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Determination of Shear Resistance and Shear Energy of Kastamonu Taşköprü Garlic

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Abstract: Kastamonu Taşköprü garlic is known all over the world. Its distinctiveness has been demonstrated in terms of its sharp aroma and high nutritional content, and it received a geographical indication in 2009. It is the first agricultural product that comes to mind that reminds Kastamonu. Kastamonu alone meets 20% of Türkiye's garlic production. A very large amount of the garlic produced is marketed in the form of hand-tied, and thousands of tons of Taşköprü garlic are sold in markets and supermarkets, reaching consumers nationwide. Products in the form of chips, granules, and powder obtained by drying garlic also increase their shelf life. For the drying process to be short and economical, garlic must be sliced and thinned. This study investigates the shear resistance and energy parameters critical for designing garlic-slicing machines. Humidity, peeled-unpeeled and clove size variables were examined in; as a result, in the average humidity of 62.7-59.3%, the maximum shear force in unpeeled garlic was 22.69 N, the shear energy was 248.9 Nmm, the shear stress was 0.165 N/mm^2, and in peeled garlic, the maximum shear force was 17.03 N, the shear energy was 148.95 Nmm, the shear stress was 0.105 N/mm^2. It was also observed that smaller garlic clove cross-sections exhibited greater hardness.

Keywords: Garlic, Shear Force, Shear Energy, Shear Stress, Energy Saving

Özet: Kastamonu Taşköprü sarımsağı tüm dünyada tanınmaktadır. Gerek keskin aroması gerekse yüksek besin içerikleri yönünden farklılığı ortaya konmuş ve 2009 yılında coğrafi işaret almıştır. Kastamonu'yu çağrıştıran. ilk akla gelen tarım ürünüdür. Kastamonu. Türkiye sarımsak üretiminin %20 sini tek başına karşılamaktadır. Üretilen sarımsağın çok büyük miktarı el bağı şeklinde pazarlanmakta. binlerce ton Taşköprü sarımsağı pazarlarda ve marketlerde satılarak sofralara ulaşmaktadır. Sarımsağın kurutulması ile elde edilen cips. granül. toz şeklindeki ürünler sarımsağın dayanma süresini de artırmaktadır. Kurutma işleminin kısa sürede ve ekonomik olabilmesi için sarımsağın dilimlenerek inceltilmesi gerekmektedir. Bu çalışmada sarımsak dilimleme makinası tasarımı için gerekli kesilme direnci ve kesilme enerjisi parametreleri araştırmıştır. Nem. soyulmuş-soyulmamış ve diş büyüklüğü değişkenlerinde incelenmiş. sonuç olarak % 62.7-59.3 nem ortalamasında soyulmamış sarımsakta maksimum kesme kuvveti 22.69 N. kesilme enerjisi 248.9 Nmm. kesilme gerilmesi 0.165 N/mm^2. soyulmuş sarımsakta maksimum kesme kuvveti 17.03 N. kesilme enerjisi 148.95 Nmm. kesilme gerilmesi 0.105 N/mm^2 olarak tespit edilmiştir. Ayrıca sarımsak diş kesitleri küçüldükçe dişlerin sertleştiği tespit edilmiştir.

Anahtar kelimeler: Sarımsak, Kesme Kuvveti, Kesilme Enerjisi, Kesilme Gerilmesi, Enerji Tasarrufu

1. Introduction

Garlic (*Allium sativum*) is a plant species belonging to the Allium genus of the Onion family (Alliaceae). Onions, chives, leeks, and green onions are also included in this Allium genus. Garlic is frequently used as a flavoring in many dishes. It creates a very diverse usage area in the kitchen with its use in kebab, soup, appetizer, sauce, and appetizer recipes in raw, cooked or powdered form and its role in enhancing the flavor of the dishes [1, 2]. Garlic can also be used to produce products such as sausage, fenugreek, pastrami, spices, canned food, brine, pickles, yogurt, tomato paste, and similar products [3-7]. Garlic products available in the market are generally in the form of garlic tablets, garlic vinegar, garlic yoghurt, garlic olives, garlic puree, garlic capsules, garlic mustard, (a wide variety of) garlic sauces, garlic powder, garlic essential oil, garlic juice (extract), dried garlic and garlic pickles [3].

The geographically indicated Taşköprü garlic is known all over the world. Garlic is the agricultural product that provides the most employment for the Taşköprü district of Kastamonu. Approximately 4000 families in Taşköprü sustain their lives with garlic production. This means that 75% of the population sustains their lives with garlic income. Since garlic farming requires a lot of labor, it plays an important role in the employment of the population in the Kastamonu-Taşköprü region. For this reason, in Kastamonu, where there is migration due to limited sources of income, garlic farming has become an important source of income by connecting the population to the field [8]. It has been determined that the local

product that reminds Kastamonu the most is garlic (38.19%) [9]. In another study, Taşköprü garlic, the symbol of Kastamonu, was determined to be this city's most recognized food product [10].

When Türkiye's garlic production for the last 10 years between 2015-2024 is examined, although it varies by year, an average of 120371 tons of garlic was produced on an area of 127932 da, and a yield of 940 kg/da was reached. In Kastamonu, which alone met 21.53% of the country's production in these years, an average of 26041 tons of garlic was obtained on an area of 26453 da, and a yield of 980 kg/da was reached (Table 1).

Table 1. Garlic statistics in Türkiye and Kastamonu (2015-2024) TUİK 2025 [11]

Years	Kastamonu			Türkiye			K/T*	K/T*
	Field (daa)	Production (ton)	Efficiency (ton/daa)	Field (daa)	Production (ton)	Efficiency (ton/daa)	Field (%)	Production (%)
2015	24000	23328	0.97	108084	94867	0.88	22.20	24.59
2016	24530	24024	0.98	119155	109161	0.92	20.59	22.01
2017	26515	25968	0.98	131451	121805	0.93	20.17	21.32
2018	25750	20540	0.80	133397	117688	0.88	19.30	17.45
2019	26550	17405	0.66	124357	103096	0.83	21.35	16.88
2020	25593	22995	0.90	126664	116840	0.92	20.21	19.68
2021	29274	33122	1.13	133710	132617	0.99	21.89	24.98
2022	29344	33168	1.13	139626	140464	1.01	21.02	23.61
2023	28675	32481	1.13	138522	142167	1.03	20.70	22.85
2024	24294	27375	1.13	124352	125000	1.01	19.54	21.90
Avg	26453	26041	0.98	127932	120371	0.94	20.70	21.53

*K/T: Kastamonu Türkiye rate, Avg: Average.

Genç [12] determined the advantageous aspects of Taşköprü garlic in his research as follows:

I. It is suitable for export due to its tolerance to climate conditions during the production phase, its large, regular, standard head sizes, and its quality.
II. It has a long shelf life and can be stored for nearly a year (10-11 months) without cold storage.
III. The dry matter ratio is between 33-37%, so it does not lose much weight.
IV. The amount of sulfurous volatile oils and their derivatives that give Taşköprü garlic its smell is higher than all other garlics grown in our country.
V. It is the only variety in our country that contains selenium element in its composition. Selenium element is a substance that reduces and prevents cancer risk.
VI. It is the richest variety of minerals, vitamins, and amino acids. It contains magnesium and potassium, which are primarily used in stress treatment, and zinc, which is good for ailments such as hair loss and infertility.
VII. Its spice ratio is higher than other garlic; it has a sharp smell and aroma. For this reason, it is the most sought-after variety in the sausage, pickle, canned, and spice industry.

Garlic is the most important agricultural product in the Kastamonu economy. Thousands of tons of garlic reach consumers and take their place on the table without being processed as hand-tied garlic. However, there is also demand for garlic products, such as chips, granules, and powder. The production of these products is possible by shearing and thinning the garlic and then drying it. Sacilik and Ünal [13] revealed the drying characteristics of sliced Taşköprü garlic in their research.

Akan and Ünüvar [14] stated in their study examining Taşköprü garlic that new employment areas should be provided for the people of the region by establishing modern facilities based on agriculture, investment, and infrastructure opportunities will be developed thanks to employment in the industry, and the development of the regional population on site will also be contributed. Akan [15] reported that garlic cannot be consumed in sufficient quantities in all societies due to its strong odor and bitterness, and a wide variety of processed alternative products should be brought to the agenda to increase consumption. Gökırmaklı and Bayram [16] emphasized that changing lifestyles and women entering the workforce will change cooking habits at home, and the ready-made food sector and sectors related to ready-made foods will grow.

Kastamonu Taşköprü garlic should be produced in the form of chips, granules, and powder to be converted into products with longer shelf life and obtain products with higher added value. For the drying process to be more economical and short-lived during these processes, the garlic should be thinned by slicing. In order to design a machine to reduce the labor needed for slicing processes, shear resistance, and energy should be determined. Many researchers have conducted various studies to determine the shear force, shear stress, and shear energy for plant-based materials [17-29]. However, no similar study has been conducted on garlic. The demand for processed products and ready-made foods has increased in recent years. Both product diversity and the production of high-value-added garlic products must be increased. This study aims to determine the shear resistance and energy of Kastamonu Taşköprü garlic and the data needed for the design of slicing machines to be developed.

2. Material and Method

This study was carried out in the Mechanical Engineering laboratories of the Faculty of Architecture and Engineering of Kastamonu University. The garlic with a head diameter of around 5 cm used in the experiment was supplied from Kastamonu in March 2025, and their stems were broken off and separated into cloves. Since the shell structures and clove shapes were different, the thin cloves in the middle of the garlic heads were not used; only the large and small cloves in the outer row were used. The cloves were kept in the same container at +4 for 10 days to equalize their humidity. In order to determine the humidity of the garlic cloves during cutting, the cut garlic cloves were weighed with a scale and kept in a drying cabinet at 105 ºC for 24 hours. The weights of the samples recorded at the end of drying were determined as the percentage of the moisture content of the cloves by the following equation (wet basis) [26].

Humidity (w.b)=[(wet material-dry material)/wet material]x100

After the first trial, the garlic used were kept in the open for 10 days to dry and then stored for 10 days again. In this way, the experiments were carried out at 2 different moisture levels (62.7% and 59.3%). Garlic cloves were also tested in 2 different ways: with and without peel.

In each trial, 20 garlic cloves were subjected to a shear test. After shearing the garlic, the resulting cross-section was painted and pressed on the paper, and the trace was transferred to the paper. The paper on which the photo was taken and was opened in a scaled manner on the Solidworks program. The outline of the cross-section was drawn by going over the edge cut precisely. The surface areas were calculated after giving depth to the 2-dimensional drawing and turning it into 3-dimensional. The measured areas were then sorted from largest to smallest and divided into four groups of five each. The effect of clove size on shear resistance was investigated by taking the averages on a group basis. The maximum shear force was determined as the most significant value measured during shear, the maximum shear stress was determined by dividing this value by the cross-sectional area, and the shear energy was determined as the energy spent during the shear process (the area under the shear curve).

The maximum shear force was determined as the largest value measured during shear, the maximum shear stress was determined by dividing this value by the cross-sectional area, and the shear energy was determined as the energy spent during the shear process (the area under the shear curve).

The experiments were carried out using the mechanism developed in Figure 1. The forces were measured with a 500 N capacity load cell and Almemo 2590 datalogger and transferred to the computer via a USB connection. The shear process was carried out with the cutter in the section in the figure at a speed of 34 mm/min.

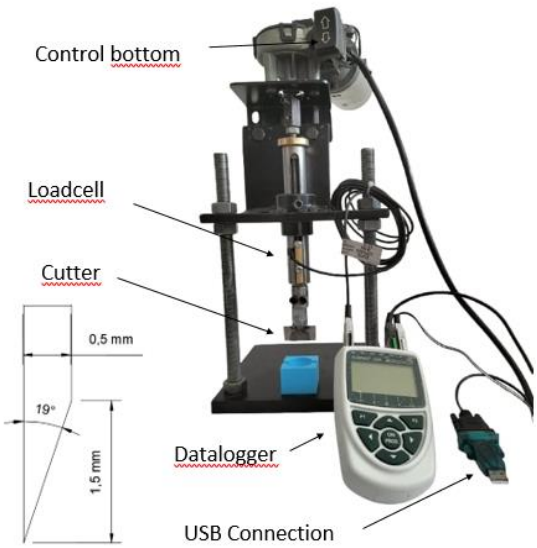

Figure 1. Experimental setup

3. Result and Discussion

As a result of the shear test conducted on 2 different varieties, peeled and unpeeled, 2 different humidity levels of 62.7%-59.3%, and 4 different section area size variables, the following results were obtained.

In U1 (unpeeled-62.7% humidity), the maximum shear force averages were determined as 21.85 N, shear energy averages as 234.1 Nmm, shear energy / cross-sectional area averages as 1.46 N/mm and shear stress averages as 0.15 N/mm^2. In U2 (unpeeled-59.3% humidity), the maximum shear force averages were determined as 23.52 N, shear energy averages as 263.74 Nmm, shear energy / cross-sectional area averages as 1.85 N/mm and shear stress averages as 0.18 N/mm^2. Considering these values, peeled garlic's average maximum shear force was determined as 22.69 N, the shear energy as 248.9 Nmm, and the shear stress as 0.165 N/mm^2.

In P1 (peeled-62.7% humidity), the maximum shear force averages were determined as 16.10 N, shear energy averages as 141.73 Nmm, shear energy / cross-sectional area averages as 0.89 N/mm, and shear stress averages as 0.10 N/mm2. In P2 (peeled-59.3% humidity), the maximum shear force averages were determined as 17.95 N, shear energy averages as 156.16 Nmm, shear energy / cross-sectional area averages as 0.91 N/mm, and shear stress averages as 0.11 N/mm^2. Considering these values, peeled garlic's average maximum shear force was determined as 17.03 N, shear energy as 148.95 Nmm, and shear stress as 0.105 N/mm^2.

In general, it is seen that unpeeled garlic requires higher shear force and shear energy than peeled garlic. Similarly, when the moisture content of garlic decreases, the required shear force and shear energy increase. This result is consistent with the research conducted on olive shoots [23], grape shoots [24], rice stalks [25], and alfalfa stalks [18].

The other researchers found shear stress about 0.017 N/mm^2 for potato [27], 0.0017 N/mm^2 for carrot [28], and 0.15-0.26 N/mm^2 for leek [29].

Table 2. Kastamonu garlic shear test results

		1	Sd	2	Sd	3	Sd	4	Sd	Avg	Sd
U1	Section area (mm²)	226.7	9.3	185.6	8.6	150.1	14.2	107.3	16.2	167.4	44.1
	Max shear force (N)	19.2	3.4	20.9	5.1	21.4	4.7	25.9	5.5	21.9	5.4
	Shear energy (Nmm)	283.5	54.3	248.1	68.5	220.1	51.1	184.7	25.3	234.1	63.3
	Shear enj / section area (N/mm)	1.3	0.2	1.3	0.4	1.5	0.4	1.8	0.3	1.5	0.4
	Shear stress (N/mm²)	0.08	0.02	0.11	0.03	0.14	0.04	0.24	0.03	0.15	0.07
U2	Section area (mm²)	211.2	26.4	158	7.92	135.4	8.91	85.6	17.9	147.6	48.2
	Max shear force (N)	21.2	3.1	22.6	4.6	23.9	4.8	26.4	3.7	23.5	4.3
	Shear energy (Nmm)	306.7	83.8	275.7	72.8	259.5	32.9	213	41.4	263.7	75.2
	Shear enj / section area (N/mm)	1.5	0.2	1.7	0.4	1.9	0.1	2.3	0.8	1.9	0.6
	Shear stress (N/mm²)	0.10	0.02	0.14	0.02	0.18	0.04	0.31	0.08	0.18	0.07
P1	Section area (mm²)	212.7	6.8	173.8	12.6	148.6	7.2	126.9	10.6	165.5	31.9
	Max shear force (N)	15.2	4.1	15.9	2.0	16.2	3.4	17.0	3.8	16.1	3.8
	Shear energy (Nmm)	158.8	30.5	147.7	49	136.1	26.2	124.3	21.2	141.7	35.8
	Shear enj / section area (N/mm)	0.8	0.1	0.9	0.3	0.9	0.1	1.0	0.2	0.9	0.2
	Shear stress (N/mm²)	0.07	0.02	0.09	0.01	0.11	0.02	0.13	0.04	0.10	0.04
P2	Section area (mm²)	243	16.8	192	6.9	154.8	11.9	119.8	31.5	177.4	47.0
	Max shear force (N)	16.3	3.0	17.0	4.7	18.9	3.1	19.6	1.9	18.0	4.0
	Shear energy (Nmm)	186	20.1	164.6	29.3	143.9	23.2	130.2	14.9	156.2	51.4
	Shear enj / section area (N/mm)	0.8	0.1	0.9	0.2	0.9	0.1	1.1	0.3	0.9	0.2
	Shear stress (N/mm²)	0.07	0.01	0.09	0.02	0.12	0.02	0.16	0.04	0.11	0.02

Sd:standart deviation, Avg: Average.

When the effect of the section area change is examined (Figure 2), it is seen that as the section areas decrease, the maximum shear forces increase and the shear energy decreases. Naturally, the shear energy consumed decreases with the reduction of the section area. Similar results have been obtained in different studies [24-25]. However, the increase in the maximum shear force gives the opposite result in these studies. This difference means that as the garlic cloves become smaller, they become tighter and harder. While some cloves in the garlic head develop and grow rapidly, some get stuck in between and cannot grow as much as the others. It is thought that the growing cloves compress the smaller cloves in between, thus densifying and hardening them. This situation is compatible with large-headed, large-toothed garlic emptying earlier due to their loose structure, and small-headed, small-toothed garlic remaining in the same environment longer without emptying.

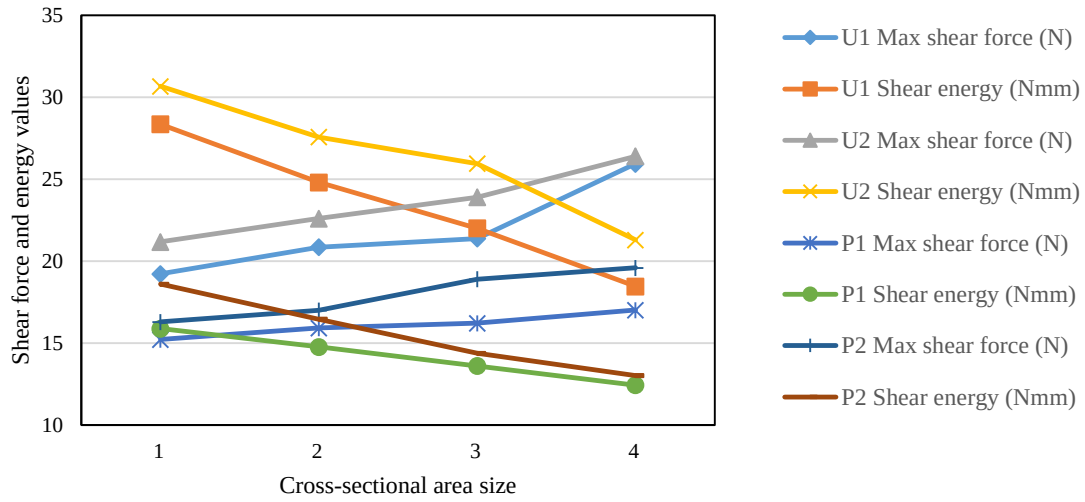

Figure 2. Comparative changes in maximum shear force and shear energy of Kastamonu garlic

When the shear forces and shear energies per unit area are examined (Figure 3), the ratio of shear energy and shear force to the section area increases as the section becomes smaller, which can be explained by the fact that the garlic cloves become harder as they become smaller.

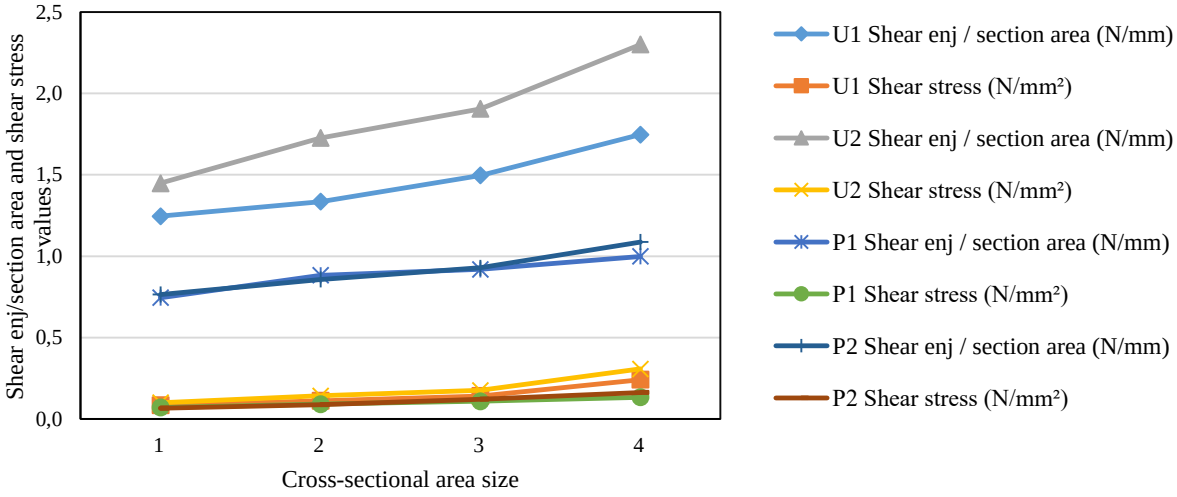

Figure 3. Comparative shear stress and shear energy/section area changes of Kastamonu garlic

4. Conclusion

In order to reduce the drying energy to be spent during the production of dried garlic products, the process should be done in thin slices. The design of the machine in which the slicing process will be carried out requires the determination of values such as the shear force, shear resistance, and shear energy. In this study, these parameters were investigated for Kastamonu garlic.

It is observed that the required shear force, shear energy, and shear stress values are higher in shelled garlic than in peeled garlic, and similarly, as the humidity decreases, shear becomes more difficult. The shear force, shear energy, and shear stress values increase. Another result of the research is that the cloves become harder as the garlic clove cross-section becomes smaller.

As a result, in the average humidity of 62.7-59.3%, the maximum shear force in unpeeled garlic was determined as 22.69 N, the shear energy as 248.9 Nmm, the shear stress as 0.165 N/mm^2, and in peeled garlic, the maximum shear force was determined as 17.03 N, the shear energy as 148.95 Nmm, the shear stress as 0.105 N/mm^2. Therefore, it would be useful to consider these measured values for a machine to be designed or manufactured for use in garlic slicing.

Conflict of Interest

The authors declare that they have no competing interests.

Ethics Committee Approval

Ethics committee approval is not required.

Author Contribution

The authors have read and agreed to the published version of manuscript.

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