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(Research Article)

Determination of the effect of cutting angle, cutting speed, and moisture content on garlic shear stress and specific shear energy

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Abstract

Türkiye produces an average of 120000 tons of garlic annually over the past 10 years. The vast majority of garlic produced nationwide is marketed in bunches, with thousands of tons sold in markets and supermarkets and reaching consumers' tables. The shelf life of this garlic after harvest varies, but averages between 4 and 10 months. It is necessary to promote dried garlic products with a longer shelf life. Products obtained by drying garlic, such as chips, granules, and powder, also increase the shelf life of garlic. For the drying process to be short and economical, the garlic must be sliced thinly. This study investigated the cutting parameters required for the design of a garlic slicing machine. The effects of moisture, cutting angle, and cutting speed variables were examined. As a result, as the moisture content of garlic decreases, the shear stress and specific shear energy increase; as the cutting speed decreases, the shear stress and specific shear energy increase; and as the cutting angle increases, these values decrease. As a result, in the study conducted with Araban garlic, shear stress values were determined to be in the range of 0.0318-0.0638 N/mm2, and specific shear energy values were determined to be in the range of 0.275-0.531 N/mm.

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

1. Introduction

The global production of Allium sativum L. garlic ranks second among Allium species after onions. Fresh garlic is widely used in cooking, while dried products are commonly used as seasonings and in the food industry [1]. Garlic is consumed worldwide as a flavoring agent in food or as an herbal medicine [2]. Studies investigating the effects of garlic on human health have indicated anti-inflammatory, anti-diabetic, anti-oncogenic, antimicrobial, antioxidant, cardioprotective, immunomodulatory, and hepatoprotective effects, recommending the inclusion of garlic in the daily diet [3].

When examining Türkiye's garlic production over the last 10 years between 2015 and 2024, it shows an upward trend, although it varies from year to year. Production quantities have increased in parallel with the increase in cultivation areas. On average, 120371 tons of garlic were produced on an area of 127932 da, reaching a yield of 940 kg/da. [4] (Figure 1.)

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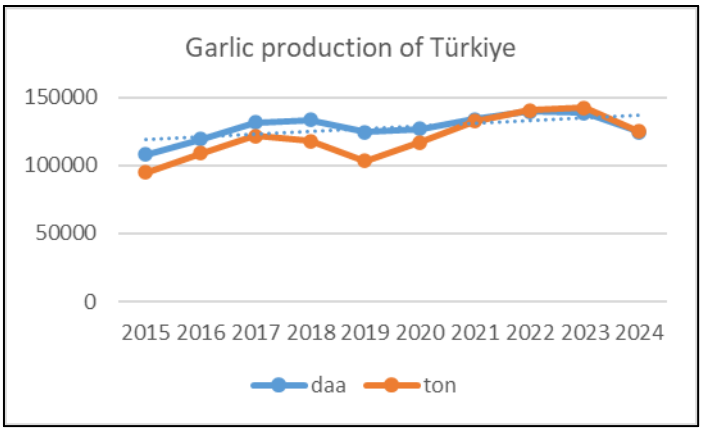

Figure 1 Garlic production in Türkiye (2015-2024)

The majority of garlic produced in Türkiye reaches consumers and is consumed on the table without undergoing any processing other than simple cleaning, either in bunches or with the stems cut off. Without cold storage, the shelf life of garlic varies depending on the variety, ranging from 4 to 10 months. Garlic tends to sprout, hollow out, and rot during storage, which shortens its shelf life and causes significant financial losses for sellers [5]. Dried garlic products are an alternative for a longer shelf life. There is also consumer demand for garlic products in the form of chips, granules, and powder. These products can be produced by slicing and thinning the garlic and then drying it. If garlic is dried to a moisture level of 10%, its shelf life is extended, new products are created, and transportation and storage costs are reduced [6]. Sacilik and Unal [7] determined the drying characteristics of sliced Kastamonu garlic in hot air in their studies. Zhou et al. [8] investigated the rehydration properties of garlic slices frozen in a vacuum and dried with hot air. Figiel [9] investigated the drying kinetics and quality of vacuum-microwave dried garlic cloves and slices.

Garlic must be produced in the form of chips, granules, and powder in order to convert it into products with a longer shelf life and to obtain products with higher added value. In order for the drying process required during these operations to be more economical and shorter, the garlic must be sliced and thinned. In order to design a machine that will reduce the labor required for slicing, it is necessary to determine the cutting resistance and shear energy. Numerous researchers have conducted various studies to determine the cutting force, shear stress, and shear energy for plant-based materials [10-19]. In recent years, there has been an increase in demand for processed products and ready-to-eat foods. The aim of this study is to determine the effect of cutting speed, cutting angle, and moisture on the cutting resistance and shear energy of garlic, thereby identifying the data required for the design of slicing machines to be developed.

2. Material and methods

This study was conducted in the Mechanical Engineering laboratories of the Faculty of Architecture and Engineering at Kastamonu University. The garlic used in the experiment was obtained from the Araban district of Gaziantep in September 2025, the stems were removed, the cloves were separated, and the garlic was peeled. The peeled garlic cloves were kept in the same closed container in a refrigerator at +4 degrees Celsius for 2 days before the cutting experiment to equalize their moisture content. In the next two experiments, they were left uncovered in the shade for 5 days to reduce the moisture content, then kept in the same closed container in the refrigerator for another 2 days to equalize their moisture content. To determine the moisture content of the garlic cloves during cutting, samples of the cut peeled garlic cloves were weighed with a precision balance and kept in a drying cabinet at 105 °C for 24 hours. After drying, the weights of the samples were determined, and the moisture content of the cloves was calculated as a percentage using the following equation [20]. In the study conducted at three different moisture levels, the moisture contents were determined to be 61.8%, 50.6%, and 45.2% (W.B.).

Moisture (W.B) = [(wet material-dry material)/wet material]x100

The angle between the blade edge and the horizontal plane was varied during the cutting of garlic cloves. Three different blades with cutting angles of 0°, 30°, and 45° were produced, and three different blade angles were used. The cutting process was performed at two different speeds: 34 mm/min and 28 mm/min.

In each experiment, ten peeled garlic cloves of randomly selected sizes were subjected to the cutting test. After cutting the garlic cloves, the cross-section obtained was stained and pressed onto tracing paper. A scaled photograph of the paper was opened in the SolidWorks program to find the cross-sectional areas [19]. The maximum cutting force, measured during cutting, was determined as the largest value. The maximum shear stress was determined by dividing this value by the cross-sectional area, and the shear energy was determined as the energy expended during the cutting process (the area under the cutting curve). The specific shear energy was also determined by dividing the shear energy by the garlic cross-sectional area.

The experiments were conducted using the apparatus developed in Figure 2. The forces were measured using a 500 N capacity load cell and an Almelo 2590 data logger and transferred to the computer via a USB connection. (Figure 2)

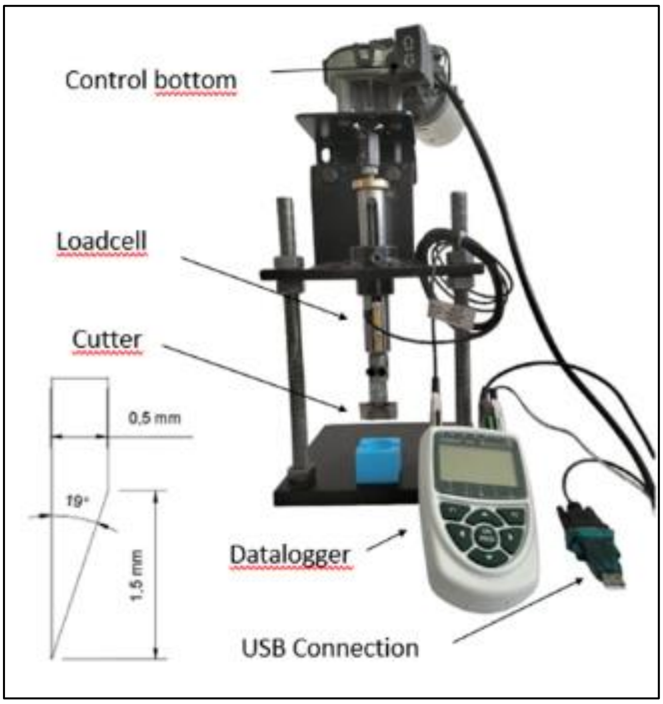

Figure 2 Experimental setup

3. Results and discussion

Three different cutting angles of 0, 30, 45 degrees (A1-A2-A3, respectively), three different moisture levels of 61.8%, 50.6%, and 45.2% (M1-M2-M3, respectively), and two different speeds of 34 mm/min and 28 mm/min (S1-S2) yielded the following results. (Table 1)

S1-M1-A1, S1-M1-A2, S1-M1-A3 had average shear energy/cross-sectional area values of 0.429-0.389-0.275 N/mm and average shear stress values of 0.042-0.039-0.032 N/mm^2, S1-M2-A1, S1-M2-A2, S1-M3-A3 have average shear energy/cross-sectional area values of 0.456-0.404-0.303 N/mm and average shear stress values of 0.046-0.044-0.035 N/ mm^2, S1-M3-A1, S1-M3-A2, S1-M3-A3 have average shear energy/cross-sectional area values of 0.487-0.456-0.342 N/mm and average shear stress values of 0.052-0.045-0.044 N/ mm^2, respectively.

For S2-M1-A1, S2-M1-A2, and S2-M1-A3, the average shear energy/cross-sectional area values were 0.444-0.411-0.361 N/mm, and the average shear stress values were 0.052-0.045-0.033 N/ mm^2, For S2-M2-A1, S2-M2-A2, and S2-M3-A3, the average shear energy/cross-sectional area values were 0.472, 0.438, and 0.369 N/mm, respectively, and the average shear stress values were 0.057, 0.051, and 0.040 N/mm^2, respectively. S2-M3-A1, S2-M3-A2, S2-M3-A3, respectively, shear energy/cross-sectional area averages of 0.532-0.475-0.388 N/mm and shear stress averages of 0.064-0.059-0.048 N/ mm^2 were determined.

Table 1 Garlic shear test results

			A1-0°	Sd	A2-30°	Sd	A3-45°	Sd
S1-34 mm/min	M1-61.8%	Section area (mm^2)	180.06	30.02	138.14	25.73	192.60	20.88
		Specific shear energy (N/mm)	0.429	0.063	0.389	0.126	0.275	0.052
		Shear stress (N/mm^2)	0.042	0.004	0.039	0.019	0.032	0.011
	M2-50.6%	Section area (mm^2)	151.91	30.06	158.80	38.24	172.40	22.26
		Specific shear energy (N/mm)	0.456	0.137	0.404	0.198	0.303	0.180
		Shear stress (N/mm^2)	0.046	0.017	0.044	0.010	0.035	0.011
	M3-45.2%	Section area (mm^2)	223.89	68.06	163.21	41.58	168.78	53.69
		Specific shear energy (N/mm)	0.487	0.108	0.456	0.234	0.342	0.259
		Shear stress (N/mm^2)	0.052	0.017	0.045	0.031	0.044	0.056
S2-28 mm/min	M1-61.8%	Section area (mm^2)	146.91	27.08	163.04	40.10	235.65	48.09
		Specific shear energy (N/mm)	0.444	0.098	0.411	0.139	0.361	0.125
		Shear stress (N/mm^2)	0.052	0.019	0.045	0.026	0.033	0.009
	M2-50.6%	Section area (mm^2)	181.84	54.21	183.02	38.58	170.42	36.41
		Specific shear energy (N/mm)	0.472	0.239	0.438	0.176	0.369	0.034
		Shear stress (N/mm^2)	0.057	0.015	0.051	0.009	0.040	0.006
	M3-45.2%	Section area (mm^2)	177.64	31.74	155.28	8.85	195.68	40.52
		Specific shear energy (N/mm)	0.531	0.053	0.475	0.180	0.388	0.179
		Shear stress (N/mm^2)	0.064	0.008	0.059	0.019	0.048	0.021

In general, it is observed that as the cutting speed increases, the shear stress and the specific shear energy per unit area decrease. These results are similar to those obtained for sisal leaves [21], goldenrod stems [22], and three different wheat varieties [23]. When the moisture content of garlic decreases, shear stress and specific shear energy increase. This result is consistent with the findings of studies conducted on alfalfa stems [12], olive shoots [16], grape shoots [17], and rice stems [18]. As the cutting blade angle increases, shear stress and specific shear energy decrease. Researchers have also found similar results in different studies [21-22], [24-25]. (Figure 3 and Figure 4)

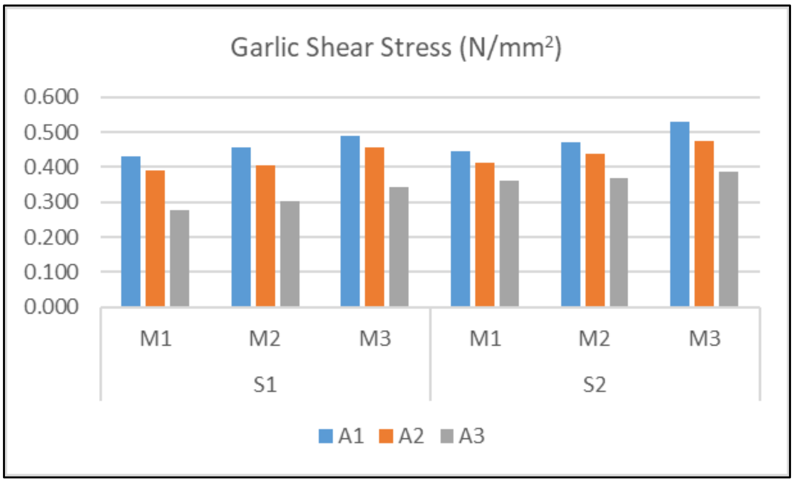

Figure 3 Changes in garlic-shear stress

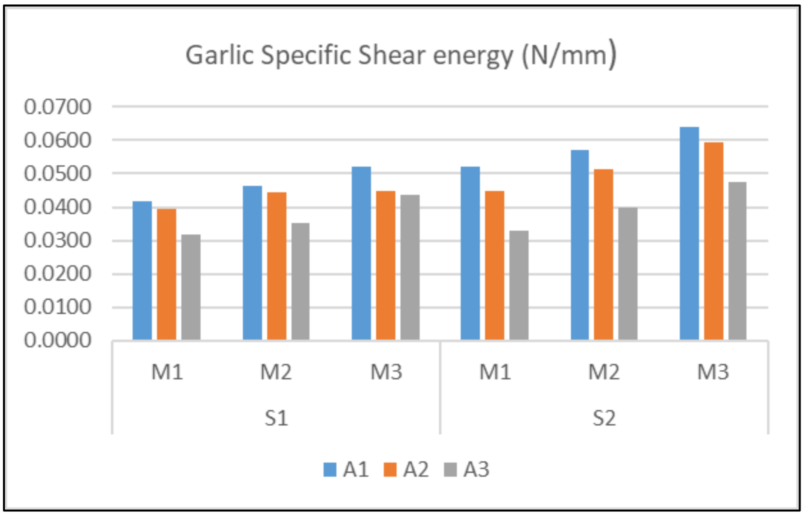

Figure 4 Changes in garlic-specific shear energy

In a study examining the cutting parameters of Kastamonu garlic [19], the specific shear energy of peeled Kastamonu garlic was found to be in the range of 0.8-1.1 N/mm, while the shear stress was found to be in the range of 0.07-0.16 N/mm². When compared to the results obtained with Araban garlic used in this study, it is possible to say that Kastamonu garlic has a harder tooth structure.

4. Conclusion

The study shows that as the moisture content, cutting speed, and cutting angle of garlic decrease, the cutting stress and specific cutting energy increase. As a result, the study conducted with Araban garlic determined that the cutting stress values ranged from 0.0318 to 0.0638 N/mm², while the specific cutting energy values ranged from 0.275 to 0.531 N/mm. This should be taken into account in slicing machine designs.

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