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RESEARCH ARTICLE

Growth, Yield Components and Tuber Yield Responses of Potato (*Solanum tuberosum* L.) Varieties in High Altitude Regions of Türkiye

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ABSTRACT

Potato is one of Türkiye's strategic crops regarding food and economic benefits. However, the need for well-adapted and productive varieties is a production problem for the country. Therefore, evaluating such varieties with high yield potential and suitable for local environmental conditions is essential. Thus, this study was conducted to select potato varieties with good agronomic characteristics suitable for high-altitude regions such as Erzurum province in 2022. In the study, 12 potato varieties, seven local (Bahar, Kaya, Kafkas, Petek, Taş, Ayaz, Deniz) and five fixed (Pomqueen, Alegria, Marabel, Agria, and Marfona) were used as plant material. It was established according to the "Randomized Blocks" experimental design with three replications. The study's results revealed that the cultivars significantly affected all the variables. The highest plant height was recorded in the Pomqueen (89.6 cm) and Kaya (85.5 cm) varieties, while Kaya had the highest number of stems per hill (6.1 pieces). Concerning yield and yield components, the highest number of tubers per hill was recorded in Ayaz (17.5 pieces), while the highest tuber yield per hill and total tuber yield were recorded in Petek (1287.1 g and 5251.5 kg da^{-1}). This variety was followed by standard Alegria (4497.5 kg da^{-1}) and local Kaya (4441.0 kg da^{-1}) varieties in total tuber yield. Therefore, considering the yield potential, especially local Petek and Kaya and standard varieties Alegria and Marabel were promising and recommended to growers in regions with high altitudes and similar agroecology.

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1. Introduction

One of the world's most widespread and vital crops, the potato is a staple food for most of the world's population and has significant health benefits. In world production, potatoes (*Solanum tuberosum* L.) are the world's third largest crop for human consumption after wheat and rice. Rich in carbohydrates, vitamins, protein, and minerals, potatoes are consumed by more than one billion people worldwide (FAO, 2008; CIP, 2010). Therefore, today, the potato crop is an inevitable solution to the problem of population growth and hunger in the world, primarily since it can be grown at many latitudes and in almost all soil and climatic conditions (except in the equatorial region) (Shitikova et al., 2022).

Since potatoes can be grown from mid-altitude regions to the highest mountain peaks, from humid to dry areas, improvements in their productivity require the development of varieties that are best adapted to a wide range of environments (Kolech et al., 2015). Therefore, plant breeding programs should improve a crop's adaptability and tolerance to biotic stress to increase yield (Tessema et al., 2020).

Producers need high-yielding and stable varieties to reduce food demand and increase yield and quality significantly.

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Varieties with these traits can be easily adapted for long-term production in different environments. Therefore, varieties with these traits may overcome the challenges of genotype x variety interactions (Gedif & Yigzaw, 2014).

Variety performance is determined by the genotypic main effect, environmental influences, and the interaction between genotypes and environments (Yan et al., 2001). Hongyu et al. (2014) stated that it is essential to determine varieties' responses to different environments as part of the evaluation process, which will help breeders accurately determine the stability and adaptability of genotypes.

It has been emphasized that it is essential to identify the best-performing varieties on a regional basis to produce high-yielding potato tubers of high marketing and processing quality (Bilate & Mulualem, 2016; Habtamu et al., 2016; Bekele & Haile, 2019). There are no varieties that are difficult to find and have many potentials suitable for all environments and all uses (Bradshaw, 2007). Therefore, evaluating genotype × environment interactions can provide the most appropriate response to environmental adaptation. Tesfaye et al. (2012) reported that genotype, location, and genotype × environment interactions significantly affected dry matter content, starch content, and yield of potato varieties. Similar results were reported by many potato researchers (Abbas et al., 2011; Asefa et al., 2016a; Wassu, 2016; Matin et al., 2017; Nasiruddin et al., 2017).

Selecting the suitable variety for the correct region is a critical parameter, as is taking many measures to grow high-yielding and high-quality potatoes. Nowadays, many variety breeding studies are carried out for potatoes, and these varieties are transferred to different regions to determine the varieties with good adaptation, high quality, and high yield. This study aimed to select the potato varieties developed in our country with high adaptability and superior performance in terms of yield and quality for high-altitude regions such as Erzurum province.

2. Materials and Methods

The research was conducted in the farmer's field in the Yarımca Neighborhood of Aziziye District of Erzurum Province in 2022. The region is at 1853 m, at coordinates 39° 55' N and 41° 61' E. A total of 202.5 mm of rainfall was recorded during the plant growth period (May to October) of the experimental year, with the highest rainfall in May (89.3 mm) and June (80.4 mm). There was no rainfall (0 mm) in August. The average maximum and minimum temperatures during the study months were 9.1 and 22.0 ℃, respectively. The highest temperatures were recorded in July (19.3 ℃) and August (22.0 ℃). As a result of the analysis of the physical and chemical properties of the soil of the test site, it was determined that it was slightly alkaline, low in lime, total nitrogen, and available phosphorus, medium in organic matter, and rich in plant-available potassium.

In the study, 12 potato varieties, seven local (Bahar, Kaya, Kafkas, Honeycomb, Taş, Ayaz, Deniz) and five fixed (Pomqueen, Alegria, Marabel, Agria, and Marfona) developed by Doga Seed in the borders of Gülşehir (The district of Nevşehir province in Türkiye) for different ecologies of the country were used as plant material (Table 1).

Table 1. Potato varieties and some characteristics.

Variety	Origin	Time of Maturity	Utilisation Characteristics
Agria	Germany	Mid Late	Table / Industrial
Alegria	Germany	Mid Early	Table
Ayaz	Türkiye (Nevşehir)	Late	Crisp
Bahar	Türkiye (Nevşehir)	Late	French Fries / Table
Deniz	Türkiye (Nevşehir)	Early	Table
Taş	Türkiye (Nevşehir)	Early	Table
Kafkas	Türkiye (Nevşehir)	Mid Early	Table
Kaya	Türkiye (Nevşehir)	Late	French Fries / Table
Marabel	Austria (Kaltenberg)	Mid Early	Table
Marfona	Netherlands	Mid Early	Table
Petek	Türkiye (Nevşehir)	Mid Early	French Fries / Table
Pomqueen	Germany	Late	French Fries

The research was established using the "Randomized Blocks" experimental design with three replications. In the study's area, farmyard manure was homogeneously mixed with the soil in autumn before planting potatoes and left for winter. In addition, ammonium sulfate (12 kg da^{-1}) of nitrogen fertilizers and 10 kg of phosphorus fertilizer triple super phosphate (P_2O_5) were applied before planting as a supplement to farm manure. Seed potato tubers of the varieties were planted by hand in May 2022 in hills with 70 cm between rows and 35 cm above rows. When the plants reached 5-10 cm in height, the

first and second hoeing were 20-25 days after this hoeing. The earthing up and irrigation procedures were carried out according to climate and soil conditions from the beginning of flowering. Potato harvesting was carried out when the green parts of the potato yellowed and dried from the bottom, the stolons were separated from the main plant and the umbilical cord, and the tuber peel reached an average thickness, unpeelable feature, and a specific size. The data on plant height (cm), number of main stem per hill, number of tuber per hill, tuber yield per hill and total tuber yield (g and kg da^{-1}) were obtained from the two outermost rows and the middle two rows by ignoring the plants at the ends.

2.1. Statistical Analysis

All the data was analyzed using the SPSS package (SPSS, Version 20.0, SPSS Inc, Chicago, IL, USA). When the F-test indicated statistical significance at the p=0.05 level, the protected least significant difference (Protected DUNCAN) was used to separate the means (Steel & Torrie, 1980).

3. Results and Discussion

3.1. Analysis of Variance

The results of the analysis of variance showed that potato cultivars had highly significant ($p<0.01$) differences in plant height, number of main stem per hill, number of tuber per hill, tuber yield per hill and total tuber yield (Table 2).

Table 2. F values on yield and yield component response variables of potato (*Solanum tuberosum* L.).

Source	DF	F Values				
		Plant Height	Stem Number Per Hill	Tuber Number Per Hill	Tuber Yield Per Hill	Total Tuber Yield
Block	**2**					
Variety	**11**	21.920**	6.220**	13.110**	3.160**	6.506**
Error	**22**					

**: Highly significant at 1% level of probability; Df: Degree of freedom.

3.2. Mean Performance of Varieties for Growth Traits and Yield Components

The mean plant height of potato varieties varied between 43.3-86.6 cm. The highest height was measured in Pomqueen, and the shortest in Ayaz. The average plant height was 65.4 cm. In terms of the highest plant height, Pomqueen (86.6 cm), Kaya (85.5 cm), and Alegria (79.6 cm) had a statistically insignificant plant height, while they differed significantly from the other varieties. Ayaz (43.3 cm), Marfona (46.9 cm), and Taş (52.6 cm) varieties had shorter plant heights than all other varieties (Table 3, Figure 1). The different ripening periods (early, medium early, medium late, and late) of the potatoes used in the study may have caused variability in terms of plant growth. In addition, plant height is also a cultivar trait. It can be directly related to many factors such as genetic structure, growing period (Karakuş et al., 2011), light period, temperature, irrigation, care treatments, and soil fertility. Therefore, significant differences were found among cultivars.

Table 3. Mean value of plant height, stem and tuber number per hill, tuber yield per hill and total tuber yield as affected by potato varieties.

Variety	Plant Height (cm)	Stem Number Per Hill	Tuber Number Per Hill	Tuber Yield Per Hill (g)	Total Tuber Yield (kg da^{-1})
Agria	65.0cd	5.7ab	6.5f	834.3de	3344.5cd
Alegria	79.6ab	5.6abc	14.0b	1102.3abc	4497.5ab
Ayaz	43.3f	4.8cde	17.5a	974.3bcd	3974.5bcd
Bahar	67.7c	5.2bcd	9.5e	719.5e	3145.0de
Deniz	74.4bc	5.1bcd	10.5de	1163.3ab	3895.5bcd
Taş	52.6ef	4.2e	10.0de	917.5bcde	3753.7bcd
Kafkas	57.5de	5.4abcd	11.0cde	810.6de	3304.5cd
Kaya	85.5a	6.1a	9.5e	1089.2abc	4441.0ab
Marabel	57.8de	5.9ab	12.5bcd	1048.8abcd	4277.0bc
Marfona	46.9f	4.0e	6.5f	567.9f	2315.0e
Petek	67.8c	4.5de	13.5bc	1287.1a	5251.5a
Pomqueen	86.6a	4.7cde	9.5e	902.0cde	3678.5bcd
Mean	**65.4**	**5.2**	**10.9**	**1026.4**	**3823.2**

Means followed by different letters in the same column are significantly different at 1% level of probability.

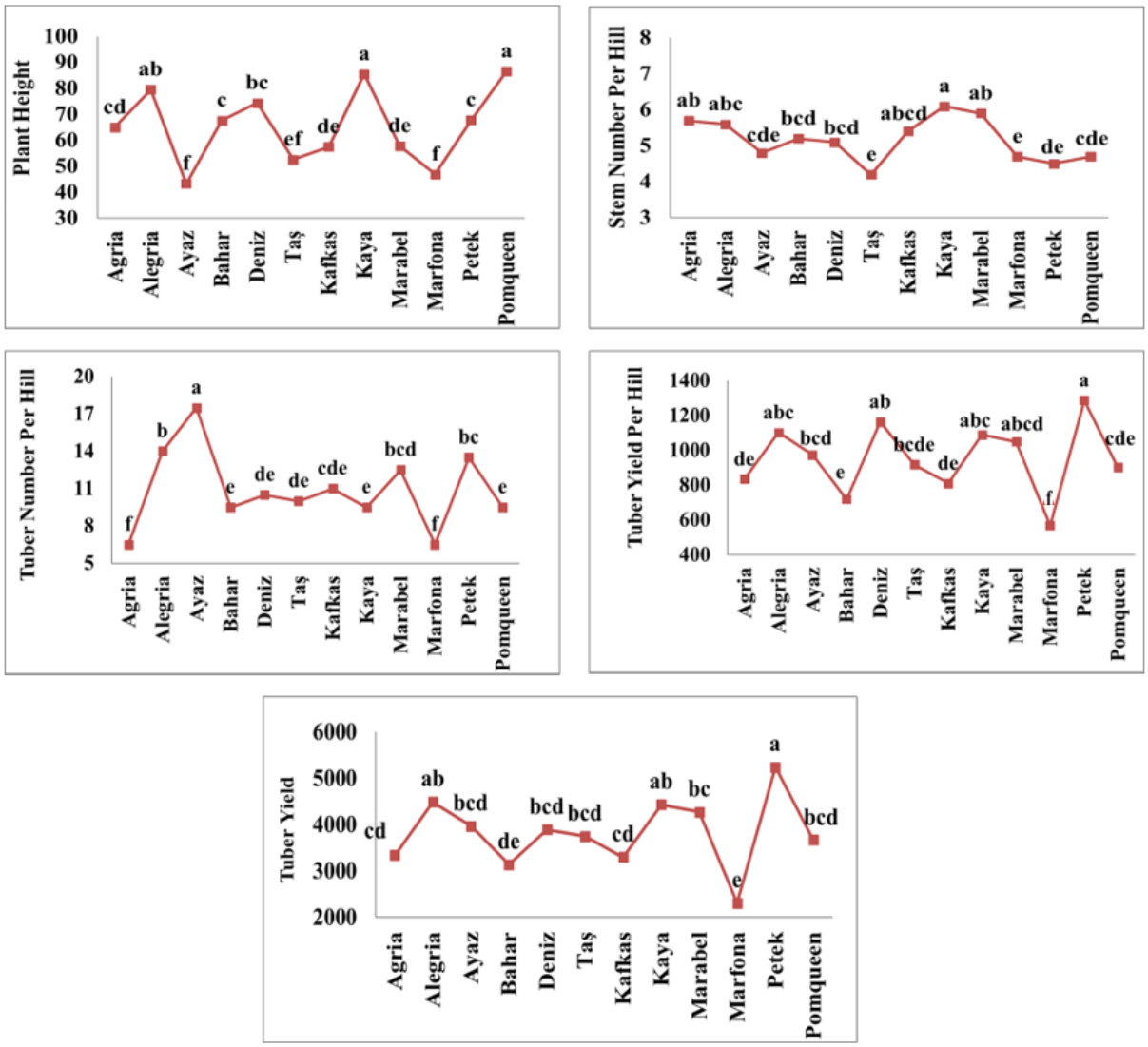

Figure 1. Influence of variety on plant height, stem and tuber number per hill, tuber yield per hill and total tuber yield of potato. Mean values with the same letter within the group are statistically similar at $p<0.01$.

The number of stems per hill was significantly affected by cultivar. The number of stems is related to the number of branches and leaves contributing to photosynthetic activity. An increase in the uptake of solar radiation can ensure higher photosynthesis and promote the synthesis and accumulation of carbohydrates, positively affecting the final tuber yield (White et al., 2007; Fantaw et al., 2019). Accordingly, the Kaya variety produced 6.1 stems per hill, higher than all other varieties. The lowest number of stems per hill was recorded for Marfona (4.0) and Taş (4.2) varieties (Table 3, Figure 1). This may be attributed to the natural genetic variation in the number of eyes on the tubers. Genetic differences among potato cultivars affect the number of shoots or eyes on tubers and, thus, the number of main stems (Struik & Wiersema, 1999; Getie et al., 2018). Potato varieties can show significant differences in plant height, number of primary branches, and tuber yield (Namugga et al., 2018). Increases in central stem density, which is affected by genetic structure, can lead to a rise in the number of tubers, and the size and weight of these tubers are determinants of potato yield (Tsegaw, 2005; Zelalem et al., 2009). In other studies on the subject, it has been determined that both plant height and central stem number values of potato varieties show significant variability (Öner & Aytaç, 2016; Kaplan, 2018; Bekele, 2018; Çakır, 2019; Atasever, 2019; Özdemir & Arslanoğlu, 2021; Gül & Sefaoğlu, 2022; Asnake et al., 2023).

The number of tubers per hill of the varieties varied between 6.5 and 17.5 pieces. Ayaz variety ranked first in terms of the number of tubers per hill with 17.5 pieces, followed by Alegria (14.0 pieces), Petek (13.5 pieces), and Marabel (12.5 pieces) varieties. The lowest number of tubers per hill was found in Agria and Marfona varieties (6.5 pieces) (Table 3, Figure 1). When the cultivars used were compared, there was a significant difference in the number of tubers per hill in most of them. Genetic structure and environmental factors influence the formation of Stolon and tuber (Zheng et al., 2018). Asefa et al. (2016b) reported significant differences in the number of tubers per plant due to genetic variation among potato varieties.

Similar studies are reporting that different varieties have different values in terms of the maximum number of tubers per hill under the same and other ecological conditions and that the number of tubers per hill determined in each potato variety varies between 3.8 and 21.6 (Dede, 2004; Öztürk et al., 2008; Kahraman et al., 2017; Kaplan, 2018). In this study, it can be said that ecological differences affect the different tuber numbers of the varieties, as stated by Zheng et al. (2018) and Aliche et al. (2019).

The average tuber yield per hill of potato varieties was highest in local varieties Petek (1287.1 g) and Deniz (1163.3 g) and lowest in standard variety Marfona (567.9 g) and local Bahar variety (719.5 g). Considering that the tuber yield per hill is a joint function of the number of tubers per hill and average single tuber weight, it can be concluded that the factors affecting such characteristics will also be effective on the tuber yield per hill. In studies conducted in different regions on this subject (Şanlı & Karadoğan, 2012; Boydak & Kayantaş, 2017; Kaplan, 2018; Kavalcı, 2019; Özdemir & Arslanoğlu, 2021), it was observed that tuber yield per hill varied between 138.54-1171.0 g.

3.3. Mean Performance of Varieties for Total Tuber Yield

Varieties were found to affect total tuber yield (Table 2). The highest tuber yield was obtained from the local variety Petek (5251.5 kg da^{-1}), followed by Alegria (4497.5 kg da^{-1}), Kaya (4441.0 kg da^{-1}) and Marabel (4277.0 kg da^{-1}). The lowest yield was obtained from the registered foreign variety Marfona (2315.0 kg da^{-1}). In terms of yield, local cultivars such as Petek and Kaya, and other local cultivars, provided higher yields than many registered foreign cultivars, especially Marfona and Agria, which are regionally superior and preferred (Table 3, Figure 1). Although local cultivars such as Petek and Kaya had fewer tubers per plant, their total tuber yields were higher because they produced larger/heavier tubers which increased yield. These results align with studies conducted in different locations and varieties (Girma, 2012; Asefa et al., 2016b). On the other hand, it was also concluded that the increase in yield may be mainly due to the number of tubers per plant (Mehdi et al. 2008; Abubaker et al., 2011).

Therefore, these results suggest that environment and genetic variation significantly affect the differential expression of many of the traits examined, including yield, among potato cultivars. The effects of genotypic and phenotypic variation on total tuber yield, tuber weight, number of main stems, and plant height were reported to be high (>20%) (Shetty et al., 2023). Similar studies have also reported it (Dash et al., 2018; Ebrahim et al., 2018; Getie et al., 2018; Fantaw et al., 2019; Tessema et al., 2020; Asnake et al., 2023). According to the researchers, the improved varieties have higher yield capacity than the standard varieties, which is consistent with the results of the present study.

4. Conclusion and Recommendations

The results confirmed differences between local and standard potato varieties in yield and other relevant agronomic traits in the study area. The study revealed that the production of any of the improved local varieties, such as Petek and Kaya, as well as Ayaz, Deniz, and Taş, resulted in the highest total potato tuber yield compared to standard varieties, such as Marfona and Agria, which are well adapted, productive and of good quality in the region.

Therefore, considering the yield potential, farmers in areas with high altitudes and similar agroecology are advised to prefer local varieties Petek and Kaya, Ayaz, Deniz, and Taş over standard varieties.

Conflict of Interest

The authors declare that they have no conflict of interest.

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