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Original article

Assessment of Tuber Damage in Potato Harvesting as Affected by Variety, Harvesting Speed, and Physical Characteristics

Ferhat Gül [a] & Hüseyin Duran [b,*]

[a] Republic of Türkiye Ministry of Agriculture and Forestry, Samsun Provincial Directore and Forestry, 55200, Samsun, Türkiye
[b] Ondokuz Mayıs University, Faculty of Agriculture, Department of Agricultural Machinery Engineering and Technology, 55200, Samsun, Türkiye

Abstract

As the global population continues to grow each year, the demand for basic foodstuffs is also increasing. Among these, potatoes are considered one of the most essential crops, and their long-term storage is critical to extending their usability. A key criterion for effective potato storage is ensuring that the tubers remain free from mechanical damage. Determining the rate of mechanical damage in potato tubers during harvesting is a critical factor affecting both yield and storage longevity. Therefore, this study aimed to assess the extent of such damage during the harvesting process. In this study, mechanical damage rates in potato tubers were evaluated using three different cultivars, Hermes (P1), Jelly (P2), and Madeleine (P3), and two harvesting speeds, 2 km/h (S1) and 3 km/h (S2). Additionally, the geometric mean diameter (GMD), tuber volume (TV), tuber surface area (TSA), and sphericity (SP) of the tubers were analyzed. The results indicated that the mechanical damage (MD) rate was highest in cultivars P1 and P2 (6.16%) and lowest in cultivar P3 (4.86%). Regarding the tractor forward speeds, the MD rate was 5.44% at speed S1 and increased to 6.01% at speed S2. Despite cultivar P3 exhibiting higher values of geometric mean diameter (GMD), tuber volume (TV), and tuber surface area (TSA), it demonstrated greater resistance to mechanical damage due to its lower MD rate. Based on the speed levels tested, it was concluded that the lower forward speed (S1) is preferable for harvesting, as it resulted in reduced mechanical damage compared to S2.

Keywords: Potato Tuber, Mechanical Damage, Harvesting Speed, Physical Characteristics.

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* **Corresponding author:**

Hüseyin Duran is a Asist. Prof. Dr. in the Department of Agricultural Machinery Engineering and Technology at Ondokuz Mayıs University, Faculty of Agriculture in Samsun, Türkiye. Her research interests include the sprayer, pesticide application techniques. He has lived, worked, and studied in Samsun, Türkiye.
Email: huseyin.duran@omu.edu.tr

INTRODUCTION

The potato is one of the few crops not originally native to Türkiye. It originates from the Andes Mountains of South America and was introduced to Türkiye approximately 150 years ago via Russia and the Caucasus (Öztürk and Polat, 2017). Today, potatoes are cultivated almost everywhere in Türkiye, with Central Anatolia being a particularly significant production region. Considering Türkiye's climate, ecological conditions, and geographical location, the potato is regarded as a promising crop for the country's agricultural future. Globally, the potato is among the most important crops that can help address the growing problem of hunger. It is known that nearly 40% of the world's population faces food insecurity, and approximately 20 million people die of hunger each year (FAO, 2020). Considering projections that the world population will reach 9,7 billion by 2050 and 10,4 billion by 2080 (Fróna et al, 2019; FAO, 2022), food insecurity and hunger are expected to become even more severe global challenges. As the fourth most widely cultivated crop in the world, following wheat, rice, and maize, potato plays a vital role in human nutrition due to its status as a staple food (Issa et al., 2020; Jennings et al., 2020; Zhang et al., 2017).

Türkiye'de 2023 yılında 1,509 milyon dekar alanda patates ekilmiştir. Toplam üretim ise 5,7 milyon ton olmuştur (Anonymous, 2024). Despite the reduction in cultivated area, production increased by 4.40% during the same period, from 4,77 million tons to 4,98 million tons. This increase in production, despite the decline in cultivated area, can be attributed to yield improvements that occurred during the same timeframe. In 2019, Niğde ranked first in Türkiye in terms of potato cultivation area, accounting for 13.05%, followed by Konya with 10.19%, and Afyonkarahisar with 10.09%. The average potato yield in Türkiye was 35,38 tons/hectare (Kadakoğlu and Karlı, 2021).

To increase potato yield, the cultivation area must be properly prepared. In potato production, the greatest yield loss typically occurs during the harvesting process (Spang and Steven, 2018). Damage to potato tubers is a significant factor that reduces the income of producers. Damaged potatoes have a lower market value, and their separation during storage results in increased labor costs and time loss (Güler, 2011). Potatoes are harvested using various tools and equipment. The simplest method is manual harvesting, which involves using a hand hoe, shovel, fork, or sometimes no equipment at all (Gulati, 2019).

Fully automatic harvesters eliminate the need for manual collection of potatoes from the field after harvesting by gathering the tubers directly into an onboard storage unit or a separate container. This significantly reduces labor requirements. Compared to traditional harvesting methods, mechanical harvesters are considered a significant innovation and improvement, as they reduce harvesting duration, minimize crop losses, and lower overall production costs (Nasr et al, 2019; Soethoudt and Castelein, 2021). Food loss-reducing intervention strategies for potato smallholders in Kenya positive business case with reduced greenhouse gas emissions (Soethoudt and Castelein, 2021).

This study was conducted to determine the rates of mechanical damage occurring in different potato cultivars at varying harvesting speeds. Considering that mechanical damage is a primary cause of post-harvest losses and reduced storage longevity in potatoes, this research was conducted to evaluate the influence of both potato cultivar and harvesting speed on the severity of damage. Furthermore, the study aimed to establish a correlation between the physical properties of the tubers such as geometric mean diameter, volume, and sphericity; and their susceptibility to mechanical damage.

MATERIALS and METHODS

The field experiments were conducted on parcel number 639, block 0, located in the Günüveren area of Sarıgazel Neighborhood, Ladik District, Samsun Province (Figure 1).

Figure 1. The experimental field and layout

The potato seed tubers used in the experiments, Hermes (P1) and Jelly (P2), were obtained from the Niğde Potato Research Institute Directorate, while the Madeleine (P3) variety was supplied by a commercial company. These three potato cultivars were specifically selected and planted on experimental plots for the purpose of this research.

A two-row potato planter of the brand Demsan (Figure 2) was used in the experiments, and some of its technical specifications are presented in Table 1.

Figure 2. The planter used in the experiment

Table 1. Technical specifications of the planter

Specifications	**Values**
Total empty weight	593 kg
Equipment type	Semi-mounted planter
Drive type	Wheel-driven
Number of rows	2
Row spacing	700-750 mm
In-row planting distance	230,250,270,290,300,310,330,350,360,390,410 mm
Working width	1400 mm
Working depth	150-200 mm
Number of seed carrier cups	2x32
Number of cupped chain conveyors	2
Seed size	Diameter: 30-100 mm
Overall dimensions	
Width (W)	1.750 mm
Length (L)	1.900 mm
Height (H)	1.495 mm

A two-row potato harvester of the brand Demsan (Figure 3) was used in the experiments, and some of its technical specifications are presented in Table 2.

Figure 3. The harvester used in the experiment

Table 2. Technical specifications of the harvester

Specifications	**Values**
Type of attachment	Semi-mounted
Drive type	PTO-driven
Number of working rows	2
Row spacing	700-750 mm
Working width	1.400 mm
Working depth	200-250 mm
Number of blades	9
Overall dimensions	
Width	1.750 mm
Length	2.500 mm
Height	1.200 mm
Weight	714 kg

A New Holland TT55 model tractor was used for the planting and harvesting operations in the experiments as a power source. A digital handheld scale (with a capacity of 50 kg and an accuracy of 10 g) was used to weigh the potato tubers. In addition, a 1/20 metric caliper was used to measure the width, length, and thickness of the tubers.

Potato planting was carried out on April 25, 2024, with an inter-row spacing of 75 cm, an in-row spacing of 25 cm, a planting depth of 10 cm, and a forward speed of 12 km/h. Before planting, the seed tubers were treated with a pesticide containing the active ingredient Bentazone to protect against the Colorado potato beetle (*Leptinotarsa decemlineata* Say) (Col. Chrysomelidae). Additionally, 100 kg/ha of DAP fertilizer was applied during planting. The potato harvest was conducted on September 28, 2024, using a semi-automatic harvester, in accordance with the experimental design.

In the experiments, three different potato varieties, Hermes (P1), Jelly (P2), and Madeleine (P3), were harvested at two different speeds: 2 km/h (S1) and 3 km/h (S2) (Bentini et al, 2006; Güler, 2011; Al-Dosary, 2016). The mechanical damage rates of the tubers were determined as percentages (Abd Elhay, 2017).

Concerning mechanical damage under different harvesting speeds, the geometric mean diameter (GMD), tuber volume (TV), tuber surface area (TSA), and sphericity (SP) values of the tubers were examined for each potato variety (Mohsenin, 1986; Patel et al, 2018).

After harvesting, the width, length, and thickness of each selected tuber were measured using a caliper (Figure 4) to determine mechanical damage (Almady et al, 2024). Tubers were collected from the designated plots during harvest in the experimental field. The surface area of the tubers was calculated using Equation 3.4, and the deformation areas were determined by calculating the ratio of the deformed surface area to the total tuber surface area. Based on the data obtained from these measurements, the mechanical damage conditions were evaluated according to the varieties and harvesting speeds using the GMD, TV, TSA, and SP values (Mohsenin, 1986; Kara, 2017).

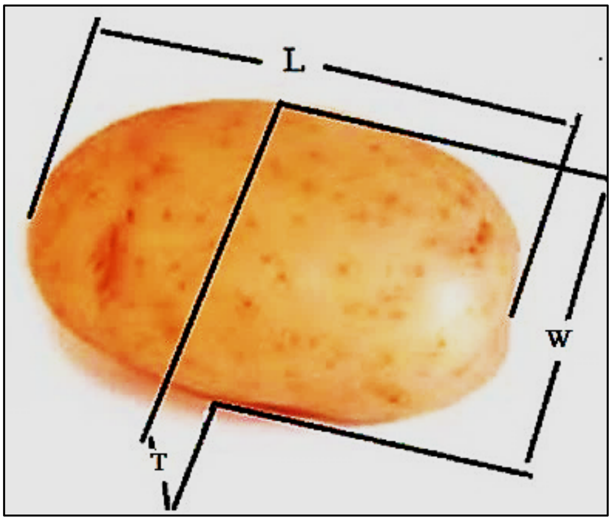


Figure 4. Measurements taken from the potato tuber: length (L), width (W), and thickness (T)

The following equations were used in the calculations (Mohsenin, 1986; Aktaş et al, 2007; Kara, 2017; Ahangarnezhad et al, 2019).

$$D_g = (LWT)^{1/3} \quad (3.1)$$

$$\text{Ø} = \frac{(LWT)^{1/3}}{L} \quad (3.2)$$

$$V = \frac{\pi}{6}(LWT) \quad (3.3)$$

$$S = \pi * D_g^2 \quad (3.4)$$

Where;

D_g: Geometric mean diameter (mm),

L: Length (mm),

W: Width (mm),

T: Thickness (mm),

V: Volume (mm^3),

Ø: Sphericity,

S: Surface area (mm^2).

During harvesting, five tubers were collected from each plot by skipping one row between each selected potato plant in every row, and the mechanical damage rate of each tuber was determined as a percentage (Abd Elhay, 2017).

In addition to mechanical damage caused by the harvester during potato harvesting, deformities such as tuber cutting or fragmentation were also identified (Figure 5) and evaluated in these cases.

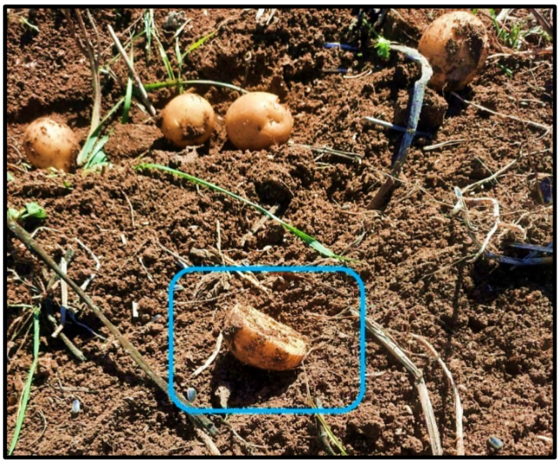


Figure 5. Example of a tuber fractured during harvesting

The experiments were conducted using a factorial randomized complete block design with three replications. The plot size was 5 × 25 meters, and a total of 18 plots were used in the study.

Variance analysis (ANOVA) was conducted to examine differences among potato varieties and harvesting speeds in terms of mechanical damage. To assess the statistical significance of these differences, the least significant difference (LSD) test was applied at a significance level of $p<0.05$. Statistical analyses were performed using SPSS software (version 15, SPSS Inc., USA), a widely used program for statistical evaluation.

RESULTS and DISCUSSION

It was determined that mechanical damage (MD) to the tubers during machine harvesting varied depending on the variety and harvesting speeds. Analysis of variance performed on the data obtained from the experiments showed that both variety and speed factors had a statistically significant effect on mechanical damage ($P \leq 0.05$) (Table 3).

Table 3. Effects of variety and harvesting speed on potato mechanical damage

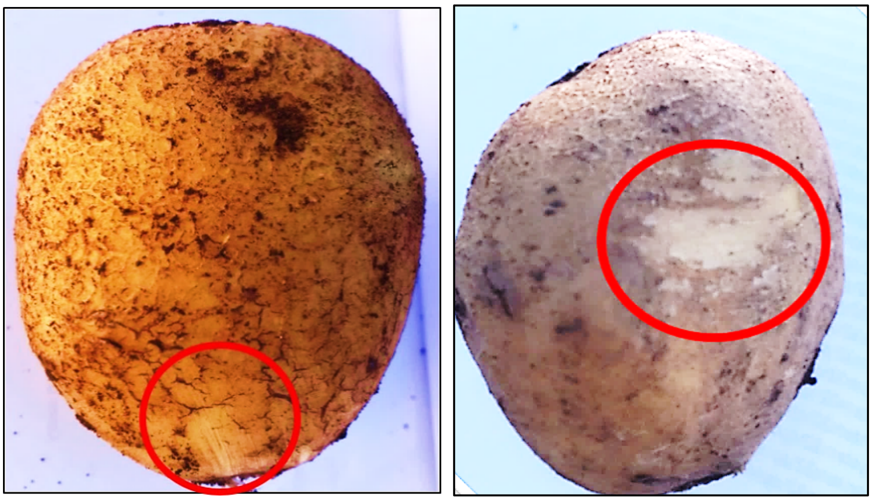
	Parameters				
Sources of Variation	**MD** (mm)	**GMD** (mm)	**TV** (mm^3)	**TSA** (mm^2)	**SP** (%)
Varieties					
P1	6.16 a	63.12 b	105,257 ab	11,000 ab	80.44
P2	6.16 a	62.79 b	95,081 b	10,622 b	75.53
P3	4.86 b	68.31 a	120,526 a	12,764 a	78.41
Speeds					
S1	5.44 b	68.85	99,656	11,188.7	78.12
S2	6.01 a	65.63	114253	11,735.4	78.13
Interaction					
P1 × S1	5.56	59.18	85,740	9,631.7	81.41
P1 × S2	6.76	67.06	124,773	12,368.9	79.48
P2 × S1	6.13	62.84	91,946	10,581.4	73.58
P2 × S2	6.19	62.75	98,217	10,662.4	77.48
P3 × S1	4.64	69.54	121,282	13,352.9	79.38
P3 × S2	5.08	67.07	119,770	12,174.9	77.43
LSD					
P	0.5787	4.2197	19,596.2	1,774.6	n.s
S	0.4725	n.s	n.s	n.s	n.s
P × S	n.s	n.s	n.s	n.s	n.s
CV (%)	7.86	5.07	14.24	12.04	4.86

* The difference between values with different letters is significant ($P<0.05$), **P1**: Hermes, **P2**: Jelly, **P3**: Madeleine, **MD**: Mechanical Damage, **S1:** 2 km/h, **S2**: 3km/h, **GMD:** Geometric Mean Diameter**, TV:** Tuber Volume**, TSA:** Tuber Surface Area**, SP:** Sphericity, ns: not significant.

Table 3 shows that the potato varieties Hermes (P1) and Jelly (P2) were found to be statistically significantly different from Madeleine (P3) in terms of mechanical damage (MD). Harvesting speeds were also found to have a significant effect on MD. For the parameters geometric mean diameter (GMD), tuber volume (TV), and tuber surface area (TSA), varieties P1 and P2 were statistically grouped, while P3 was placed in a different group. No statistically significant differences were found among varieties and speeds for sphericity (SP) (Ahangarnezhad et al., 2019; Varnamkhasti et al, 2008).

Mechanical Damage (MD)

In this study, it was determined that both potato varieties and harvesting speeds had a significant effect on mechanical damage (MD) at different harvesting speeds (Table 3). Güler (2011) and Altuntaş (2001) also reported that harvesting speed is an important factor affecting MD when using machines for potato harvesting. While the Hermes (P1) and Jelly (P2) varieties exhibited high and the same levels of mechanical damage, the Madeleine (P3) variety showed a lower rate of damage. Similarly, Misener and Tai (1993) indicated in their study that the sensitivity of different varieties can influence the extent of mechanical damage.



(a) (b)

Figure 6. Potato tubers exposed to mechanical damage

During harvest, the MD rate was recorded as 6.16% for the P1 (a) and P2 varieties, and 4.86% for the P3 (b) variety (Figure 6). It can be inferred that the P1 and P2 varieties used in the experiment were more susceptible to damage during harvesting with the semi-automatic potato harvester compared to the P3 variety.

When the forward speeds during harvesting with the tractor were examined, it was observed that the MD rates were lower at the lower speed compared to the higher speed. Similarly, Specht (1966) reported that the forward speed of the tractor caused varying degrees of damage to the tubers. Bentini et al. (2006) also reported that the moisture levels on the surface of potato tubers and the MD rates varied depending on harvesting speed, which was investigated at two different speeds, slow and fast. In the present study, the MD rate was recorded as 5.44% at speed S1 and 6.01% at speed S2. Similarly, Bal (1990) stated that MD tends to be lower at reduced harvesting speeds. Additionally, Al-Dosary (2016) reported that forward speeds during harvesting resulted in varying levels of damage to potato tubers. The findings indicated that the lowest mechanical damage occurred at a harvesting speed of 1.5 km/h. Although both variety and harvesting speed had statistically significant effects on MD, their interaction was not found to be statistically significant. The MD rates ranged from 4.64% to 6.76%.

Geometric Mean Diameter (GMD)

The MD rates of potato tubers varied during harvest depending on the characteristics of the varieties (Table 3). The GMD values were calculated as 63.12 mm for the Hermes (P1) variety and 62.79 mm for the Jelly (P2) variety. In contrast, the Madeleine (P3) variety had a higher GMD value of 68.31 mm. Misener and Tai (1993) stated that the tuber structure and sensitivity of potato varieties can influence damage rates during harvesting with machinery. When these values are considered alongside MD data, it is evident that the varieties P1 and P2, which had lower GMD values, experienced higher rates of MD, whereas the P3 variety, which had a higher GMD value, exhibited a lower MD rate. It might be expected that mechanical damage would increase with larger tuber size, based on the assumption that a higher geometric mean diameter indicates larger tubers. However, due to the greater resistance of certain varieties to mechanical damage, lower MD rates were observed. Similarly, Misener and Tai (1993) emphasized that selecting varieties with higher resistance to mechanical damage is a proper and effective approach.

When the GMD values were examined in terms of harvesting speeds, they were found to be 68.85 mm for S1 and 65.63 mm for S2. The difference between these speeds was not statistically significant in terms of GMD. Similarly, the interaction between varieties and harvesting speeds was also found to be statistically insignificant.

Tuber Volume (TV)

Tuber volume (TV) was found to be statistically significant among the varieties (Table 3). The highest TV value was observed in the P3 variety at 120,526 mm^3, followed by P1 and P2 varieties with values of 105,257 mm^3 and 95,801 mm^3, respectively. This indicates that the P3 variety consists of larger tubers due to its greater volume. A similar pattern was observed in the GMD values. Although larger tubers like those of the P3 variety are generally expected to exhibit higher MD, it was found to have a lower MD rate compared to the other two varieties. The lower MD rate of the P3 variety, despite its higher GMD and TV values relative to P1 and P2, is attributed to its greater resistance to mechanical damage.

When the TV was examined in terms of harvesting speeds, it was found to be statistically insignificant. The TV values were 99,656 mm^3 and 114,253 mm^3 for speeds S1 and S2, respectively. Additionally, the interaction between varieties and harvesting speeds was also found to be insignificant with respect to TV.

Tuber Surface Area (TSA)

Significant differences were observed among the varieties in terms of TSA (Table 3). The highest TSA value was recorded for the P3 variety at 12,764 mm^2, while the values for the P1 and P2 varieties were 11,000 mm^2 and 10,622 mm^2, respectively. This indicates that the P3 variety consists of larger tubers. Although tubers with larger surface areas are expected to experience greater mechanical damage, the P3 variety exhibited a lower MD rate, likely due to its inherent varietal characteristics. A linear relationship was found among the measured parameters of tuber length, width, thickness, mass, volume, and geometric mean diameter, whereas an inverse relationship was observed with size dimensions (Ahangarnezhad, 2019). Similar patterns were noted for GMD and TV as well.

In the experiment, harvesting speeds were found to have no statistically significant effect on tuber surface area. The TSA values for speeds S1 and S2 were recorded as 11,188.7 mm^2 and 11,735.4 mm^2, respectively. Additionally, the interaction between varieties and harvesting speeds was determined to be insignificant.

Sphericity (SP)

It was determined that SP was not statistically significant in terms of varieties and harvesting speeds. The findings indicate that sphericity is not a parameter that varies depending on the potato varieties, which is consistent with previous studies. The SP values were recorded as % 80.44, % 75.53, and % 78.41 for varieties P1, P2, and P3, respectively. According to harvesting speeds, SP values were found to be % 78.12 and % 78.13 for S1 and S2, respectively. Additionally, the interaction between varieties and harvesting speeds was found to be statistically insignificant for sphericity.

CONCLUSION

The highest mechanical damage (MD) was observed in Hermes (P1) and Jelly (P2) varieties, both with a rate of 6.16%, while the Madeleine (P3) variety exhibited a lower damage rate of 4.86%. When examining the forward speeds during harvesting with the tractor, the MD rate was 5.44% at the lower speed of 2 km/h (S1), and 6.01% at the higher speed of 3 km/h (S2).

The geometric mean diameter (GMD) was calculated as 63.12 mm and 62.79 mm for the P1 and P2 varieties, respectively. For the P3 variety, this value was found to be higher, at 68.31 mm.

In terms of tuber Volume (TV), the P3 variety had the highest value at 120.526 mm^3, followed by the P1 and P2 varieties with values of 105,257 mm^3 and 95,801 mm^3, respectively.

Significant differences were observed among the varieties in terms of tuber surface area (TSA). The highest TSA value was recorded in the P3 variety with 12,764 mm^2, followed by P1 and P2 varieties with 11,000 mm^2 and 10,622 mm^2, respectively.

In general, although the P3 variety had higher values of GMD, TV, and TSA, it exhibited a lower rate of MD. Therefore, it can be concluded that the P3 variety is more resistant to MD. Considering the harvesting speeds in the experiment, the lower speed (S1) resulted in a lower MD rate compared to the higher speed (S2), suggesting that S1 can be considered a preferable harvesting speed.

According to the obtained results, it was determined that MD varied depending on the potato varieties and harvesting speeds. As the sensitivity of the potato varieties increases, it is considered more appropriate to select lower harvesting speeds during mechanical harvesting. To prevent mechanical damage during mechanical harvesting of potatoes, it is important to understand the characteristics of the varieties and select appropriate harvesting speeds accordingly. Additionally, researching to improve the parts of harvesting machines that cause mechanical damage would be beneficial.

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