Determination of physical-mechanical characteristics in potatoes (Fianna variety) as parameters for mechanical design

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Abstract: Potatoes are one of the most important agricultural products due to their great nutritional and industrial value. However, the mechanization of this crop is low in many countries. The main aim of this investigation was to characterize the Fianna potato variety. The potatoes were characterized morphologically (polar diameter, equatorial diameter, thickness, geometric diameter, arithmetic diameter, sphericity, and weight), mechanically (static friction coefficient, rolling angle, and axial compression), and by impact and firmness tests. The sample potatoes were distributed into four groups (S1, S2, S3, and S4) according to their size. A random complete blocks design was used to determine the mean values of their characteristics. The results of the physical characteristics showed a higher coefficient of variation in the S1 group. All values tended to decrease except sphericity. The results of the mechanical tests show that the coefficient of static friction increases as the size of the potato decreases, while the relationship of the rolling angle was the opposite. The axial compression results showed values that decreased from Group S1 to Group S4 except for Young's modulus, which ranged from 1.306 to 3.697 MPa in the four groups. Determining these data is necessary because they represent design parameters useful for the development of mechanical equipment.

Keywords: characterization, coefficient of friction, design parameters, rolling angle, Young modulus.

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1 Introduction

Potato (*Solanum tuberosum* L.) is the fourth-largest production crop in the world, only after rice, wheat, and corn. China ranks first in production, close to a quarter of the world volume (SIAP, 2019). In Mexico, potato production oscillates around approximately 1.8 million tons annually; Sonora State has the highest production (26% of the national volume), and the country's per capita consumption is 15.1 kg (SIAP, 2020).

Around the world, potatoes are harvested mechanically, manually or by a combination of both, depending on the target market (fresh consumption or processed), the land area to harvest (López, 2003), and the availability and access to adequate technology in place. Currently, small-farmland producers are opting for mechanical harvesting to increase their profits. According to Mejia and Castellanos (2018), a producer

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who uses agricultural machinery obtains at least double the profits compared with a producer who uses low or scarce mechanization. The purpose of the design of machines is to create elements that are used daily in different spheres of production to benefit the producer; therefore, the characterization of the potatoes is important, and it is necessary to establish design parameters to create technology appropriate to the conditions of a place of production. Knowing the physical-mechanical characteristics of potatoes helps to generate adequate technology capable of performing tasks that satisfy specific needs in production processes, providing the best quality conditions and generating economic benefits. Considering that the market requires potato minimum characteristics of quality, potatoes selected for size and quality do not affect their physical appearance and internal tissue for consumption (NMX-FF-022-2002).

During potatoes' postharvest, it is necessary to comply with minimum quality specifications in relation to the percentage of defects present on its surface (Quality: A with 0%–5%, B with 6%–15%, and C with 16%–25%). According to the current Mexican Norm, NMX-FF-022-2002, the three categories are described according to their weight, equatorial diameter, and color. For the commercialization of potatoes, the quality of the tubers depends on their physical and mechanical characteristics, which must be known for their handling during harvesting, cleaning, classification, and storage, maintaining their quality and quantitative characteristics (Jaiswal et al., 2023; Abd Elhay, 2017; Ahangarnezhad et al., 2019).

There are previous investigative works about the physical and mechanical characteristics of different varieties of potato tubers: Spunta (Al-Hamed et al., 2018); Kufri Badshah (Patel et al., 2018); Agria (Ahangarnezhad et al., 2019), Marfona and Sante (Abedi et al., 2019), and Cardinal, Chipsona, Desiree, Lady Rosetta, and Satellite (Abbasi et al., 2019). Vázquez et al. (2012) mentioned that in Mexico, a variety of white-colored potatoes (Fianna, Alpha, Gigant, Mondial, Atlantic, among others) are allocated for fresh consumption markets and industrial use (SIAP, 2020); however, information on the properties of the Fianna variety is scarce, and no studies have characterized the physical-mechanical properties of the Fianna variety to obtain data that support the design of harvest and postharvest machines.

The main aim of this study was to determine the physical and mechanical properties of the Fianna potato variety, such as axial dimensions (length, width, and thickness), geometric mean diameter, arithmetic diameter, sphericity, surface area, weight, volume, density, static friction coefficient, rolling angle, impact, firmness tests, and axial compression. The obtained data will be used as a design parameter for future technological developments in the potato postharvest process.

2 Materials and methods

Potato tubers of the Fianna variety were collected in the field in the Profesor Graciano Sánchez area, which belongs to the municipality of Tlaxco, Tlaxcala, Mexico (19°43’08.1” N, 98°18’12.0” W). The tubers are seasonal and grown during the June–October cycle in 2020. They were harvested manually and transported in eight plastic boxes to avoid mechanical damage.

2.1 Experimental design

The potatoes were distributed into four groups (S1, S2, S3 and S4) according to their size (the width of the potato), based on the Mexican Norm NMX-FF-022-2002, which for each group is S1 (66–75 mm), S2 (56–65 mm), S3 (51–55 mm) and S4 (44–50 mm). The sample size in each group was 220 potatoes, randomly chosen. The applied experimental design was that of random complete blocks.

2.2 Determination of physical characteristics

Three perpendicular axial measurements were established as shown in Figure 1: length (the longest tuber diameter or polar diameter), width (median diameter or equatorial diameter), and thickness (small diameter or thickness) of the potato tubers were measured with a digital Insize Vernier caliper (0–300 mm - series 1114 - Germany) with a 0.01 mm resolution.

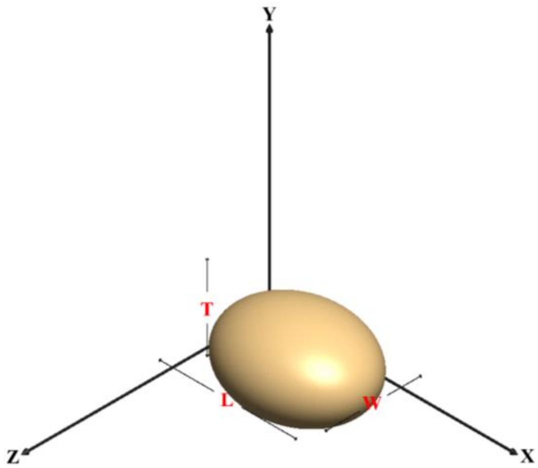


Figure 1 Axial dimensions of the potato tuber

The geometric mean diameter (D_g, mm), arithmetic diameter (D_a, mm), sphericity (ϕ, %), and surface area (S_a, mm^2) were calculated with Equations 1 to 4 (Mohsenin, 1986; El-Raie et al., 1996; Goyal et al., 2007):

$$D_g = (L * W * T)^{1/3} \quad (1)$$

$$D_a = \frac{(L+W+T)}{3} \quad (2)$$

$$\phi = \left(\frac{D_g}{L}\right) * 100 \quad (3)$$

$$S_a = \pi\left(D_g\right)^2 \quad (4)$$

where L is the length of the potato tuber in mm, W is the width of the potato tuber in mm, and T is the thickness of the potato tuber in mm.

The weight of each potato tuber (W_t) was measured with a digital scale (DyNamic- MS-K07-China) with a 0.1 g graduation. Volume (V) was determined through the Archimedes principle, where in the potato was submerged in a previously weighed 2000 mL glass beaker and filled with water until 1400 mL (Rady et al., 2017). The registered change represented the weight of displaced water, which was divided by the known density of water at room temperature (20.20°C ± 3.18°C); the weight of displaced water was the reading on the scale of the submerged object minus the weight of the recipient and the water (Ibrahim and Mostafa, 2012). Equation 5 was used to determine the volume (Mohsenin, 1986; Wilhelm et al., 2005):

$$V = \frac{W_w}{\rho_w} \quad (5)$$

where W_w is the weight of the displaced water in g, and ρ_w is the density of the water, which is equal to 0.998 g cm^{-3}.

The density (ρ_t, g cm^{-3}) of each tuber was calculated with Equation 6 (Mohsenin, 1986; Wilhelm et al., 2005):

$$\rho_t = \frac{W_t}{V} \quad (6)$$

where W_t is the weight of the tuber in g, and V is the volume of the tuber in cm^3.

2.3 Determination of the mechanical characteristics

The static friction coefficient of the tubers was determined with a device (own design) that consisted of a wooden board where a galvanized steel sheet or a commercial neoprene sheet could be attached, adjustable to different degrees with increments of 0.25° (Figure 2). The platform design was based on the authors (Li et al., 2018; Shafaei et al., 2020; Onwe et al., 2020). Three potatoes were held together with masking tape and placed on the device. The inclination angle was gradually incremented until the tubers started to slide without rolling. After each repetition, a dry cloth was used to clean the different platforms. (Mohsenin, 1986; Teye and Abano, 2012; Abd Elhay, 2017). Thirty repetitions were performed for each size and material. Equation 7 was used to calculate the static friction coefficient (Mohsenin, 1986; Nam et al., 2018):

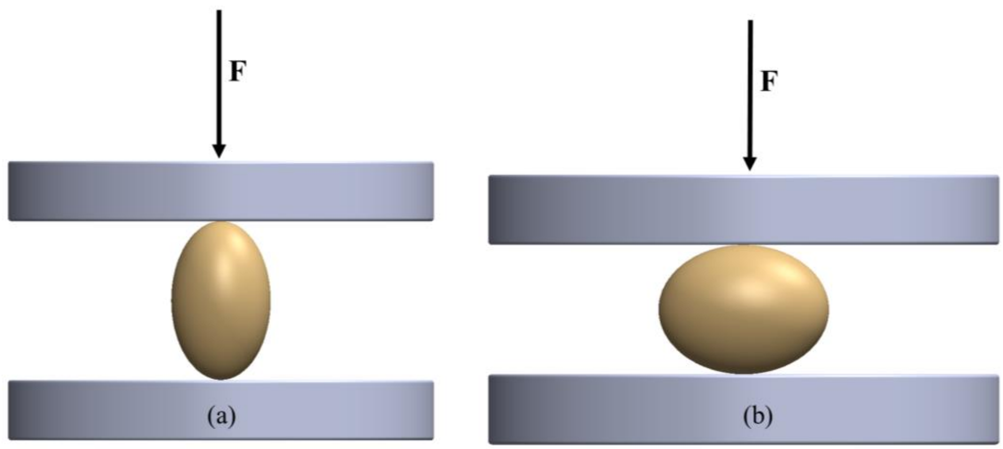
$$\mu_s = tan\,\theta_s = \frac{h_s}{b_s} \quad (7)$$

where θ_s is the inclination angle when the tubers started to slide in degrees, (°); h_s is the elevated height in mm, and b_s is the distance of the base in mm.

The rolling angle of the tubers was determined with the same device used to determine the static friction coefficient (Figure 2) and with the same samples. Tubers were individually placed, and the inclination angle was varied until they started to roll (Abd Elhay, 2017). Thirty repetitions were performed for each size group and material.

Figure 2 Device to determine the static friction coefficient and the rolling angle

To perform the axial compression test, potatoes were stored for five days after being harvested at a room temperature of 19°C±1°C with a relative humidity of 56% ± 10%. Tests were made with unwashed potatoes to simulate field conditions. Thirty tubers of each size were selected, and two treatments were applied (15 tubers in the horizontal position and 15 in the vertical position), as shown in Figure 3. The axial compression tests to determine the mechanical characteristics of the potato tubers only considered the compression load (N), extension through compression as deformation (mm), deformation percentage (%), and Young modulus (MPa). A universal machine was used for mechanical tests, and the INSTRON equipment (Model 3382, Norwood, MA, EUA) was controlled through a computer by means of Bluehill® 2 INSTRON software. The vertical displacement speed of the controller of the machine was 50 mm min^{-1} (ASAE, 2005) with a load cell of 100 kN. Parallel plates 15 cm in diameter were used. The moisture content of the tubers obtained was 79%, and the test was performed at a room temperature of 19°C±1°C and 41%± 1.46% relative humidity.



(a) vertical position (b) horizontal position

Figure 3 Diagram of potato positions in the axial compression test

In the impact and firmness test, sample potatoes were stored for eight days after harvest at a room temperature of 20°C ± 1°C with a relative humidity of 44% ± 3% without being washed. They were dropped at different heights (50, 75, and 100 cm) in plastic boxes and galvanized steel sheets, and five repetitions were performed for each group (S1, S2, S3, and S4). The firmness was determined with a Wagner Force Five model FDV-30 texture analyzer. The test was performed using the same samples as in the impact test from zero to three days later, and the control samples (healthy potatoes) for all groups were tested.

2.4 Statistical analysis

The statistical analysis was developed using RStudio, a statistical software through comparisons of multiple means with the Tukey test to determine the significant differences among the different tuber group sizes.

3 Results and discussion

3.1 Physical characteristics

The width mean values for each group were S1=74.80 mm, S2=61.57 mm, S3=52.88 mm, and S4=46.88 mm. These data showed that they are within the ranges established by Mexican Norm NMX-FF-022-2002 for each group. According to the results shown in Figure 4, potatoes in Group S4 showed the largest dispersion in length (12.19%) and width (8.84%). The thickness of the S4 group potatoes showed the largest coefficient variation at 13.49%, followed by that of the S1 group at 10.80%. The S1 group potatoes (66–75 mm) are in the upper range limit since the producers in the region place giant sized potatoes (>76 mm) together with the potatoes in the S1 group since they are the closest similar group and because they have no market on their own.

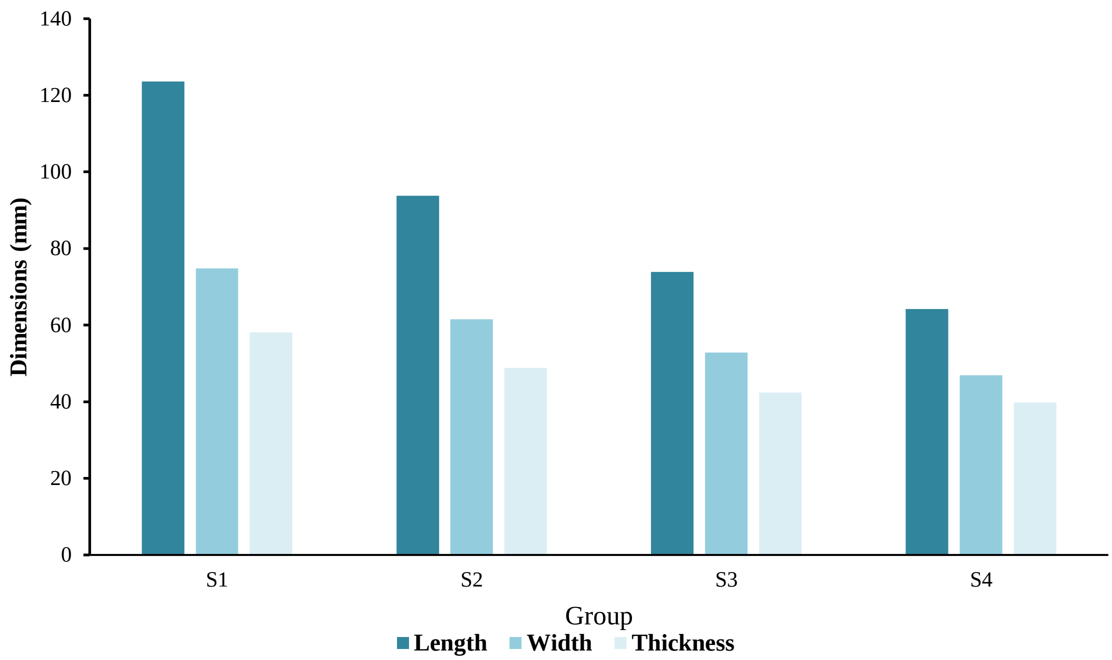


Figure 4 Means of the axial dimensions of the potato in the four classification groups

The geometric mean diameter and arithmetic diameter results are shown in Table 1. A larger dispersion was observed in the S1 group, with values of 7.19% and 7.43%, while the S3 group showed the lowest coefficient variations, with values of 5.87% and 6.05%, respectively.

The potatoes' sphericity is shown in Table 1. This parameter increases from the S1 to the S4 group. In previous investigations by Tabatabaeefar (2002), Gamea et al. (2009), Altuntas et al. (2013), Abd Elhay (2017), and Ahangarnezhad et al. (2019), a similar mean sphericity was reported with values of 71%, 76.3%, 75.97%, 75.4%, and 74.1% for the Agria, Diamont, Jelly, Diamont and Agria varieties, respectively, while in this investigation, the value of mean sphericity in the four size groups was 72.07%.

The values of mean weight (Table 1) are within the ranges established by Mexican Norm NMX-FF-022-2002, and these values are shown as follows: S1=231–360 g, S2=141–230 g, S3=71–140 g, and S4=40–70 g. The potatoes in the S4 group turned out with a mean that was very close to the upper range limit with a coefficient variation of 13%, while those in the S1 group had a coefficient variation of 21.81% because the weight range in the S1 group was larger than that in the S4 group because of the producers included giant potatoes in the S1 group (>371 g).

Volume and density results are shown in Table 1. The dispersion of data obtained for the potato volume decreased from the S1 group to the S4 group, which means that the potatoes in the S4 group were more uniform. The mean density value in Groups S1, S2, and S3 was 1.08 g cm^{-3}, and for the S4 group, it was 1.07 g cm^{-3}, while the general average was 1.077 g cm^{-3}, which is similar to the results obtained by authors such as Rady et al. (2017) with a value of 1.08 g cm^{-3}, Patel et al. (2018) with a value of 1.067 g cm^{-3}, Abedi et al. (2019) with values of 1.069 g cm^{-3} and 1.082 g cm^{-3}, respectively, and Ahangarnezhad et al. (2019) with a value of 1.05 g cm^{-3}.

According to mean comparisons, using the Tukey test, a significant difference (p<0.001) was confirmed between the weights for each chosen size group (Figure 5). Significant differences (p<0.001) in geometric mean diameter, arithmetic diameter, surface area and volume are shown in Table 1. All these values are directly proportional regarding the size, with lower values in the smaller potatoes (S4) and values increasing until the S1 group. While in sphericity the difference is significant with p<0.001, higher values were obtained in the smaller sized potatoes (S3 and S4) and mentioned values decreased while the size increased, this being because, in this variety, the biggest potatoes tend to be more oval, and the smaller ones tend to be more spherical. Regarding the density, the significant difference is significant (p<0.001), tuber sizes group are classified by density into two groups, the first group including S1, S2, and S3 groups and the second group only consisting of the S4 group.

Table 1 Mean values, maximums and minimums with standard deviation and coefficient variations of some of the physical characteristics of potatoes

Parameter	Group	Mean	Max.	Min.	SD	CV (%)	ANOVA
Geometric mean diameter (mm)	S1	81.10[a]	101.89	71.72	5.83	7.19	***
	S2	65.44[b]	77.13	58.42	4.33	6.62	
	S3	54.73[c]	64.07	47.67	3.21	5.87	
	S4	49.14[d]	65.36	40.38	3.02	6.15	
Arithmetic diameter (mm)	S1	85.51[a]	106.99	75.44	6.36	7.43	***
	S2	68.07[b]	79.85	60.78	4.68	6.88	
	S3	56.40[c]	65.89	50.11	3.41	6.05	
	S4	50.29[d]	66.78	40.40	3.05	6.07	
Sphericity (%)	S1	66.09[c]	80.47	53.04	5.58	8.45	***
	S2	70.30[b]	86.82	54.20	6.00	8.54	
	S3	74.83[a]	90.15	51.76	7.68	10.26	
	S4	77.09[a]	96.47	52.27	7.03	9.12	
Surface area (mm^2)	S1	20770.12[a]	32617.40	16157.56	3078.78	14.82	***
	S2	13509.98[b]	18689.97	10723.45	1820.58	13.25	
	S3	9440.89[c]	12894.77	7138.71	1116.31	11.82	
	S4	7614.98[d]	13420.82	5121.96	968.45	12.72	
Weight (g)	S1	311.37[a]	614.20	217.60	67.90	21.81	***
	S2	161.86[b]	238.00	119.40	31.25	19.15	
	S3	95.72[c]	152.00	63.30	17.47	18.25	
	S4	67.44[d]	87.40	44.10	8.76	13.00	
Volume (cm^3)	S1	289.10[a]	574.65	201.80	63.46	21.95	***
	S2	150.47[b]	224.75	111.52	29.15	19.37	
	S3	89.12[c]	139.78	59.52	16.12	18.08	
	S4	63.14[d]	82.46	41.38	8.14	12.89	
Density (g cm^{-3})	S1	1.08[a]	1.16	1.05	0.02	1.47	***
	S2	1.08[a]	1.10	1.02	0.01	1.18	
	S3	1.08[a]	1.15	1.04	0.02	1.57	
	S4	1.07[b]	1.10	1.04	0.01	1.07	

Note: SD – Standard deviation, CV – Variation coefficient, *** - They are significantly different according to the Tukey test (p <0.001).

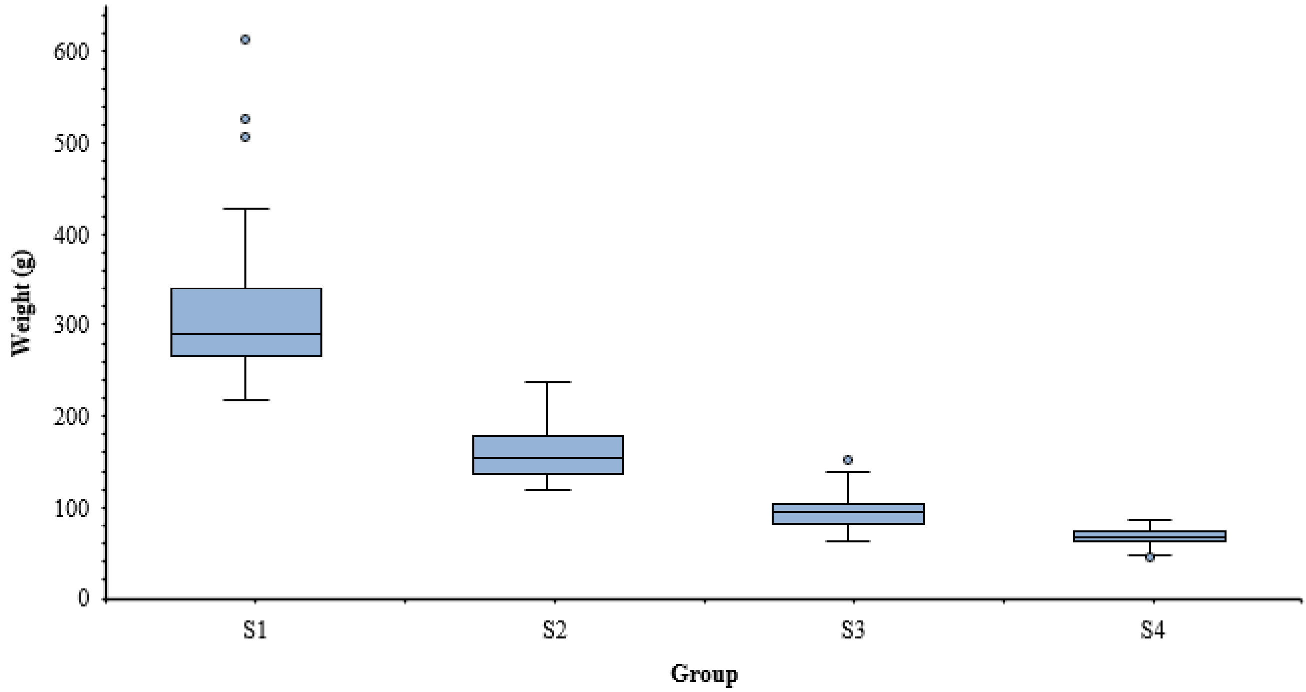


Figure 5 Weight mean comparisons by Tukey's test in the different groups

3.2 Mechanical characteristics

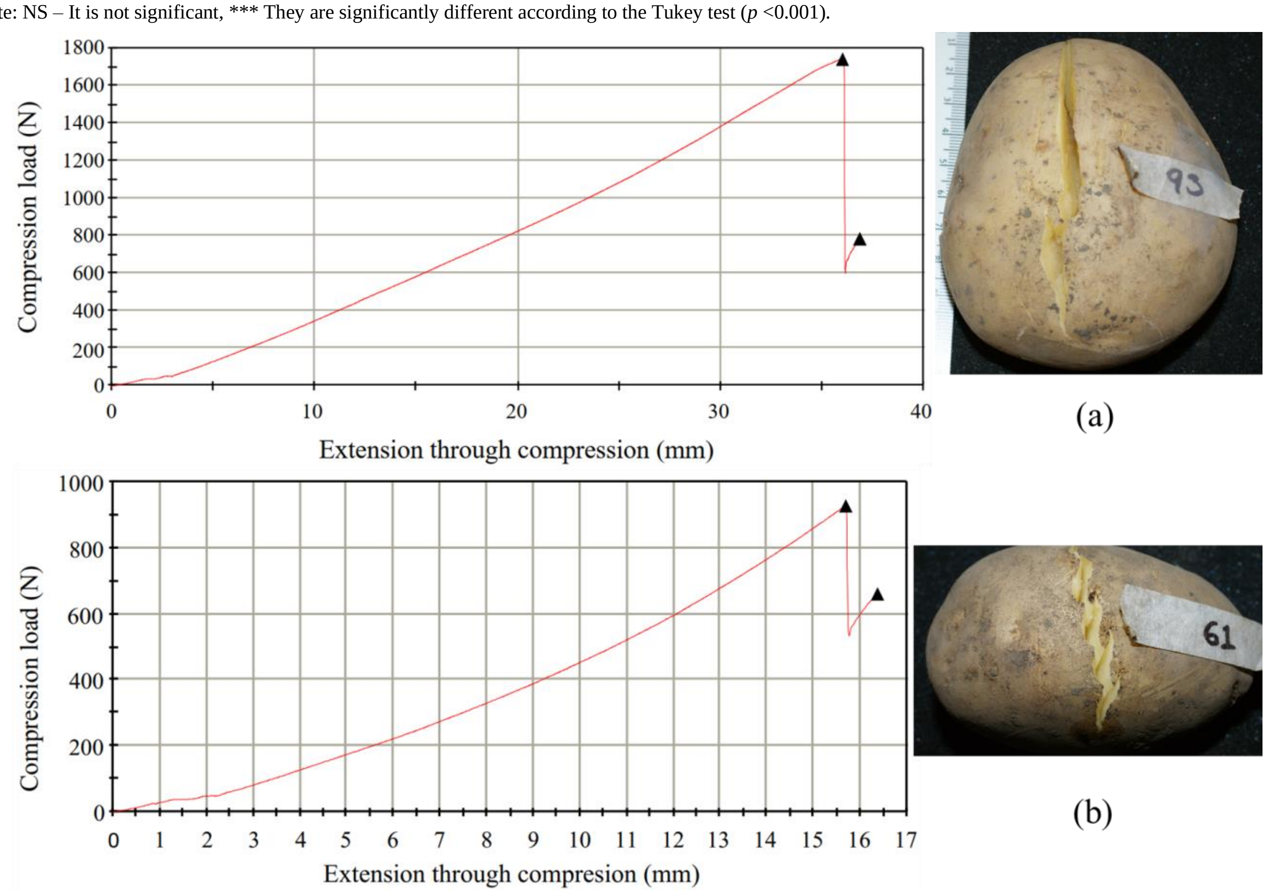
The mean values with their standard deviation of the static friction coefficient and the rolling coefficient are shown in Table 2. Three different surfaces were used. It was observed that on the galvanized steel sheet, lower coefficients were obtained with a mean of 0.400. Similar results were obtained by Yurtlu et al. (2011) with the Marabel variety, with a value of 0.396, while Patel et al. (2018) reported a value of 0.567 for the Kufri Badshah variety. The static friction coefficient increased in relation to sphericity for the three materials. The lowest were from Group S1, and the highest were from Group S4, except for the commercial neoprene material. The results obtained for the rolling angle were the opposite of the static friction coefficient. In Group S1, higher data were obtained compared to those in the S4 group; the only exception was the S3 group, which was less round than the S2 group, for which higher results were obtained. A mean rolling angle of a minimum of 15.05° was obtained on the galvanized steel sheet, and the maximum rolling angle on commercial neoprene was 15.58°. Abd Elhay (2017) obtained similar results with the Astrix variety on galvanized steel sheets, with a value of 14.80°.

The mean comparisons for the static friction coefficient and rolling angle are shown in Table 2. The mean values are significantly different, except when comparing the average of the materials used in the rolling angle test. For the static friction coefficient, statistically, there were two groups of mean classifications: the S3 group obtained the highest values, and the S1 group obtained the lowest values, while the S2 and S4 groups were within a combination of the mentioned groups. At the rolling angle, it was observed that the galvanized steel sheet showed a lower mean than the wooden and commercial neoprene sheets. There were two mean groups: the highest mean was obtained in the S1 group, and the corresponding lowest means were obtained in S3, S2, and S4. When comparing the average value of the rolling angle between the three materials, it was observed that the material did not present a significant difference.

Table 2 Mean values with standard deviation of the static friction coefficient and the rolling coefficient of potatoes on different surfaces

Parameter	Group	Surface			General mean	ANOVA
		Wooden board	Galvanized steel sheet	Commercial neoprene		
Static friction coefficient	S1	0.534 ± 0.079	0.334 ± 0.055	0.800 ± 0.103	0.556[b]	**
	S2	0.551 ± 0.078	0.373 ± 0.042	0.859 ± 0.117	0.594[ab]	
	S3	0.592 ± 0.074	0.428 ± 0.063	0.860 ± 0.135	0.626[a]	
	S4	0.596 ± 0.104	0.457 ± 0.058	0.794 ± 0.111	0.615[ab]	
	Mean	0.568[b]	0.398[c]	0.828[a]	***	
Rolling angle (°)	S1	18.78 ± 5.07	16.81 ± 2.74	18.83 ± 5.00	18.14[a]	***
	S2	14.81 ± 4.74	14.69 ± 3.56	14.57 ± 4.71	14.69[b]	
	S3	14.99 ± 4.53	14.88 ± 3.55	15.22 ± 4.89	15.03[b]	
	S4	13.18 ± 2.75	13.96 ± 2.73	13.28 ± 2.69	13.47[b]	
	Mean	15.44[a]	15.08[a]	15.47[a]	NS	

Note: NS – It is not significant, *** They are significantly different according to the Tukey test (p <0.001).



(a) potato from the S1 group in the vertical position; (b) potato from the S3 group in the horizontal position

Figure 6 Load-deformation curves (extension through compression) in the axial compression test

The axial compression results in all four size groups and in the two positions are shown in Table 3. The potatoes in a vertical position fractured lengthwise along the tuber (polar diameter), as shown in Figure 6 (a), while those in the horizontal position fractured through their width (equatorial diameter), as shown in Figure 6 (b). In the potatoes placed in the vertical position, the values obtained for compression loads and the Young modulus were lower (1050.056 N and 1.297 MPa, respectively) compared to those in the horizontal position (1430.043 N and 3.123 MPa, respectively), while the extension through compression and the compression deformation percentage showed opposite results: in the vertical position, with mean values of 29.995 mm and 27.31%, and in the horizontal position, with mean values of 19.59 mm and 17.43%, respectively. Patel et al. (2018) reported a similar relationship between the positions of the potatoes in the axial compression results with mean weights of 88.12 g and 89.58 g. The values obtained from the Young modulus spanned from 1.306 to 3.697 MPa, which are within the range (1.04 to 5.76 MPa) that ASAE (2005) presented. The mean comparison results were significantly different (p<0.0001), except for the mean weight comparisons, which did not present a significant difference because the potato tubers had physical similarities.

Table 3 Mean values from the axial compression test with potatoes of different sizes in two positions

Parameter	Group	Vertical Position	Horizontal position	General mean	ANOVA
Weight (g)	S1	284.267 ± 46.848	316.080 ± 57.211	300.174[a]	***
	S2	197.540 ± 29.494	203.327 ± 17.326	200.434[b]	
	S3	101.407 ± 18.857	106.853 ± 16.770	104.130[c]	
	S4	69.707 ± 8.894	66.933 ± 9.511	68.32[d]	
	Mean	163.230[a]	173.298[a]	NS	
Max. compression load (MPa)	S1	1343.231 ± 258.551	2059.810 ± 288.738	1701.521[a]	***
	S2	1184.198 ± 208.101	1607.989 ± 141.654	1396.094[b]	
	S3	929.157 ± 173.225	1198.920 ± 146.781	164.038[c]	
	S4	743.639 ± 139.973	853.451 ± 122.539	798.545[d]	
	Mean	1050.056[b]	1430.043[a]	***	
Extension through compression (mm)	S1	36.174 ± 4.828	24.057 ± 4.941	30.115[a]	***
	S2	35.555 ± 7.341	20.663 ± 1.715	28.109[a]	
	S3	26.290 ± 4.502	17.882 ± 1.546	22.086[b]	
	S4	21.963 ± 3.522	15.750 ± 1.391	18.856[c]	
	Mean	29.995[a]	19.588[b]	***	
Max. compression deformation (%)	S1	33.134 ± 4.212	21.371 ± 5.278	27.253[a]	***
	S2	33.060 ± 5.048	17.958 ± 1.601	25.509[a]	
	S3	23.713 ± 3.893	16.365 ± 1.546	20.039[b]	
	S4	19.348 ± 3.477	14.033 ± 1.356	16.691[b]	
	Mean	27.314[a]	17.432[b]	***	
Young modulus (MPa)	S1	1.343 ± 0.237	3.697 ± 0.478	2.520[a]	***
	S2	1.214 ± 0.183	3.356 ± 0.304	2.285[ab]	
	S3	1.326 ± 0.180	2.956 ± 0.393	2.141[bc]	
	S4	1.306 ± 0.329	2.482 ± 0.554	1.894[c]	
	Mean	1.297[b]	3.123[a]	***	

Note: NS – It is not significant. *** - They are significantly different according to the Tukey test (p <0.001).

Table 4 Potato firmness at different heights of fall impact

	Days after impact	Height of fall (cm)	S1 (N)	S2 (N)	S3 (N)	S4 (N)	Average (N)	ANOVA
Impact on Plastic	Zero	50	9.30	9.33	9.24	9.77	9.41[ab]	***
		75	10.41	8.20	11.12	7.87	9.40[ab]	
		100	10.86	7.62	11.17	8.42	9.52[ab]	
	Three	50	8.23	7.99	9.45	8.84	8.63[ab]	
		75	6.90	7.85	8.43	7.88	7.76[ab]	
		100	7.56	7.22	8.88	7.38	7.76[ab]	
Impact on Galvanized steel sheet	Zero	50	8.44	8.99	6.46	10.81	8.67[ab]	
		75	7.47	7.14	7.12	11.52	8.31[ab]	
		100	7.74	8.28	7.57	8.57	8.04[ab]	
	Three	50	9.06	7.86	8.22	8.78	8.48[ab]	
		75	8.34	8.30	7.68	7.48	7.95[ab]	
		100	7.20	7.62	7.60	8.13	7.64[b]	
Control sample potato			10.33	9.02	11.16	9.36	9.97[a]	

Note: *** - They are significantly different according to the Tukey test (p <0.001).

Table 4 shows the firmness results obtained using control sample potatoes and potatoes used in the impact tests. The firmness test results at zero days did not present a clear tendency, while at three days of storage, a firmness decrease was observed. According to the obtained mean values in the four groups, the firmness at zero days using potatoes in the impact tests decreased by 1.93 N compared to the control sample potatoes in all four size groups, while at three days after impact, the highest value was 2.63 N. Both values were obtained with the galvanized steel sheet at an impact height of 100 cm. Statistically different mean values were obtained ($p<0.001$), with a higher firmness in the control sample potatoes and the potatoes with impact tests at 100 cm height three days later on a galvanized steel sheet a lower firmness was obtained.

4 Conclusion

The physical-mechanical characteristics of the Fianna potato variety were determined to help understand its behavior during harvest, postharvest operations, and transportation. Furthermore, they function as support for designing and redesigning mechanical equipment that improves the performance and efficacy of these operations at a lower cost. Currently, in the study zone, there is low technology both in harvest and postharvest. The potatoes are collected and classified in the field manually and subjectively based on the experience of the worker only; however, the workers become confused due to the variation in shape among the tubers. The fatigue of the worker during the workday also affects these operations, provoking classification errors. Many potatoes are placed in a range that does not correspond, which represents an economic loss for the producer and an additional profit for the buyer or middleman. This error is mainly due to the axial dimensions of the potato. There are 7.25% long tubers with a width less than what is established, but with a mean weight within the range and with a constant relation that this potato variety presents, that the sphericity decreases while the size increases, having a rounder shape in the S4 group and more oblong one in the S1 group. The parameters obtained represent important data, necessary to make a design, the machines can improve their functionality with these data, such as: the static friction coefficient, the potatoes in the S4 group showed higher values and they decrease as the potato become bigger in size; the rolling angle increased while the potatoes increased in size, although exceptions were detected due to the shape of the potato being changeable. At the beginning of the compression tests, it was determined that the potatoes in the horizontal position can withstand a higher compression load with less deformation than the potatoes in the vertical position, but in both positions, the compression load incremented proportionally with the size of the tubers. The firmness results showed a slow decrease over time since the impact, and these characteristics changed directly with the material type, area and height of the impact, temperature, relative humidity, and quantity of exposed light from the tubers. All these values obtained will be very useful in the development of technology for the mechanization of the harvest and postharvest stages of potatoes.

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