAS Institute, 2017), and statistical significance was considered at $p < 0.05$.The results were presented as mean ± standard deviation. Zinc applications (n=4) in potato varieties (n=10) were visualized using a heatmap and hierarchical clustering. The heatmap was plotted using the 'pheatmap' R package (version 1.0.12) (Kolde, 2019). Visualization of correlations between parameters was produced using the 'gcorrplot' R package (version 0.1.4.1) (Kassambara and Kassambara, 2019).

3. Results and Discussion

3.1 Chlorophyll contents (SPAD unit)

Chlorophyll contents (SPAD unit) are given in *Table 4*. The result mentioned a significantly important interaction between the varieties and Zn treatment ($p < 0.05$). The highest chlorophyll content was obtained by foliar spraying 1.25 g l^{-1} Zn on Agria with a SPAD value of 52.60±2.07, and the minimum SPAD value of 33.67±2.49 was exhibited by L. Rosetta after control treatment (Zn_o). Significant differences were noted in chlorophyll contents among the varieties used in the study ($p < 0.05$). The maximum SPAD value among varieties was found in Agria, and the minimum SPAD value was L. Rosetta. A comparison of several doses of Zn showed significant differences among themselves ($p < 0.05$). The maximum SPAD value was noted after 2.500 g l^{-1} treatment, showing improvement over the control treatment indicating a SPAD value. (*Table 4*).

The effect of the different Zn treatments on plant growth and the various plants was largely determined by the soil or edaphic factor. In particular, alkaline pH greatly reduced the solubility of Zn, causing it to co-precipitate with other elements, including Ca, especially on $CaCO_3$ or loam soils (González-Caballo et al., 2022). Sarkar et al. (2018) mentioned that the specific effect of Zn on photosynthesis indicates that Zn is involved in the synthesis of carbohydrates depending on the plant species such that the degree of Zn deficiency reduces net photosynthesis by 50-70% (Mattiello et al., 2015). Especially, the size of the leaves where the photosynthesis takes place affects the total photosynthetic capacity of the plant (Ödemiş and Çalışkan, 2014), which is rather sensitive to the Zn spraying, according to these observations. Overall, the results demonstrate that foliar Zn application at appropriate growth stages enhances chlorophyll content in potato, and that varietal differences, Zn dose, and soil properties interactively determine the magnitude of the response. These findings are consistent with previous studies indicating that Zn availability directly affects photosynthetic capacity and plant physiological performance.

***Table 4. Effects of Zn treatment on Chlorophyll Contents (SPAD Unit) in different varieties of potato*.**

Varieties	Chlorophyll Contents (SPAD unit)				
	Zn_0	**Zn_1**	**Zn_2**	**Zn_3**	**Mean**
Belmondo	$37.73\pm2.17^{k-n}$	$40.53\pm0.87^{g-n}$	$45.80\pm1.05^{a-h}$	$44.87\pm2.40^{c-i}$	**42.23 ± 3.73^{CD}**
Soylu	$37.13\pm2.24^{l-n}$	$39.33\pm0.86^{g-n}$	$41.33\pm1.46^{f-m}$	$44.27\pm0.60^{d-k}$	**40.52 ± 3.00^{CD}**
Marabel	$38.80\pm3.15^{i-n}$	$40.93\pm2.23^{g-m}$	$45.23\pm2.80^{b-i}$	$48.03\pm4.77^{a-f}$	**43.25 ± 4.74^{BC}**
Agria	$45.40\pm2.19^{b-i}$	$49.63\pm2.25^{a-d}$	52.60 ± 2.07^{a}	51.93 ± 3.69^{ab}	**49.89 ± 3.70^{A}**
Russet Burbank	35.70 ± 2.69^{mn}	$39.07\pm2.25^{h-n}$	$44.43\pm1.37^{d-k}$	$42.97\pm1.59^{d-l}$	**40.54 ± 3.97^{CD}**
Lady Olympia	$37.90\pm1.61^{j-n}$	$43.33\pm2.20^{d-l}$	$48.30\pm0.82^{a-e}$	$51.50\pm1.28^{a-c}$	**45.26 ± 5.54^{B}**
Lady Claire	$37.30\pm1.87^{l-n}$	$43.17\pm1.95^{d-i}$	$48.50\pm2.52^{a-e}$	52.03 ± 1.44^{ab}	**45.25 ± 6.06^{B}**
Madeleine	35.57 ± 0.65^{mn}	$39.03\pm0.40^{h-n}$	$42.23\pm1.79^{e-m}$	$44.77\pm0.91^{c-j}$	**40.40 ± 3.72^{D}**
L. Rosetta	33.67 ± 2.49^{n}	$38.80\pm1.78^{i-n}$	$41.30\pm1.59^{f-m}$	$46.27\pm1.78^{a-g}$	**40.01 ± 5.02^{D}**
Alegria	33.70 ± 2.74^{n}	$40.33\pm0.85^{g-n}$	$43.67\pm3.30^{d-i}$	$49.67\pm1.46^{a-d}$	**41.84 ± 6.34^{CD}**
Mean	**37.29 ± 3.73^{D}**	**41.42 ± 3.50^{C}**	**45.34 ± 3.87^{B}**	**47.63 ± 3.87^{A}**	

* Results are given as mean (±SD). All values shown in a single column and row are statically different using the Duncan test ($p < 0.05$). Abbreviation: Zn_0; Control 0.0 g l^{-1} Zn, Zn_1;0.625 g l^{-1} Zn, Zn_2; 1.250 g l^{-1} Zn, Zn_3; 2.500 g l^{-1} Zn

3.2 Plant height (cm)

The plant height (cm) of potatoes is given in *Table 5*. The results showed significant differences ($p < 0.05$) between the varieties and Zn treatments. The maximum plant height was obtained after using the 2.500 g l^{-1} Zn on L. Claire which obtained a height of 64.63±0.51 cm. The minimum plant height of 46.17±0.21 cm was exhibited after the treatment of Marabel with Zn_0. The study showed differences among varieties were significantly different ($p < 0.05$). The maximum plant height was found in the Lady Olympia variety and the minimum value was noted for L. Rosetta. Significant differences were noted among Zn doses ($p < 0.05$). The tallest plants were noted after treatment with 2.500 g L^{-1} Zn_3, showing sharp improvement over the plant height of each variety noted after control treatment (*Table 5*).

Table 5. Effects of Zn treatment on plant heights (cm) in different varieties of potato

Varieties	Plant Heights (cm)				
	Zn_0	**Zn_1**	**Zn_2**	**Zn_3**	**Mean**
Belmondo	$49.59\pm0.65^{p-t}$	$52.85\pm1.47^{l-q}$	$56.05\pm1.37^{i-m}$	$61.54\pm0.51^{a-f}$	**$55.01\pm4.70^{A-C}$**
Soylu	$48.74\pm0.88^{r-t}$	$53.38\pm1.24^{l-p}$	$57.86\pm1.94^{f-k}$	$61.33\pm1.27^{a-g}$	**$55.33\pm5.08^{A-C}$**
Marabel	46.17 ± 0.21^{t}	$55.09\pm1.37^{j-n}$	$59.46\pm1.28^{c-i}$	63.67 ± 0.67^{a}	**56.10 ± 6.83^{AB}**
Agria	$49.81\pm0.85^{p-t}$	$54.18\pm0.96^{k-o}$	$58.45\pm0.58^{e-j}$	63.30 ± 1.14^{ab}	**56.43 ± 5.28^{A}**
Russet Burbank	46.82 ± 0.48^{t}	$52.74\pm0.72^{i-q}$	$57.49\pm1.60^{h-k}$	$61.86\pm0.51^{a-e}$	**54.73 ± 5.89^{BC}**
Lady Olympia	$49.33\pm1.21^{q-t}$	$54.23\pm0.96^{k-o}$	$59.62\pm0.33^{b-i}$	$62.61\pm1.39^{a-d}$	**56.45 ± 5.39^{A}**
Lady Claire	48.15 ± 1.12^{st}	$51.14\pm1.22^{o-s}$	$56.31\pm0.79^{i-m}$	64.63 ± 0.51^{a}	**$55.06\pm6.58^{A-C}$**
Madeleine	48.26 ± 2.21^{st}	$52.58\pm1.54^{m-q}$	$58.82\pm0.56^{d-j}$	$62.71\pm0.96^{a-c}$	**$55.59\pm5.95^{A-C}$**
Lady Rosetta	48.21 ± 0.42^{st}	$52.15\pm1.33^{n-r}$	$56.53\pm1.27^{i-l}$	$60.90\pm0.94^{a-h}$	**54.45 ± 5.04^{C}**
Alegria	48.11 ± 1.65^{st}	$52.95\pm2.42^{l-q}$	$57.70\pm0.72^{g-k}$	64.15 ± 0.67^{a}	**$55.73\pm6.33^{A-C}$**
Mean	**48.32 ± 1.45^{D}**	**53.13 ± 1.60^{C}**	**57.83 ± 1.56^{B}**	**62.67 ± 1.43^{A}**	

* Results are given as mean (±SD). All values shown in a single column and row are statically different using the Duncan test ($p < 0.05$). Abbreviation: Zn_0; Control 0.0 g l^{-1} Zn, Zn_1;0.625 g l^{-1} Zn, Zn_2; 1.250 g l^{-1} Zn, Zn_3; 2.500 g l^{-1} Zn

Treatment of different concentrations of Zn showed improvement and positive results, as depicted by plant height. In a previous study, it was found that 4 kg of da^{-1} zinc treatment increased plant height by 11.0% compared to the control (Mahmud et al., 2021). In the studies carried out with lentils (Singh and Bhatt, 2013), peanuts (Irmak et al., 2015), and coriander (Özbek, 2020), it was observed that increasing amounts of Zn treatments had a beneficial effect on plant height by increasing photosynthetic activity in plants, and the results obtained were compatible with our study. Moreover, the promotion of growth appears to be more pronounced during the vegetative stage than the generative stage. Foliar Zn applications have been shown to stimulate overall growth, improve root strength and plant vigor (particularly leaf color), and enhance chlorophyll content, leading to positive morphological and agronomic changes in potato varieties (Brestic and Allakhverdiev, 2022; Meng et al., 2023).

These results align with previous findings indicating that Zn fertilization positively affects both plant growth and photosynthetic performance (Das et al., 2018).

3.3 Number of Tubers (Tubers plant^{-1})

Tubers per plant of varieties were given in *Table 6*. An interaction was noted among the varieties for tubers per plant using different Zn doses ($p < 0.05$). The maximum number of tubers per plant was obtained from the Zn_3 treatment for Agria with 8.95±0.05 tubers per plant, and the minimum number of tubers per plant was noted using Zn_o (control) for L. Rosetta with 6.10±0.08 tubers per plant. Significant differences ($p < 0.05$) in the number of tubers per plant were visible among the experimental varieties. The highest number of tubers per plant was obtained from Agria, and the minimum number of tubers per plant was noted on Soylu. Significant differences ($p < 0.05$) were found among Zn doses. Each increase in the dose of Zn ended up with an increased number of tubers, with a maximum number of tubers obtained after the treatment with Zn_3, and a minimum number of tubers per plant after Zn_o treatment (*Table 6*). These findings suggest that foliar Zn application positively influences tuber formation, thereby enhancing yield. Previous studies support these results: Zn application increased tuber yield by 10.67% compared to the control (Al-Jobori et al., 2014), and foliar Zn treatments improved tuber number as well as other yield- and quality-related traits in potatoes (Gaj et al., 2020). Hussain et al. (2022) emphasized that Zn fertilization promotes tuber number and yield by enhancing protein and carbohydrate metabolism, as well as enzyme activity in the plant. Similarly, Mondal et al. (2015) reported that the beneficial effects of Zn on tuber formation contribute significantly to yield improvement.

Table 6. Effects of Zn treatment on Number Tubers per Plant in different varieties of potato

Varieties	Number of Tubers per Plant				
	Zn_0	**Zn_1**	**Zn_2**	**Zn_3**	**Mean**
Belmondo	6.41±0.21^{no}	6.80±0.20^{k-o}	7.61±0.23$^{e-ı}$	8.62±0.14^{a-d}	**7.36±0.90^{CD}**
Soylu	6.18±0.15^{no}	6.52±0.15^{m-o}	6.90±0.45$^{ı-o}$	7.91±0.10^{b-g}	**6.88±0.71^{E}**
Marabel	6.94±0.09^{h-o}	7.92±0.52^{b-g}	8.49±0.21^{a-e}	8.76±0.10^{a-c}	**8.03±0.77^{A}**
Agria	7.09±0.34^{g-n}	7.74±0.27^{d-k}	8.64±0.12^{a-d}	8.95±0.05^{a}	**8.10±0.79^{A}**
Russet Burbank	6.69±0.30^{l-o}	7.62±0.20^{e-l}	7.77±0.30^{d-j}	8.44±0.18^{a-e}	**7.63±0.69^{BC}**
Lady Olympia	6.82±0.4 $^{j-o}$	7.56±0.67$^{e-ı}$	8.74±0.28^{a-c}	8.86±0.06^{ab}	**7.99±0.95^{AB}**
Lady Claire	6.40±0.18^{n-o}	7.41±0.21^{f-m}	7.82±0.25$^{c-ı}$	8.42±0.23^{a-e}	**7.51±0.79^{CD}**
Madeleine	6.53±0.25^{m-o}	7.62±0.40^{e-l}	7.84±0.60$^{c-ı}$	8.32±0.14^{a-f}	**7.58±0.76^{C}**
Lady Rosetta	6.10±0.08^{o}	6.82±0.23^{j-o}	6.79±0.63^{k-o}	7.89±0.35^{c-h}	**6.90±0.74^{E}**
Alegria	6.14±0.08^{no}	6.95±0.14^{h-o}	7.40±0.18^{f-m}	8.04±0.18^{a-g}	**7.13±0.7 ^{DE}**
Mean	**6.53±0.39^{D}**	**7.30±0.54^{C}**	**7.80±0.72^{B}**	**8.42±0.40^{A}**	

* Results are given as mean (±SD). All values shown in a single column and row are statically different using the Duncan test ($p < 0.05$). Abbreviation: Zn_0; Control 0.0 g l^{-1} Zn, Zn_1;0.625 g l^{-1} Zn, Zn_2; 1.250 g l^{-1} Zn, Zn_3; 2.500 g l^{-1} Zn

3.4 Tuber Weight per Plant (g plant^{-1})

The interaction of varieties and Zn doses showed significant variations ($p < 0.05$) in terms of gain in tuber weight per plant. Considering the interaction, the maximum tuber weight plant^{-1} of 205.20±11.03 g was obtained from the Zn_3 treatment from Agria, and the lowest tuber yield per plant of 82.73±4.01 g was exhibited on L. Rosetta with on Zn_0 (*Table 7*). The difference in mean tuber weight (g) for varieties was important ($p < 0.05$). When the varieties were compared, the maximum value of tuber weight per plant was obtained from Agria, and the minimum value was obtained from Soylu. The tuber yield per plant indicated significantly different effects with increasing Zn doses ($p < 0.05$). Consequently, the maximum tuber yield of the plant was noted after the foliar treatment of Zn_3, and the minimum tuber yield was obtained from Zn_o (Control) foliar treatment (*Table 7*).

Zinc application not only increased total tuber number but also improved tuber weight per plant (Hussein et al., 2022; Aryal et al., 2023). Sarkar et al. (2018) reported that Zn fertilization can increase cytokinin levels as well as photosynthesis and respiration rates, which reduces apical dominance and promotes the formation of more tubers per plant. Previous studies corroborate these findings. The positive effect of Zn on tuber formation has also been highlighted by Farouk (2015). Similarly, Mahmud et al. (2021) reported that Zn fertilization between 0 and 5 kg ha^{-1} increased potato yield from 29.50 to 35.83 tons ha^{-1}. Comparable improvements in tuber yield were reported in wheat by El-Sobky (2021), and Seleiman et al. (2023) observed increased potato tuber yield following exogenous Zn application.

Table 7. Effects of Zn treatment on tuber weight per plant (g) in different varieties of potato.

Varieties	Tubers Weight per plant (g)				
	Zn_0	Zn_1	Zn_2	Zn_3	Mean
Belmondo	97.09±8.48^{m-o}	111.74±6.27^{i-o}	132.55±5.38^{f-l}	171.35±9.11^{a-e}	**128.18±29.86^{BC}**
Soylu	87.67±7.02^{no}	101.65±6.87^{l-o}	112.81±14.87^{i-o}	142.94±4.00^{d-j}	**111.27±22.63^{D}**
Marabel	116.13±1.98^{h-o}	144.92±17.71^{d-i}	166.43±11.61^{b-f}	184.06±9.66^{a-c}	**152.89±28.28^{A}**
Agria	119.65±8.76^{h-n}	137.86±8.43^{e-k}	173.60±10.26^{a-d}	205.20±11.03^{a}	**159.08±35.39^{A}**
R. Burbank	107.49±11.04^{k-o}	133.46±4.61^{f-l}	138.97±9.02^{e-k}	165.16±9.84^{b-f}	**136.27±22.72^{B}**
L. Olympia	111.40±11.92^{i-o}	135.05±20.42^{f-l}	187.34±23.52^{a-c}	194.00±3.05^{ab}	**156.95±39.07^{A}**
L. Claire	96.67±7.11^{m-o}	127.78±5.60^{g-m}	138.98±7.97^{e-k}	161.52±8.20^{b-g}	**131.24±25.19^{BC}**
Madeleine	101.83±9.73^{l-o}	134.42±10.86^{f-l}	142.43±16.99^{d-j}	158.21±5.03^{c-g}	**134.22±23.61^{B}**
L. Rosetta	82.73±4.01^{o}	111.64±6.78^{i-o}	109.36±18.73^{j-o}	143.33±11.16^{d-j}	**111.77±24.51^{D}**
Alegria	85.27±3.63^{o}	116.53±4.53^{h-o}	127.94±4.12^{g-m}	147.50±6.16^{d-h}	**119.31±23.90^{CD}**
Mean	**100.59±14.19^{D}**	**125.50±16.24^{C}**	**143.04±27.09^{B}**	**167.33±21.76^{A}**	

* Results are given as mean (±SD). All values shown in a single column and row are statically different using the Duncan test ($p < 0.05$).
Abbreviation: Zn_0; Control 0.0 g l^{-1} Zn, Zn_1;0.625 g l^{-1} Zn, Zn_2; 1.250 g l^{-1} Zn, Zn_3; 2.500 g l^{-1} Zn

3.5 Mean Tuber Weight (g)

Mean tuber weight (g) showed a statistically significant interaction between varieties and Zn treatments ($p < 0.05$). The maximum mean tuber weight of 22.93±1.11 g was obtained from the Zn_3 treatment using Agria. The minimum mean tuber weight of 13.56±0.49 g was obtained after Zn_o (control) treatment using Lady Rosetta (*Table 8*). The difference in mean tuber weight (g) among varieties was significantly different ($p < 0.05$). The highest mean tuber weight was noted on Lady Olympia, and the lowest mean tuber weight was obtained from Lady Rosetta (*Table 8*) among the varieties. Average tuber weight (g), increased with each increase in dose of Zn ($p < 0.05$). The maximum and minimum mean tuber weight were obtained after the Zn_3 treatment and the Zn_0 (control) treatment (*Table 8*).

Table 8. Effects of Zn treatment on mean tuber weight (g) in different varieties of potato.

Varieties	Mean tuber weight (g)				
	Zn_0	Zn_1	Zn_2	Zn_3	Mean
Belmondo	15.14±0.81^{j-m}	16.43±0.44^{h-k}	17.42±0.19^{f-j}	19.88±0.75^{b-e}	17.22±1.89^{BC}
Soylu	14.17±0.79^{k-m}	15.57±0.68^{i-m}	16.30±1.14^{h-l}	18.08±0.27^{d-h}	16.03±1.61^{D}
Marabel	16.73±0.06^{g-j}	18.24±1.06^{d-h}	19.59± 0.88^{b-f}	21.01±0.85^{a-c}	18.89±1.80^{A}
Agria	16.86±0.43^{g-j}	17.80±0.46^{d-i}	20.08±0.91^{b-d}	22.93±1.11^{a}	19.42±2.53^{A}
Russet Burbank	16.04±0.94^{h-i}	17.50±0.14^{e-j}	17.88±0.48^{d-i}	19.56±0.73^{b-f}	17.75±1.42^{B}
Lady Olympia	16.30±0.74^{h-l}	17.81±1.09^{d-i}	21.39±2.02^{a-c}	21.90±0.19^{ab}	19.35±2.68^{A}
Lady Claire	15.10±0.71^{j-m}	17.25±0.26^{f-j}	17.76±0.46^{d-i}	19.19±0.45^{c-g}	17.32±1.59^{BC}
Madeleine	15.57±0.91^{i-m}	17.64±0.54^{d-i}	18.13±0.81^{d-h}	19.00±0.29^{c-g}	17.58±1.44^{B}
Lady Rosetta	13.56±0.49^{m}	16.37±0.43^{h-k}	16.03±1.27^{h-i}	18.15±0.62^{d-h}	16.03±1.83^{D}
Alegria	13.88±0.43^{l-m}	16.77±0.31^{g-k}	17.29±0.14^{f-j}	18.34±0.37^{d-h}	16.57±1.75^{CD}
Mean	15.33±1.27^{D}	17.14±0.95^{C}	18.19±1.83^{B}	19.80±1.68^{A}	

* Results are given as mean (±SD). All values shown in a single column and row are statically different using the Duncan test ($p < 0.05$).
Abbreviation: Zn_0; Control 0.0 g l^{-1} Zn, Zn_1;0.625 g l^{-1} Zn, Zn_2; 1.250 g l^{-1} Zn, Zn_3; 2.500 g l^{-1} Zn

3.6 Size distribution of tubers (%)

The distribution of tuber size (g) was significantly (>10 g) affected by the concentrations of foliar Zn spray. The highest percentage of small tubers was obtained from the L. Rosetta and Alegria (50%) in the control (Zn_o) treatment (*Figure 1*). The highest age of medium tubers (10-20 g) was obtained by the Soylu (70.1%) after application of control (Zn_o) treatment (*Figure 2*). The highest percentage of large tubers (20 < g) was obtained from the Agria (89.4%) using 2.50 g l^{-1} (Zn_3) treatment (*Figure 3*).

The tubers were grouped as small, medium, and large. They induced 26.1% small tubers, 36.9% medium, and 38.0% large tubers on the control treatment without any Zn. They induced 14.6% small tubers, 34.8%% medium, and 50.6% large tubers after treatment with Zn_1. 10.6% of small tubers, 29.4% of medium tubers, and 60.0% of large tubers were produced after Zn_2 treatment.11.0 % of small tubers, 23.5% of medium tubers, and 65.5% of large tubers were exhibited after using Zn_3 (*Figure 4*). In the tuber distribution (g) with increasing rates of Zn treatment, a decrease in the number of small tubers and an increase in the number of large tubers was observed (*Figure 4*). This is attributed to the fact that Zn plays an active role in the vegetative development period of the plant and increases the rate of photosynthesis (Hussein et al., 2022).

Tamanini Junior et al. (2023) informed of the positive effects of $ZnSO_4$ on crop development and the transport of nutrients to growing tubers. Later studies revealed that the use of Zn helped increase the mean weight of tubers moving from small to medium and moving from medium to large size (Khan et al., 2019). The results obtained in this study are in agreement with the previously described information. The previous study showed that applying Zn also helped increase individual tubers' mean weight from small to large (Hussein et al., 2022). Mahmud et al., (2021) reported in their study that 4 kg ha^{-1} zinc fertilization increased the yield of larger tubers in potatoes compared to the control. Results show that the yield increase was the cumulative effect of increased numbers of large tubers.

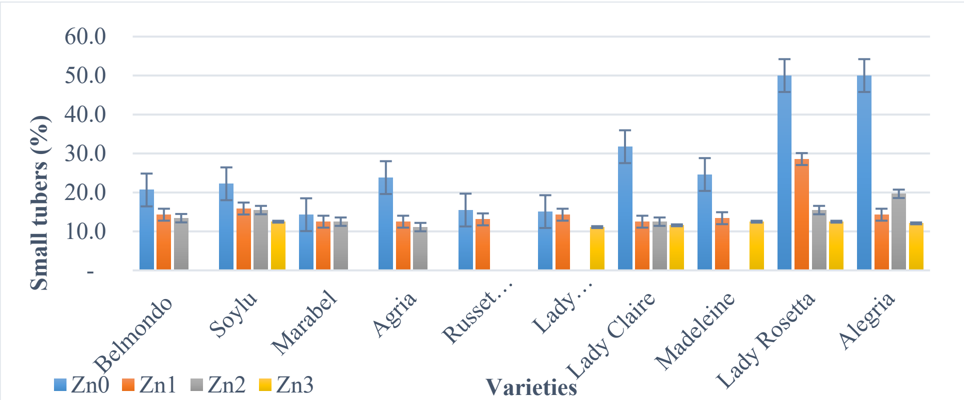

Figure 1. The distribution of the small tubers (%) in the different varieties with increasing concentrations of the zinc application. Four treatments Zn_0 (Control), Zn_1 (0.625 g l^{-1}), Zn_2 (1.250 g l^{-1}), and Zn_3 (2.500 g l^{-1})

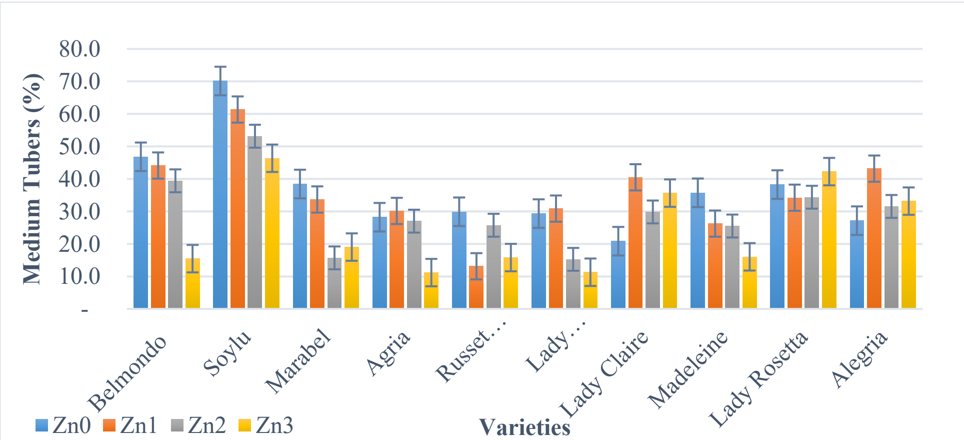

Figure 2. The distribution of the medium tubers (%) in the different varieties with increasing concentrations of the zinc application. Four treatments Zn_0 (Control), Zn_1 (0.625 g l^{-1}), Zn_2 (1.250 g l^{-1}), and Zn_3 (2.500 g l^{-1})

Visualization of correlations between variables is given in *Figure 5*. There is a positive correlation between the chlorophyll content of the plant, the leaf area index, the plant height, the number of tubers in the plant, the tuber yield, and the mean tuber weight. In terms of tuber distribution (%), it is clear that chlorophyll has a negative relationship with small and medium-sized tubers and a positive relationship with large tubers. The leaf area index was positively correlated with plant height, number of tubers per plant, tuber yield per plant, mean tuber weight, and large tuber ratio, while negatively correlated with small and medium tuber ratios. The number of tubers per plant and tuber yield was positively correlated with the mean number of tubers and large tuber ratios; on the other hand, a negative relationship was found between small tuber and medium tuber ratios (*Figure 5*).

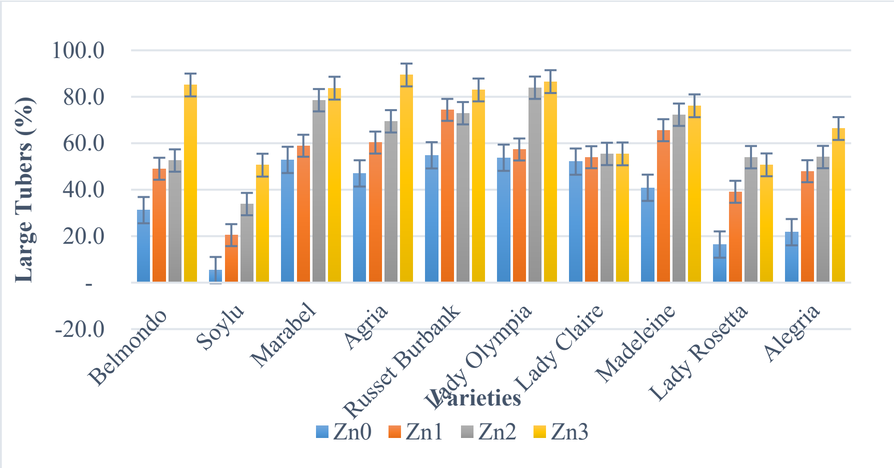

Figure 3. The distribution of the large tubers (%) in the different varieties with increasing concentrations of the zinc application. Four treatments Zn_0 (Control), Zn_1 (0.625 g l^{-1}), Zn_2 (1.250 g l^{-1}), and Zn_3 (2.500 g l^{-1}).

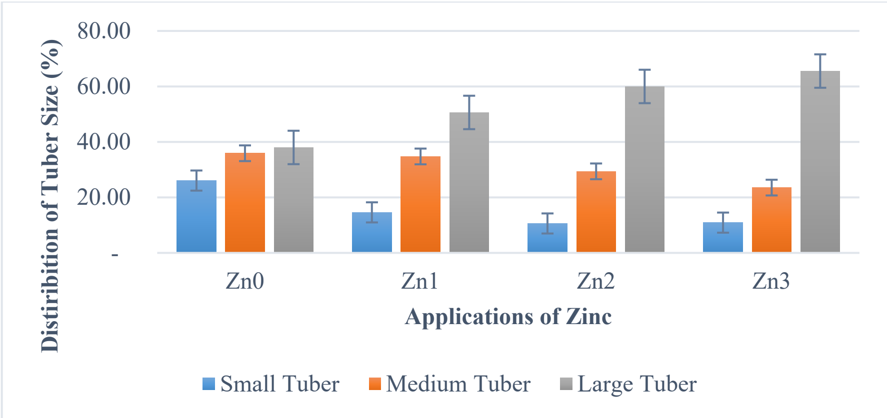

Figure4. The distribution of the tubers (%) in the different concentrations of the zinc application. Four treatments Zn_0 (Control), Zn_1 (0.625 g l^{-1}), Zn_2 (1.250 g l^{-1}), and Zn_3 (2.500 g l^{-1}).

Then, two types of dendrograms, namely a horizontally directed genotype dendrogram and a vertically directed trait dendrogram, were partitioned (*Figure 6*). A light-to-dark-red color intensity with negative values in all studied traits is displayed for V6-1 (Lady Olympia-control), indicating large tuber, mean tuber weight and chlorophyll content, and for V3-1 (Marabel-Control) indicating leaf area index. This is followed by V2-1 (Soylu-Control) which obtained negative values in most of the traits except for large tuber. A darker blue color intensity with higher positive values for most of the studied traits was found in V9-1 (Lady Rosetta-Control), V10-1 (Alegria-Control) representing a higher susceptibility to the small tuber, V2-1 (Soylu-control) for medium tuber and V4-4 (Agria-Zn_3) mean tuber weight and tuber yield per plant.

Heatmap hierarchical clustering analysis is one of the most common multivariate statistical methods that allows the genotypes and the examined traits in the studies to be evaluated together (Erkek et al., 2025). The comparisons presented in this way define the relationship between the practices (Islam et al., 2024). The cluster heatmap analysis also groups various traits between genotypes (Sakinah et al., 2021). Heat map analysis is widely preferred for comparing traits in many plants. For example, it is successfully used in alfalfa (Wang et al., 2024) and field crops such as mung beans (Islam et al., 2024).

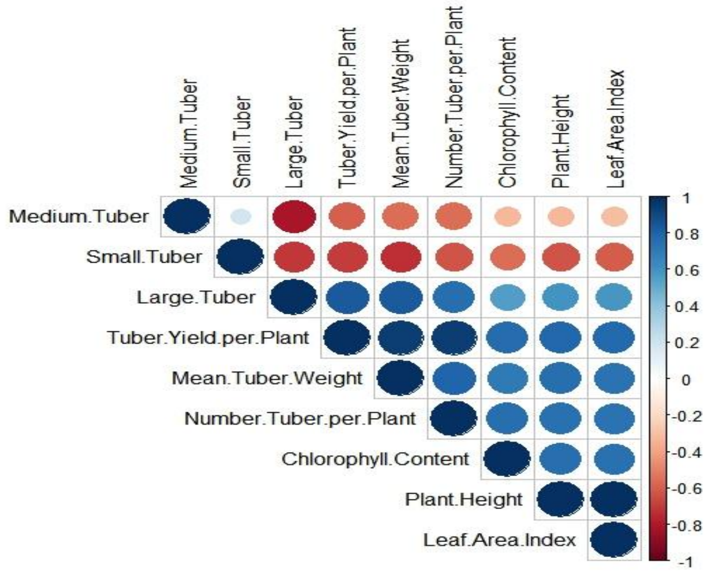

Figure 5. Visualization of correlations between variables

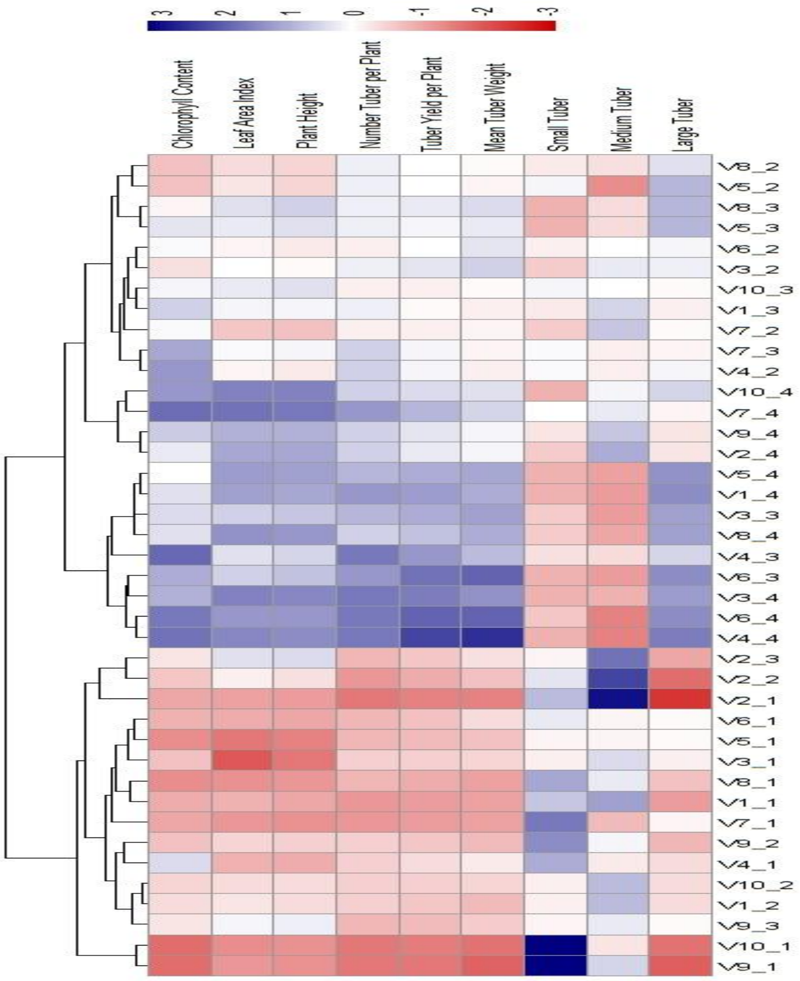

Figure 6. Heat map of hierarchal clustering analysis of parameters for potato varieties (n = 10) and zinc treatments (n=4). V1:Belmondo, V2:Soylu, V3:Marabel,V4:Agria, V5:Russet Burbank, V6;Lady Olympia, V7:Lady Claire, V8:Madeleine, V9:Lady Rosetta, V10:Alegria. 1: Zno; Control (0.0 g l^{-1}Zn), 2: Zn_1; 0.625 g l^{-1}Zn, 3: Zn_2; 1.250 g l^{-1} Zn, 4: Zn_3; 2.500 g l^{-1} Zn

4. Conclusion

According to the results obtained in our study, it was observed that Zn application at increasing doses through foliar application increased the photosynthetic activity of the plant. As a consequence of this, plant height increased. An increase in the tuber yield of each variety was observed in this study, which was carried out on alkaline soils by applying foliar zinc to increase the yield of potatoes. In summary, ıt was concluded that a zinc dose of 2.500 g l^{-1} applied by the foliar spraying method increased potato yield positively in potato varieties, especially the Agria variety, with different genotypic characteristics grown under greenhouse conditions.

Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

The author declares that there is no conflict of interests

Authorship Contribution Statement

Concept: Koçak Şahin, N.; Design: Koçak Şahin, N.; Data Collection or Processing: Koçak Şahin, N.; Statistical Analyses: Koçak Şahin, N.; Literature Search: Koçak Şahin, N.; Writing, Review and Editing: Koçak Şahin, N.

References

Al Jabri, H., Saleem, M., Rizwan, H. M., Hussain, I., Usman, K. and Alsafran, M. (2022). Zinc oxide nanoparticles and their biosynthesis: overview. *Life*, 12: 594.

Al-Jobori, K. M. and Al-Hadithy, S. A. (2014). Response of potato (*Solanum tuberosum*) to foliar application of iron, manganese, copper and zinc. *International Journal of Agriculture and Crop Sciences*, 7: 358.

Anonymous (2024a). Ankara University, Faculty of Agriculture, Department of Soil Science and Plant Nutrition, Soil Analysis Results, Ankara, Türkiye.

Anonymous (2024b). Ankara Su ve Kanalizasyon İdaresi (ASKI). https://www.aski.gov.tr/TR/SuAnalizSonuclari.aspx (Accessed Date: 15.09.2024) (In Turkish)

Aryal, M., Pandey, K. R., Dhakal, S., Tumbapo, S. and Joshi, Y. (2023). Performance of potato cultivar “rolpa” local (*Solanum tuberosum* L.) under different mulching conditions and zinc levels at rolpa, Nepal. *Peruvian Journal of Agronomy*, 7:27-41.

Brestic, M. and Allakhverdiev, S. I. (2022). Photosynthesis under biotic and abiotic environmental stress. *Cells*, 11(24): 3953.

Çağlar, S. K. and Koç, C. (2023). The role and importance of village institutes in rural development and planning in Turkey. *Urban Academy*, 16(3):1620-1638. (In Turkish)

Das, S. K., Avasthe, R. K., Singh, M., Dutta, S. K. and Roy, A. (2018). Zinc in plant soil system and management strategy. *Agrica*, 7:130-136.

Demir, M. and Çalışkan, S. (2017). The effect of iron fertılızatıon on plant growth, yıeld and qualıty of potato (*Solanum tuberosum* L.). *KU Journal of Natural Sciences,* 20:241-245. (In Turkish)

Dhaliwal, S., Sharma, S. V and Shukla, A. K. (2022). Impact of micronutrients in mitigation of abiotic stresses in soils and plants: A progressive step toward crop security and nutritional quality. *Advances in Agronomy*, 173:1-78.

Duan, M., Liu, T., Liu, B., Yin, S., Zang, J., Zhao, C., Lv, G. and Zhang, T. (2023). Zinc nutrition and dietary zinc supplements. *Critical Reviews in Food Science and Nutrition*, 63(9):1277-1292.

El-Sobky, E. S. E. (2021). Response of wheat to micronutrients foliar application, compost and N fertilizer level. *Communications in Soil Science and Plant Analysis*, 52(13):1510-1526.

Erkek, B., Yaman, M., Sümbül, A., Demirel, S., Demirel, F., Çoskun, Ö. F., Say, A., Eren, B., Aydin, A. and Eroglu, A. (2025). The natural diversity of scrataegus monogyna Jacq. In Northeastern Türkiye encompasses morphological, biochemical, and molecular features. *Horticulturae*, 11: 238.

Ete Aydemir, Ö. (2024). The effect of zinc fertilization on dry matter yield and micronutrient uptake of different maize genotypes in zinc-deficient acid soil. *Akademik Ziraat Dergisi*, 13(2): 369-375. (In Turkish)

Fageria, N. K., Baligar, V. C. and Li, Y. C. (2008). The role of nutrient-efficient plants in improving crop yields in the twenty-first century. *Journal of Plant Nutrition*, 31(6):1121-1157.

Farouk, S. (2015). Improving growth and productivity of potato (*Solanum tuberosum* L.) by some bio-stimulants and lithovit with or without boron. *Journal of Plant Production,* 6(12): 2187-2206.

Gaj, R., Górski, D. and Majchrzak, L. (2020). The effect of potassium and micronutrient foliar fertilization on the content and accumulation of microelements, yield and quality parameters of potato tubers. *Agriculture*, 10(11):530.

Gonzalez, F., Pavek, M.J., Holden, Z.J. and Garza, R. (2023). Evaluating potato evapotranspiration and crop coefficients in the Columbia Basin of Washington state. *Agricultural Water Management*, 286:108371.

González-Caballo, P., Barrón, V., Torrent J Del Campillo, M. C. and Sánchez-Rodríguez, A. R. (2022). Wheat and maize grown on two contrasting zinc-deficient calcareous soils respond differently to soil and foliar application of zinc. *Journal of Soil Science and Plant Nutrition*, 22:1718–1731.

Gupta, S., Srivastava, P. K. and Singh, R. P. (2023). Application of plant growth-promoting microbes to enrich zinc in potatoes for nutritional security and sustainable agriculture. *Rhizosphere*, 25:100665.

Hussain, S., Khan, S.M., Jamal, A., Mihoub, A., Saeed, M. F., Khalid, M. S., Babar, S. and Ahmad, S. (2022). Improvement of growth, yield and biochemical properties of potato (*Solanum tuberosum* L.“Montreal” and “Red Bull”) by foliar application of zinc under calcareous soil conditions. *Gesunde Pflanze*, 74:561-570.

Hussein, A., Jiang, W., Wang, X., Shahid, S., Saba, N., Ahmad, M., Dar, A., Masood, S. U., Imran, M. and Mustafa, A. (2022). Mechanistic impact of zinc deficiency in human development. *Frontiers in Nutrition*, 9:717064.

İkinci, A. and Aldanmaz, Ş. (2022). The effect of boron and zinc containing foliar fertilizer applications on leaf mineral content of '0900 Ziraat' cherry (*Prunus avium* L.) cultivar. *Journal of Tekirdag Agricultural Faculty,* 19(2): 283-295. (In Turkısh)

Irmak, S., Cıl, A. N., Yucel, H. and Kaya, Z. (2015). Effects of zinc application on yield and some yield components in peanut *Arachis hypogaea* in the Eastern Mediterranean Region. *Journal of Agricultural Sciences*, 22 (1):109-116.

Islam, R., Hossain, J., Huda, S., Azam, G., Hossain, F., Zaman, A. U., Moula, S., Ahmed, N. U., Hossain, J., Sabagh, A.E. and Islum, M. S. (2024). Assessment of drought tolerance in mung bean [*Vigna radiata* (L.) Wilczek] through phenology, growth, protein yield, and cluster heatmap analysis. *The Philippine Agricultural Scientist*, 107(4): 6.

Kara, K. (2016). Determination of the performance of some potato varieties in Erzurum conditions. *Atatürk University Journal of the Agricultural Faculty,* 47(2): 95-99. (In Turkish)

Kassambara, A. and Kassambara, M. A. (2019). Package 'ggcorrplot'. R package version 0.1, 3(3): 908.

Khan, M. W., Rab, A., Ali, R., Sajid, M., Aman, F., Khan, I., Husseın, I. and Ali, A. (2019). Effect of potassium and zinc on growth, yield and tuber quality of potato. *Sarhad Journal of Agriculture*, 35:330-335.

Kolde, R. (2019). Pheatmap: Pretty heatmaps. R package version, 1(2): 726.

Laurent, C., Bravin, M. N., Crouzet, O., Pelosi, C., Tillard, E., Lecomte, P. and Lamy, I. (2020). Increased soil pH and dissolved organic matter after a decade of organic fertilizer application mitigate copper and zinc availability despite contamination. *Science of the Total Environment*, 709: 135927.

Mabesa, R. L., Impa, S. M., Grewal, D. and Johnson-Beebout, S. E. (2013). Contrasting grain-Zn response of biofortification rice (*Oryza sativa* L.) breeding lines to foliar Zn application. *Field Crops Research*, 149: 223-233.

Mahmoud, A. W. M., Abdeldaym, E. A., Abdelaziz, S. M., El-Sawy, M. B. and Mottaleb, S. A. (2019). Synergetic effects of zinc. Boron, silicon, and zeolite nanoparticles confer tolerance in potato plants subjected to salinity. *Agronomy*, 10(1): 19.

Mahmud, N. U., Ferdous, Z., Ullah, H., Ahmed, N. U., Molla, S. H. and Anwar, M. (2021). Effect of zinc on grading, quality and yield of potato (*Solanum tuberosum*) in Bangladesh. *İnternational Journal of Agricultural Technology*, 17(5):1821-1832.

Mattiello, E. M., Ruiz, H. A., Neves, J. C., Ventrella, M. C. and Araújo, W. L. (2015). Zinc deficiency affects physiological and anatomical characteristics in maize leaves. *Journal of Plant Physiology*, 183:138-143.

Meng, Y., Xiang, C., Huo, J., Shen, S., Tang, Y. and Wu, L. (2023). Toxicity effects of zinc supply on growth revealed by physiological and transcriptomic evidence in sweet potato (*Ipomoea batatas* (L.) Lam). *Scientific Reports,* 13: 19203.

Mondal, S. S., Patra, B. C. and Banerjee, H. (2015). Micronutrient Management. In: Advances in Potato Cultivation Technology. Ed(s): Mondal, S. S., Patra, B. C. and Banerjee, H., Kalyani Publishers, New Delhi, India.

Ödemiş, B. and Çalışkan, M. E. (2014). Photosynthetic response of potato plants to soil salinity. *Turkish Journal of Agricultural and Natural Sciences*, 1(2): 1429–1439.

Ok, F. Z., and Şanlı, A. (2024). The effects of foliar gibberellic acid applications on tuber yield, quality and dormancy period in potato (*Solanum tuberosum* L.). *Turkish Journal of Agriculture-Food Science and Technology*, 12(11): 1865-1871.(In Turkish)

Özbek, D. G. (2020). *The effects of zinc application on the yield and quality criteria of coriander (Coriandrum sativum L.) in Kayseri conditions* (MSc. Thesis). Erciyes University, Natural and Applied Sciences Institute, Kayseri, Türkiye. (In Turkish)

Phuphong, P., Cakmak, I., Yazici, A., Rerkasem, B. and Prom-u-Thai, C. (2020). Shoot and root growth of rice seedlings as affected by soil and foliar zinc applications. *Journal of Plant Nutrition*, 43: 1259-1267.

Rusinovci, I., Aliu, S., Demirbaş, S., Zeka, D. and Jakupi, M. (2024). The effect of heavy metals in potato (*Solanum Tuberosum* L.) genotypes for some physiological parameters. *Journal of Tekirdag Agricultural Faculty,* 21(4):980-987.

Sakinah, A., Musa, Y., Farıd, M., Anshorı, M.F., Arıfuddın, M. and Laraswatı, A. (2021). Cluster heatmap for screening the drought-tolerant rice through hydroponic culture. IOP Conf Ser: *Earth Environment Science*, 807:042045.

Saltali, K. and Nedirli, A. (2021) Phosphorus sorption by gyttja and its effect on the pH value and phosphorus in acidic soils. *Turkish Journal of Agriculture and Forestry*, 45: 402-410.

Sarkar, S., Banerjee, H. and Sengupta, K. (2018) Agronomic fortification of zinc in potato production in Indian context: A review. *Journal of Applied and Natural Science*, 10(3): 1037-1045.

SAS Institute Inc. (2017). JMP® Statistical Discovery Software, version 17.0, Cary, NC, U. S. A.

Seleiman, M. F., Al-Selwey, W. A., Ibrahim, A. A., Shady, M. and Alsadon, A. A. (2023). Foliar applications of ZnO and SiO_2 nanoparticles mitigate water deficit and enhance potato yield and quality traits. *Agronomy*, 13(2): 466.

Sillanpaeae, M (1990). Micronutrient assessment at the country level: An international study: FAO Soils Bulletin 63:208., Rome, Italy.

Singh, A. K. and Bhatt, B. P. (2013). Effect of foliar application of zinc on growth and seed yield of late-sown lentil (*Lens culinaris*). *Indian Journal of Agricultural Sciences*, 83: 622-626.

Singh, B., Sharma, J., Sood, S., Bhardwaj Siddappa, V., Dalamu, S., Kardile, H. B., Sharma, V., Bhawna, D., Vinod, K., Dua, V. K., Goutam, U. and Pandey, N. K. (2023). Genetic variations in tuber dry matter (%), yield and mineral concentrations in a diversity panel of tetraploid potatoes. *Potato Research*, 66:179-193.

Tamanini Junior, C., Anderle, L. Z., De Souza, L. B., Balena, L., Malanchuk, J. P., De Matos, C. K. and Kawakami, J. (2023). Tuber yield and quality of potato processing cultivars submitted to nitrogen rates. *Horticulcure Brasileira*, 41: e2562.

Usta, A., Yilmaz, M., Kocamanoğlu, Y. O. and Genc, E. (2018). Effects of land covers on hydro-physical soil characteristics in semi-arid environments: the case of Gumushane-Siran, Turkey. *Applied Ecology and Environmental Research*, 16: 5.

Wang, F., Wu, H., Yang, M., Xu, W., Zhao, W., Qiu, R., Kang, N. and Cui, G. (2024). Unveiling salt tolerance mechanisms and hub genes in alfalfa (*Medicago sativa* L.) through transcriptomic and WGCNA analysis. *Plants*, 13: 3141.

Yahaya, S. M., Mahmud, A. A., Abdullahi, M. and Haruna, A. (2023). Recent advances in the chemistry of nitrogen, phosphorus and potassium as fertilizers in soil: A review. *Pedosphere*, 33: 385-406.

Younas, N., Fatima, I., Ahmad, I. A., and Ayyaz, M. K. (2023). Alleviation of zinc deficiency in plants and humans through an effective technique; biofortification: A detailed review. *Acta Ecologica Sinica*, 43(3): 419-425.

Zhu, Y., Yu, Q., Luo, Q., Zhang, H., Zhao, J., Ju, Z., Du, Y. and Yang, Y. (2021). Impacts of climate change on suitability zonation for potato cultivation in Jilin Province Northeast China. *Scientific Reports,* 11(1): 13103.