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Some Mechanical Properties of Chestnut in Relation to Product Processing and Equipment Design

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ABSTRACT

Mechanical properties provide information to design and develop suitable machines (equipment) for processing, transporting, and conveying chestnuts. Four chestnut cultivars that have not been studied before were investigated in the study carried out for this purpose. Some engineering properties of Macit 55, Akyüz, Ali Nihat, and Bouche de Betizac chestnut cultivars were determined and compared. The mechanical properties were determined by rupture force, rupture energy, deformation, and firmness values. The friction coefficients of chestnut varieties on a galvanized sheet, stainless steel, and rubber surfaces were investigated. Mechanical properties were determined using a Universal Testing Machine. The values obtained from the samples were obtained by compression between the parallel plate along the X, Y, and Z axes. For the static friction coefficient, while the galvanized sheet surface had the lowest value (0.145), the rubber surface had the highest value (0.212). For rupture forces, the force required to break the chestnut at the Z loading axis position (714.09 N) was higher than the required force at the Y loading axis position (396.35 N) of the fruit.

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Introduction

Castanea sativa Mill. It belongs to the genus Castanea of the Fagaceae family, which includes trees such as beech (Fagus), oak (Quercus), commonly known as "chestnut" or "sweet chestnut" (Yüksel et al., 2020). Chestnut has been a valuable resource for the population's survival in many parts of Asia, Southern Europe, North Africa, and many countries with a coast to the Mediterranean (Oyedele et al., 2018). Chestnuts are mainly grown in China (1,140,746 tons), Republic of Korea (77,257 tons), Türkiye (58,952 tons) and Bolivia (56,227 tons) (FAO, 2019). It is seen that Türkiye is the third in the world. It grows naturally in Türkiye's Aegean, Mediterranean, Marmara, and Western Black Sea regions (Yüksel et al., 2020).

Chestnut has rich nutritional content and high nutritional value. Nuts usually contain a high-fat percentage, while chestnuts contain more carbohydrates. In addition, chestnut differs significantly from other fruits in terms of its chemical and nutritional composition and moisture content. Chestnut fruit contains 40-45% moisture, 5% protein, 5% fat and 40-45% carbohydrates under normal conditions. Since ancient times, chestnuts have been a source of carbohydrates in the human diet. The fruit is also known to contain vitamins C and A. For example, 100 grams of chestnut fruit contains 50 milligrams of vitamin C (Atasoy and Altıngöz, 2011). It also contains phosphorus, potassium, chlorine, magnesium, sodium, iron, and calcium. Chestnut fruit can be consumed fresh and processed in different ways, such as chestnut puree, canned and candied chestnuts. In addition, fruit peels are used in tannin production, and leaves and flowers are used in the pharmaceutical and cosmetic industry (Dönmez et al., 2016).

Improving the quality of processed or fresh chestnuts depends on determining the engineering properties. Mechanical effects may damage harvest or post-harvest crops. It can deteriorate more quickly due to damage to its outer layers. These factors negatively affect the storability and shelf life of products. For this reason, it is essential to know the mechanical properties of agricultural products (Altikat and Temiz, 2019). Separation systems of agricultural machinery, transmission, and mechanical properties of agricultural products are the most important parameters in the design of processing and packaging systems (Ahangarnezhad et al., 2019).

Many researchers have studied the mechanical properties of hard-shelled and granular products. Keluwak seeds (Hawa et al., 2020), Cashew Kernels (Isa and Oguntuase, 2013), Tiger nuts (Emurigho et al., 2020), peanuts (Uyeri and Uguru, 2018), hazelnuts (Bohnhoff et al., 2019) Nuts (The mechanical properties of hard-shelled fruits such as Chengmao et al., 2017) and walnuts (Gülsoy et al., 2019) were determined by the researchers. There are few studies on the mechanical properties of chestnut. Yurtlu and Yeşiloğlu (2011) examined the four chestnut varieties, Albayrak, Altınay, Ünal, and 554-14, and determined their breaking strength and breaking energies comparatively. Hamleci and Güner (2015) investigated some physical and mechanical properties of Sarıaşlama, Ayıtabanı, and Vakit chestnut varieties, such as shell breaking force, fracture energy, and specific deformation.

In this study, three axes of compression (X; Y; Z) of previously unexamined chestnut samples of Macit 55, Akyüz, Ali Nihat, and Bouche de Betizac chestnut cultivars. The mechanical properties were determined under the applied loading force. In addition, static and dynamic friction coefficients of chestnut varieties on a galvanized sheet, stainless steel, and rubber surfaces were determined. In this study, in addition to the physical properties of Macit 55, Akyüz, Ali Nihat, and Bouche de Betizac chestnuts, the mechanical properties of chestnut samples were determined under the loading force applied to three compression axes (X, Y, Z) of the previously unexamined cultivars. The study determined chestnut varieties' static and dynamic friction coefficients on a galvanized sheet, stainless steel, and rubber surfaces.

The aim of the study; It will help determine the engineering properties of chestnut varieties and adjust and design equipment and systems used after harvests, such as harvesting and post-harvest cleaning, sorting, and storage. Parameters obtained from the investigation of their mechanical behavior under compression load will shed light on the shelling and grinding equipment design. Dynamic frictional force must be overcome to transfer and transport products through equipment. Therefore, the required holding and bearing forces are related to static and dynamic friction coefficients. There is no research in the literature on the determination of the static and dynamic friction coefficients of the selected chestnut samples in the studies on chestnuts. The static and dynamic friction forces of the selected chestnut cultivars on different surfaces were determined in the study. The results and methods of this study can be used as a reference for other chestnut varieties.

Materials and Methods

Macit 55, Akyüz, Ali Nihat, and Bouche de Betizac chestnut varieties used in the study were obtained from the application gardens of Ondokuz Mayıs University, Horticulture Department. The experiments were conducted in a laboratory environment (41°21’ 55’’ N, 36° 11’ 14’’ E; 190 m above sea level, Samsun, Türkiye). For each chestnut cultivar, samples were randomly collected from 5 trees during the 2019 harvest seasons.

Chestnut samples were kept in perforated polyethylene bags in cold storage (0°C, 75-85% humidity) until measurement. Before starting the experiments, foreign materials were removed from the chestnuts. In addition, broken, spoiled, and immature chestnuts were manually cleaned.

The mechanical properties of the chestnuts, rupture force, deformation, rupture energy, and firmness values were found using a Lloyd (Figure 2) (Lloyd Instrument LRX Plus, Lloyd Instruments Ltd, an AMATEK Company) biological material test device (Kacal and Korucu., 2017). A load cell with a capacity of 1000 Newton (N) was used in the applications performed with the device. With the load cell, the force was applied to the chestnuts' X, Y, and Z axes at a compression speed of 10 mm/min. The X axis is the length dimension of the chestnut with the largest measurement value, and the applied loading force is specified as F_X. The Y axis is the chestnut's mid-size width dimension, and the applied loading force is indicated as F_Y. The Z axis is the thickness dimension of the chestnut with the smallest measurement value, and the applied loading force is specified as F_Z (Figure 1).

The data obtained from the device was transmitted to a computer with NEXYGEN Plus software, and the data was processed.

Test table, wooden box (60x120x100 mm), and pulley mechanism of Lloyd Materials Testing Machine were used to measure friction coefficients. The wooden box filled with chestnuts and an open bottom is connected to the load cell of the Lloyd Biological Materials Testing Device (Figure 3). With the opening at the bottom of the box, the chestnuts were allowed to contact the friction surfaces. The horizontal pull (friction force) was recorded with the software of the Lloyd device. Friction tests were performed at a sliding speed of 100 mm/min.

For each test, the vertical travel distance of the Lloyd Materials Testing Machine was set to 120 mm. Three different surfaces, galvanized sheet, stainless steel, and rubber, were used in the tests. During the tests, a gap of approximately 10 mm was left between the bottom of the wooden box and the test surface. Tests were performed on all abrasive surfaces for each chestnut variety with ten replications to determine the friction coefficients. (Yurtlu and Yeşiloğlu, 2011).

Statistical analysis of the data was processed using the system of IBM SPSS Statistics 21 program software. ANOVA test was used to investigate the effects of statistical effects of chestnut cultivars on mechanical properties. The statistical effects of the variety and friction surfaces on the dynamic and static friction coefficients were determined by the same method. Experiments were carried out with 10 replications. In addition, the difference between the means was statistically made using the DUNCAN multiple comparison test.

Results and discussion

As a result of the tests, the rupture force, rupture energy, deformation, firmness and coefficients of static and dynamic friction values of the mechanical properties of chestnut varieties.

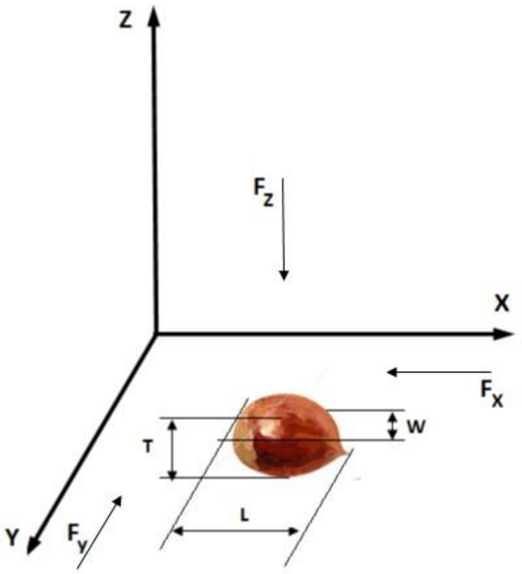

Figure 1. Chestnut dimensions and load axes

Figure 2. Lloyd Instrument universal testing machine

Figure 3. Wooden box used in friction tests

In the study, the mechanical (rupture force, deformation, rupture energy, and firmness) and coefficiency of friction properties (static and dynamic friction coefficient) values were determined by the applications on Macit 55, Akyüz, Ali Nihat and Bouche de Betizac chestnut varieties.

Rupture Force

Chestnut shell rupture forces were investigated by taking into account the chestnut varieties and the loading axes of the chestnuts. The rupture force values of chestnut varieties are shown in Table 1. It was determined that the lowest rupture force value for all varieties was on the Y axis. Considering the Y axis, the Bouche de Betizac variety was the chestnut variety with the largest rupture force value (589.88-401.06 N). Bouche de Betizac variety was followed by Akyüz (575.88 – 412.03 N), Ali Nihat (333.90 – 496.59 N), and Macit 55 (206.73 – 104.72 N), respectively. The highest value of the rupture force applied among the chestnut varieties investigated was obtained in the Z axis. It was determined that the largest rupture force value in the Z-axis among the cultivars was in Akyüz (921.20 – 996.11 N) cultivar. Bouche de Betizac (729.70 - 867.50 N), Ali Nihat (646.18 - 849.13 N), and Macit 55 (331.87 - 408.58 N) followed this variety, respectively. The largest rupture force values applied to the X axis were obtained in Bouche de Betizac (584.65 – 788.10 N). Other cultivars are Akyüz (579.48 – 687.21 N), Ali Nihat (502.07 – 607.98 N), and Macit 55 (315.47 – 398.24 N) cultivars. According to the statistical analysis result, as seen in Table 1, the effect of chestnut varieties, loading axes, and interactions (Variety × Ori. Of loading) on the rupture force ($P \leq 0.01$) was found to be statistically significant.

The results obtained are compatible with the studies of other researchers. Isa and Oguntuase (2015) found that the rupture force applied to the axial position of the cashew kernel sample was greater than that of the lateral position. According to Balami et al. (2012), in their study on the cocoyam specimen, it was determined that the rupture force obtained in the vertical direction was greater than that in the horizontal position. He et al. (2021), in their study on fresh lotus seeds, reported that the value of the ruptured tube in the vertical (275. 10 N) position was greater than that in the horizontal (150.95 N) position. In their study, Davies and Yusuf (2017) determined the rupture force of the velvet tamarind fruit as 47.93 N in the horizontal position and 56. 75 N in the vertical position. In the same study, they determined the rupture force of the velvet tamarind seed as 1653. 58 N in the horizontal position and 1774.51 N in the vertical position. It was determined that the rupture force of the velvet tamarind seed and fruit obtained in the vertical direction was greater than that in the horizontal position.

Deformation

The deformation values caused by force applied to the chestnuts are shown in Table 1. Macit 55 cultivar had the lowest deformation value among all studied chestnut cultivars. Z-axis has the lowest deformation value among the chestnut axis regions where force is applied. The lowest deformation value obtained from the Z axis of chestnuts was obtained from Macit 55 (4.48 – 6.99 mm). This variety is, respectively, Akyüz (6.10 - 7.28 mm), Ali Nihat (5.87 - 7.91 N), and Bouche de Betizac (7.44 - 13.58 mm) followed. All chestnut cultivars reached the greatest deformation value on the X axis. While Bouche de Betizac (11.30 – 15.31 mm) had the largest deformation value along the X axis, the other cultivars were Ali Nihat (12.03 – 15.35 mm), Akyüz (11.17 – 13.68 mm), and Macit 55 (8.47 – 10.13 mm), respectively. The highest value in the Y axis was obtained in Bouche de Betizac (8.16 – 11.18 mm). This cultivar was followed by Akyüz (8.41 – 9.90 mm), Ali Nihat (7.35 – 10.66 mm), and Macit 55 (6.62 – 8.34 mm) cultivars, respectively. According to the statistical analysis result; chestnut varieties, loading axes) were found to be statistically significant at the level of their effect on deformation (P≤0.01), and their interactions (Variety × Ori. Of loading) were not statistically significant at the level of their effect on deformation (P≥0.05). He et al. (2021) found that the deformation values of fresh lotus seeds were greater in the vertical position than in the horizontal position. The results of the study are compatible with the studies of the researchers.

Rupture Energy

As seen in Table 1, where the rupture energy values of chestnut varieties are given, the largest rupture energy occurred in the Bouche de Betizac variety. The lowest rupture force energy was found in Macit 55 variety. The highest rupture energy value was obtained in the X-axis in the force-applied regions of chestnut varieties. The largest rupture energy value in the x-axis was measured in Akyüz (3.20 – 4.63 J). Other cultivars following Akyüz were Bouche de Betizac (2.53 - 4.25 J), Ali Nihat (1.48 - 2.54 J), and Macit (1.28 - 1.49 J). It was determined that the lowest rupture energy value in chestnut axes was on the Y-axis. Bouche de Betizac (1.78 – 2.24 J) variety has the highest rupture energy values obtained from the Y-axis. Other cultivars are Akyüz (1.32 – 2.44 J), Ali Nihat (1.07 – 2.27 J), and Macit 55 (0.46 – 0.75 J), respectively. Varieties with rupture energy values obtained from the Z-axis of chestnut cultivars, from largest to smallest, are respectively Bouche de Betizac (1.01 – 2.54 J), Akyüz (0.91 – 2.06 J), Ali Nihat (1.07 – 2.12 J), and Macit 55 (0.27 – 0.58 J) has been determined. According to the statistical analysis result; chestnut varieties, loading axes) on rupture, energy was found to be statistically significant at (P≤0.01) level, and interactions (Variety x Ori. Of loading) were found to be statistically significant at P≤0.05 level.

Isa and Oguntuase (2015) found that the rupture energy value of the cashew kernel sample in the axial position (0.1651 Nm) was greater than that in the lateral position (0.0098 Nm). The results of the study are compatible with the studies of the researchers.

Firmness

Akyüz had the highest firmness value among all the researched chestnut varieties. This variety was followed by Ali Nihat, Bouche de Betizac, and Macit 55. The largest firmness value was obtained in the Z-axis in terms of chestnut axes. In terms of the Z-axis, chestnut varieties with firmness values from largest to smallest are Akyüz (136.29 – 153.93 mm^{-1}), Ali Nihat (88.16 – 128.10 m^{-1}), Bouche de Betizac (62.43 – 104.72 mm^{-1}), and Macit 55 (57.66 – 84.60 mm^{-1}). The lowest firmness value was obtained in the Y-axis in the chestnut axis. The hardness value in the Y axis is from largest to smallest, respectively, for Akyüz (41.79 – 67.39 mm^{-1}), for Bouche de Betizac (38.22 – 70.58 mm^{-1}), for Ali Nihat (37.47 – 66.02 mm^{-1}) and Macit 55 (15.80 – 25.73 mm^{-1}). The largest firmness value in the X axis has obtained in Akyüz (43.71 – 52.31 mm^{-1}) variety. Other cultivars were Bouche de Betizac (36.92 – 56.46 mm^{-1}), Ali Nihat (32.71 – 44.98 mm^{-1}), and Macit 55 (31.15 – 47.01 mm^{-1}), respectively. According to the statistical analysis result, Chestnut cultivars, loading axes, and interactions (Variety x Ori. Of loading) were found to be statistically significant at the level of the effect (P≤0.01) on firmness.

Table 1. Measurement parameters and some statistical values for rupture force, deformation, rupture energy, firmness

Variety	Loading Direction	Rupture Force N	Deformation mm	Rupture Energy J	Firmness N mm^{-1}
Macit 55	X	339.24±19.79	9.29±0.47	1.37±0.05	36.96±3.62
	Y	154.86±13.74	7.79±0.27	0.61±0.04	19.79±1.51
	Z	358.67±15.17	5.53±0.43	0.43±0.05	63.83±2.32
Akyüz	X	615.55±19.85	12.61±0.58	3.90±0.29	46.04±1.69
	Y	512.86±34.33	9.20±0.31	1.95±0.19	56.27±5.09
	Z	963.85±15.12	6.69±0.24	1.61±0.23	144.42±3.34
Ali Nihat	X	557.39±16.32	13.29±0.56	2.24±0.24	42.28±1.98
	Y	428.04±28.57	8.87±0.59	1.66±0.22	49.18±4.54
	Z	721.86±29.07	6.68±0.28	1.48±0.18	108.88±6.36
Bouche de Betizac	X	670.52±36.32	13.90±0.79	3.38±0.27	48.79±3.47
	Y	531.61±34.04	9.77±0.67	2.11±0.08	55.61±5.67
	Z	810.41±23.77	9.10±1.13	1.99±0.31	92.79±7.85
Variety					
Macit 55		271.96±26.99^{a}	7.44±0.44^{a}	0.75±0.41^{a}	39.77±5.61^{a}
Akyüz		697.42±53.22^{c}	9.50±0.68^{b}	2.49±0.30^{c}	83.25±11.75^{b}
Ali Nihat		569.10±32.24^{b}	9.61±0.72^{b}	1.80±0.21^{b}	66.79±7.68^{b}
Bouche de Betizac		670.85±34.86^{bc}	10.93±0.74^{b}	2.50±0.83^{c}	65.73±6.07^{b}
	X	556.58±28.93^{b}	12.47±0.48^{c}	2.77±0.25^{b}	44.54±1.64^{a}
	Y	396.35±35.80^{a}	8.86±0.28^{b}	1.54±0.15^{a}	44.24±3.88^{a}
	Z	714.09±49.67^{c}	6.99±0.40^{a}	1.38±0.16^{a}	103.31±6.78^{b}
P Values					
Variation		0.000	0.000	0.000	0.000
Loading Direction		0.000	0.000	0.000	0.000
Type × Loading Direction		0.000	0.099	0.009	0.000

Table 2. Measurement parameters and some statistical values for the coefficient of friction

Variety	Abr. Surface	Dynamic Coefficient of Friction	Static Coefficient of Friction
Macit 55	Galvanized sheet	0.169±0.007	.135±0.006
	Stainless steel	0.254±0.004	0.168±0.004
	Rubber	0.298±0.030	0.187±0.007
Akyüz	Galvanized sheet	0.178±0.006	0.136±0.011
	Stainless steel	0.395±0.008	0.166±0.006
	Rubber	0.348±0.040	0.251±0.016
Ali Nihat	Galvanized sheet	0.227±0.018	0.168±0.003
	Stainless steel	0.264±0.007	0.209±0.006
	Rubber	0.356±0.030	0.226±0.003
Bouche de Betizac	Galvanized sheet	0.206±0.012	0.140±0.006
	Stainless steel	0.364±0.009	0.171±0.016
	Rubber	0.419±0.007	0.184±0.004
Means			
Macit 55		0.240±0.021[a]	0.164±0.008[a]
Akyüz		0.307±0.035[ab]	0.184±0.018[ab]
Ali Nihat		0.283±0.022[ab]	0.201±0.009[a]
Bouche de Betizac		0.330±0.032[b]	0.166±0.006[b]
	Galvanized sheet	0.195±0.009[a]	0.145±0.005[a]
	Stainless steel	0.319±0.018[ab]	0.179±0.007[b]
	Rubber	0.355±0.018[ab]	0.212±0.006[c]
P Values			
Variety		0.000	0.000
Abrasion Surface		0.000	0.000
Variety × Abr. Sur.		0.000	0.000

Coefficient of Friction

According to the analysis of variance (ANOVA) with the values obtained from the chestnut cultivars used in the research, it was determined that the friction surfaces and cultivars used as controlled variable parameters significantly affect both the static and dynamic friction coefficients. The ANOVA test showed that the variation of friction coefficients with varieties, surfaces, and variety x surface interactions were significant ($P<0.01$). Duncan's multiple comparison tests were performed to determine the differences and significance levels between the mean of abrasive surfaces and cultivars (Table 2). The lowest dynamic friction coefficient value was found on the galvanized sheet surface. It was determined that there was no significant difference between the dynamic friction coefficient values for stainless steel and rubber surfaces. Bouche de Betizac was the variety with the highest dynamic friction coefficient (0.330). There was no significant difference between Ali Nihat and Akyüz varieties in dynamic friction force values. The lowest dynamic friction coefficient value was obtained in Macit 55 (0.240).

Duncan's multiple comparison test results show a significant difference between the static friction coefficient values for the galvanized sheet, stainless steel, and rubber surfaces. The highest static friction coefficient was on the rubber surface (0.212). The lowest static friction coefficient was obtained on the surface of the galvanized sheet (0.145). It was determined that there was no difference between Ali Nihat and Macit 55 varieties in terms of static friction coefficient values among chestnut cultivars. Ali Nihat variety has the largest (0.201), and Macit 55 has the lowest (0.164) static friction coefficient value.

According to the results of the ANOVA test, it was determined that the interaction and variations between surfaces and types showed the same tendency of importance levels of static and dynamic friction coefficients. The highest dynamic friction force value was on the rubber surface and Bouche de Betizac (0.405- 0.431) chestnut variety. The lowest dynamic friction force value was observed on galvanized sheet surface and Macit 55 (0.16 – 0.18) chestnut variety. The highest static friction force value was found on rubber surfaces and the Akyüz chestnut variety (0.22 - 0.28). The lowest static friction force value occurred on galvanized sheet surface and Macit 55 chestnut variety (0.12 – 0.14).

Davies and Mohammed (2013) determined the static friction coefficients of bitter cola nuts and shell samples in their study. It was determined that the static friction coefficient values of the bitter kola nuts and shell samples were higher on the rubber surface than on the galvanized steel surface. Ganjloo et al. (2017) reported in their study on green peas that it is larger on the rubber surface than on the galvanized steel surface. Davies and Yusuf (2017) obtained the highest value of the static friction coefficients of velvet tamarind fruits and seeds on the rubber surface. The static friction coefficient of velvet tamarind fruits was the lowest on the stainless steel (0.41) surface. This was followed by the galvanized sheet (0.47) and rubber (0.53)

Conclusions

- The research determined that the rupture force value applied to the Z-axis of chestnut varieties was the highest. More rupture energy is required in the X-axis for dividing all investigated chestnut varieties by compression.

- The study revealed that chestnut varieties needed 2.77 J on the X-axis and 1.38 J on the Z-axis rupture energy. It is seen that the Rupture energy is at least in the Z-axis of the chestnuts. Considering this situation, it may be more appropriate to use the Z-axis than other axes in dividing the shell by compression.
- Among all friction surfaces used in the research, the highest static and dynamic friction coefficients were obtained for the rubber surface. It was determined that the lowest value of both static and dynamic friction coefficient was on the Galvanized sheet surface. Chestnut varieties and friction surfaces significantly affect chestnuts' static and dynamic friction coefficients.

Among all varieties, the static friction coefficient value to the environment varies up to 0.251 on the rubber surface and up to 0.168 on the galvanized sheet surface. It has been determined that the average dynamic friction force varies up to 0.419 on the rubber surface and up to 0.227 on the galvanized sheet surface.

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