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Correlation between the protein content and mechanical properties of wheat

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Abstract: The mechanical properties of wheat varieties are important in the milling industry. This study investigated the correlation between the protein content of 5 wheat varieties and their mechanical properties of rupture force, energy absorbed, and hardness. Based on correlation coefficients, a strong correlation was found between the protein content of all wheat varieties investigated and their mechanical properties. The correlation levels between the protein content and rupture force, energy absorbed, and hardness were r = 0.953, 0.883, and 0.884 for X-X load orientation and r = 0.955, 0.963, and 0.954 for Y-Y load orientation, respectively.

Key words: Hardness, mechanical properties, protein content, wheat

Introduction

Wheat mainly consists of starch (60%-68%), protein (7%-18%), moisture (8%-18%), lipids (1.5%-2%), cellulose (2%-2.5%), and ash (1.5%-2%) (Matz 1991). In the first growth stage, protein accumulates and spreads within an endosperm to create a network. After protein accumulation, starch begins to accumulate within the protein network. If protein accumulation continues and starch accumulation ends quickly, the protein content of wheat will increase. The greater the amount of protein that accumulates and surrounds the starch, the harder and glassier the wheat will become (Elgün and Ertugay 2002).

The mechanical properties of grain are important in the grinding and milling processes, and for designing machines for these tasks (Kang et al. 1995; Saiedirad et al. 2008; Yücel et al. 2009). These properties are also important in order to design machines for harvesting, cleaning, separating, and processing. The effect of a wheat grain's mechanical properties on grinding energy is greater than that of its other physical properties (Dziki 2008). Rupture force, energy absorbed, and hardness are important mechanical properties of a wheat grain. Rupture force is the minimum force needed to rupture the individual grain. Energy absorbed is the energy required during the loading to rupture the individual grain (Sirisomboon et al. 2007). Hardness is the resistance of the individual grain to deformation under applied forces (Kang et al. 1995; Dobraszczyk et al. 2002; Turnball and Rahman 2002). Hardness is also defined as the ratio of the rupture force to

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the deformation at the rupture point of the grain (Sirisomboon et al. 2007).

Several studies have been conducted that consider the moisture-dependent physical and mechanical properties of wheat, such as those by Delwiche (1993), Kang et al. (1995), Dobraszczyk et al. (2002), Dursun and Güner (2003), Tabatabaeefar (2003), Karimi et al. (2009), Kalkan (2009), Kalkan and Kara (2011), and Babic et al. (2011). However, Tabatabaeefar (2003) and Karimi et al. (2009) did not investigate the mechanical properties of wheat grains. Delwiche (1993) measured the hardness of individual wheat kernels using near-infrared transmittance. Kang et al. (1995) analyzed the mechanical properties of wheat, such as yield stress, yield strain, modulus of deformability, and energy to yield point. Dobraszczyk et al. (2002) studied the fracture properties of endosperm machined from individual wheat kernels from several wheat varieties. The mechanical behavior of different wheat varieties was determined by Dursun and Güner (2003) using compression loading between 2 parallel plates. They reported rupture force decreased and rupture energy increased as wheat moisture content increased. Kalkan (2009) reported that while the rupture force values of wheat grains decreased as the moisture content increased the deformation at rupture point, energy absorbed, and grain hardness did not show any regular variation with the moisture content. Babic et al. (2011) analyzed the physical and stress-strain properties of 3 wheat varieties.

The literature also includes detailed evaluations of the influence of moisture content on the mechanical properties of other agricultural products. Several studies have been carried out dealing with the mechanical properties of products such as sunflower (Gupta and Das 2000), shea nut (Olaniyan and Oje 2002), soybean (Dursun et al. 2004), corn (Dursun et al. 2004; Seifi and Alimerdani 2010; Kalkan et al. 2011), faba bean (Altuntaş and Yıldız 2007), chestnut (Moreira et al. 2007), mung bean (Unal et al. 2008), and cumin seeds (Saiedirad et al. 2008). Gupta and Das (2000) reported that the compressive force needed to initiate rupture of both sunflower seed hulls and kernels decreased with an increase in moisture content, while the energy absorbed at rupture increased. Altuntaş and Yıldız (2007) reported that the rupture energy of the faba bean grain generally increased with an increase in moisture content, while the rupture energy increased.

The mechanical properties of several grains have recently been reported. However, published studies describing the correlation between the protein content and mechanical properties of wheat varieties do not exist. The objective of the work reported in this paper was to determine the correlation between the protein content of 5 wheat varieties and their mechanical properties of rupture force, energy absorbed, and hardness.

Material and methods

After preliminary experiments, 5 wheat varieties with considerable variation in protein content were selected as study materials, namely cv. Daphan, cv. Nenehatun, cv. Doğu-88, cv. Lancer, and cv. Kunduru-1149. The wheat samples came from different regions of Turkey. The grains were cleaned by hand to remove dirt, stones, foreign objects, and broken grains. Because the mechanical properties of wheat are affected by moisture content (Dziki 2008), the moisture content of the wheat varieties was adjusted to approximately 12.5 ± 0.2% (dry basis). Samples were placed inside separate perforated boxes, kept in a large plastic bag, and refrigerated at 15 °C for 30 days to allow moisture to distribute uniformly throughout the samples.

The moisture content of the wheat varieties was determined using the standard method of oven drying at 105 °C for 24 h (Suthar and Das 1996). The moisture content of each variety was 12.37%, 12.69%, 12.72%, 12.51%, and 12.23% (dry basis) for cv. Daphan, cv. Nenehatun, cv. Doğu-88, cv. Lancer, and cv. Kunduru-1149, respectively. The protein content was determined according to approved AACC methods (AACC 2000) and was reported on a dry basis.

The axial dimensions, namely length, width, and thickness, of 50 randomly selected grains for each variety were measured using digital calipers to an accuracy of 0.01 mm. The geometric mean diameter, sphericity, and surface area were calculated using the following equations (Mohsenin 1986):

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

$$\phi = \frac{(LWT)^{1/3}}{L} \tag{2}$$

$$S = \pi D_g^2 \tag{3}$$

where L is the length (mm), W is the width (mm), T is the thickness (mm), D_g is the geometric mean diameter (mm), φ is the sphericity (%), and S is the surface area (mm^2).

The mechanical properties of the wheat grains were determined using a quasi-static loading device (Turgut et al. 1998). A single grain was positioned on the lower plate of the device, and the lower plate was then moved upward with a fixed speed of 0.027 mm s^{-1}, compressing the grain between the 2 parallel plates until it fractured (ASAE 2005). The load cell connected to the upper plate of the device converted the force applied to the single grain during compression into electronic signals, and then transferred the signals to a computer through a data acquisition board, recording the data on the computer for offline analyses. Loading was applied to each grain in 2 main directions, namely X-X and Y-Y load orientations (Figure 1). Twenty grains were tested for each compression test (ASAE 2005). The fixed loading speed of the device and elapsed time were used to determine the deformation that occurred during loading up to the rupture point for each individual grain (Vursavuş and Özgüven 2004, Altuntaş and Yıldız 2007). The rupture force was measured directly by the loading device. The energy absorbed was calculated from the area under the load-deformation curve using the following equation (Mohsenin 1986, Vursavuş and Özgüven 2004, Altuntaş and Yıldız 2007):

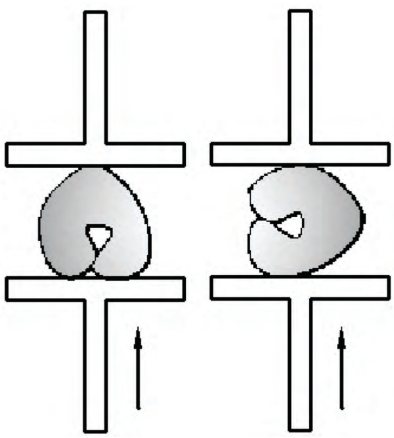

Figure 1. Loading directions of a single grain.

$$E_a = 1/2(F_r.D_r) \tag{4}$$

where E_a is the energy absorbed (mJ), F_r is the rupture force (N), and D_r is the deformation at the rupture point (mm).

Hardness was calculated using the following equation (Sirisomboon et al. 2007):

$$Q = F_r / D_r \tag{5}$$

where Q is the hardness (N mm^{-1}).

The tests were carried out at the Cereal Technology Laboratory in the Food Engineering Department and Biological Material Laboratory of the Agricultural Machinery Department of Atatürk University, Erzurum, Turkey.

Results

Protein contents and mechanical properties of wheat varieties

As seen in Table 1, the protein content of cv. Kunduru-1149 was the highest of all the wheat varieties, followed in order by cv. Lancer, cv. Doğu-88, cv. Nenehatun, and cv. Daphan. Figure 2 shows the rupture force, energy absorbed, and hardness values of the wheat varieties for both the X-X and the Y-Y load orientations. The rupture force values of cvs. Daphan, Nenehatun, Doğu-88, Lancer, and Kunduru-1149 for the X-X and Y-Y load orientations were 80.45 and 90.76 N, 96.57 and 111.01 N, 114.92 and 127.41 N, 122.18 and 134.04 N, and 131.81 and 146.76 N, respectively (Figure 2a). The absorbed energy values for cvs. Daphan, Nenehatun, Doğu-88, Lancer, and Kunduru-1149 were 19.60, 23.00, 32.51, 33.10, and 34.33 mJ, respectively, for the X-X load orientation. The corresponding values were 26.38, 33.79, 43.92, 45.09, and 53.23 mJ, respectively, for

Table 1. Some physical and chemical properties of the wheat varieties in this study.

Variety	Moisture content (% dry basis)	Protein content (% dry basis)	Length (mm)	Width (mm)	Thickness (mm)	Geometric mean diameter (mm)	Sphericity (%)	Surface area (mm^2)
Daphan	12.37 ± 0.30	10.91 ± 0.02	6.28 ± 0.38	2.94 ± 0.33	2.73 ± 0.31	3.69 ± 0.31	58.82 ± 3.42	42.85 ± 6.85
Nenehatun	12.67 ± 0.04	11.86 ± 0.29	7.02 ± 0.34	3.22 ± 0.26	2.74 ± 0.29	3.96 ± 0.22	56.33 ± 2.45	49.12 ± 5.57
Doğu-88	12.72 ± 0.37	13.13 ± 0.15	6.33 ± 0.45	3.19 ± 0.24	2.78 ± 0.27	3.83 ± 0.26	60.51 ± 1.68	46.01 ± 6.12
Lancer	12.51 ± 0.35	14.38 ± 0.20	6.71 ± 0.19	2.96 ± 0.20	2.81 ± 0.18	3.82 ± 0.17	56.90 ± 1.83	45.75 ± 3.95
Kunduru-1149	12.23 ± 0.43	16.54 ± 0.13	7.97 ± 0.39	3.24 ± 0.21	3.05 ± 0.27	4.29 ± 0.23	53.81 ± 1.52	57.81 ± 6.03

Means ± standard deviation

Table 2. Mechanical properties and protein contents of the wheat varieties in this study.

	Mechanical properties	Daphan (10.91% dry basis)	Nenehatun (11.86% dry basis)	Doğu-88 (13.13% dry basis)	Lancer (14.38% dry basis)	Kunduru-1149 (16.54% dry basis)	P	Correlation coefficients, *r*
X-X	Rupture force (N)	80.45 ± 12.75a	96.57 ± 17.64ab	114.92 ± 30.20bc	122.18 ± 11.73c	131.81 ± 24.66c	**	0.953 *
	Energy absorbed (mJ)	19.60 ± 5.16a	23.00 ± 8.32ab	32.51 ± 15.01bc	33.10 ± 10.71bc	34.33 ± 11.39c	**	0.883 *
	Hardness (N mm^{-1})	159.87 ± 32.70a	188.55 ± 27.39b	190.58 ± 30.28b	206.87 ± 26.96 b	209.10 ± 24.84c	**	0.884 *
Y-Y	Rupture force (N)	90.76 ± 20.83a	111.01 ± 21.76ab	127.41 ± 22.97bc	134.04 ± 26.79 bc	146.76 ± 34.53c	**	0.955 *
	Energy absorbed (mJ)	26.38 ± 8.84a	33.79 ± 12.63ab	43.92 ± 14.42bc	45.09 ± 16.67bc	53.23 ± 22.59c	**	0.963 **
	Hardness (N mm^{-1})	169.72 ± 29.39a	210.48 ± 32.61b	212.00 ± 28.88b	231.63 ± 29.32b	259.41 ± 33.30b	**	0.954 *

Means ± standard deviation. Values in the same row with different lowercase letters (a,b,c) are significantly different at $P < 0.01$.
** = significant at 1%; * = significant at 5%.

the Y-Y load orientation (Figure 2b). The hardness values for cvs. Daphan, Nenehatun, Doğu-88, Lancer, and Kunduru-1149 were 159.87, 188.55, 190.58, 206.87, and 209.10 N mm^{-1}, respectively, for the X-X load orientation, while the hardness values of the grains were 169.72, 210.48, 212.00, 231.63, and 259.41 N mm^{-1}, respectively, for the Y-Y load orientation (Figure 2c). For both the X-X and Y-Y load orientations, there was an important observed difference in the values of rupture force, energy absorbed, and hardness among varieties ($P < 0.01$).

Correlation between protein content and mechanical properties of wheat varieties

Correlation analysis results are shown in Table 2 as Pearson correlation coefficients (r). Figure 3 provides a graphical representation of the correlation between protein content and the mechanical properties of the wheat varieties. The rupture force, energy absorbed, and hardness values correlated to protein content at r = 0.953, r = 0.955, and r = 0.883, respectively, for the X-X load orientation and at r = 0.963, r = 0.884, and r = 0.954 for the Y-Y load orientation.

Discussion

While the wheat variety giving the least resistance to rupturing was cv. Daphan, the highest rupture force was necessary for cv. Kunduru-1149 for both the X-X and Y-Y load orientations. The small rupture forces measured for lower protein content might have resulted from the fact that the grains with lower

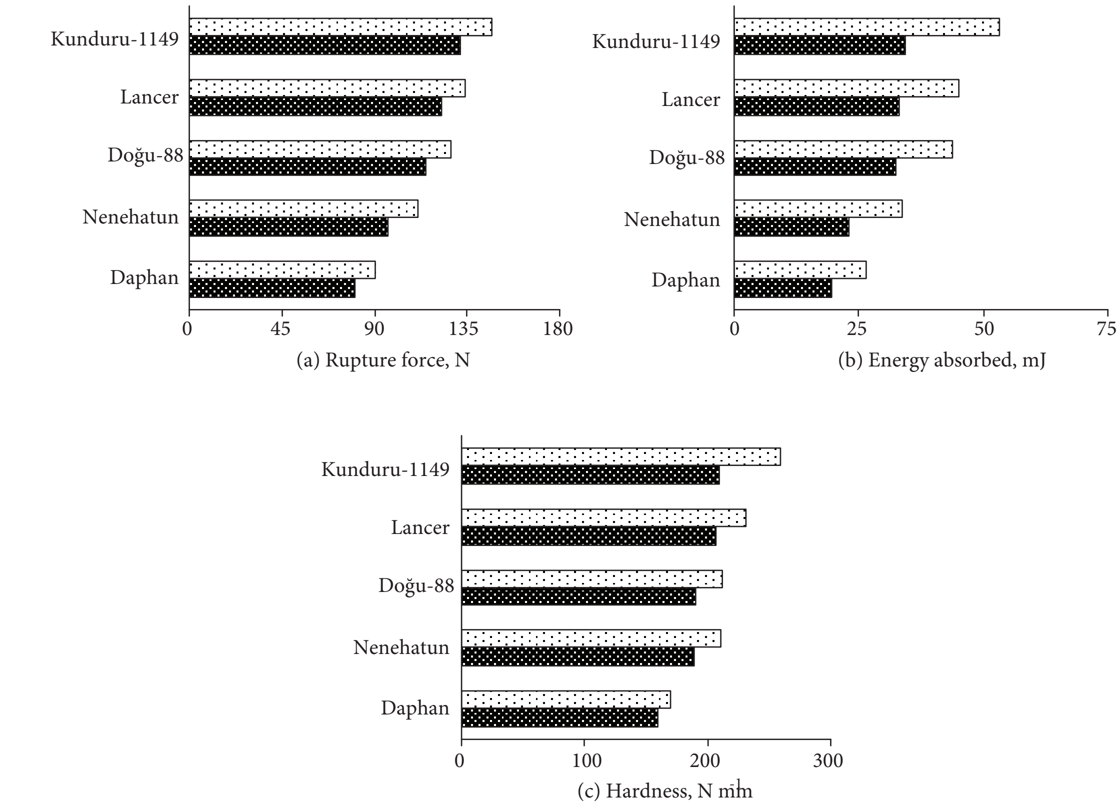

Figure 2. Mean values of a) rupture force, b) energy absorbed, and c) hardness according to the protein content of the wheat (X-X load orientation, Y-Y load orientation).

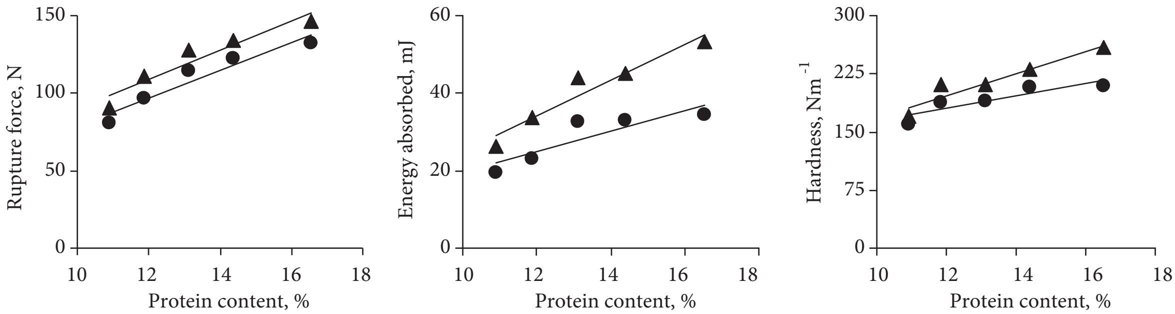

Figure 3. Correlation between the protein content and the mechanical properties of the wheat varieties (● X-X load orientation, ▲ Y-Y load orientation).

protein content tended to be softer. In addition, wheat grains loaded in the X-X load orientation required less rupture force than grains loaded in the Y-Y load orientation.

Wheat (Dursun and Güner 2003; Kalkan and Kara 2011) and many other agriculture products such as barley (Dursun and Güner 2003), sunflower (Gupta and Das 2000), faba bean (Altuntaş and Yıldız 2007), soybean (Dursun et al. 2004), corn (Dursun et al. 2004; Kalkan et al. 2011), and cumin seeds (Saiedirad et al. 2008) have a negative correlation between moisture content and rupture force. However, Kalkan and Kara (2011) indicated that the rupture forces of 2 durum wheat varieties, Kunduru and Çeşit-1252, were generally higher than the rupture force of bread wheat varieties (Bayraktar and Kırik) with the same moisture content. Similar results were also obtained in other studies (Dursun and Güner 2003; Ponce-Garcia et al. 2008). This can be explained by a high correlation between rupture force and protein content.

Following the trend noted with rupture force, both the highest and the lowest values of energy absorbed were obtained in cv. Kunduru-1149 and cv. Daphan for the X-X and Y-Y load orientations, respectively, and wheat grains required less energy before rupture when compressed at the X-X load orientation than at the Y-Y load orientation. In contrast to their correlation to rupture force, wheat and other agricultural products have positive correlation with energy absorbed. According to Kalkan (2009), energy absorbed showed a negative correlation with some wheat varieties (Kızıltan-91, Çeşit-1252, and Kırik) while it was unrelated for some wheat varieties (Pehlivan and Bayraktar-2000). However, the energy absorbed by the wheat grain during loading up to rupture was lower at lower protein content levels due to the grain's soft texture at those levels.

The hardness value was the highest for both the X-X and Y-Y load orientations for cv. Kunduru-1149, followed in order by cv. Lancer, cv. Doğu-88, cv. Nenehatun, and cv. Daphan. Moreover, hardness values obtained at the X-X load orientation were lower than those of the Y-Y load orientation. It was also seen that the highest hardness value was obtained in cv. Kunduru-1149, which had the highest protein content. A strong correlation was found between protein content and the mechanical properties of wheat varieties at nearly identical moisture content levels. It is generally known that there is a positive correlation between hardness and the protein content of wheat (Preston 1998, Dobraszczyk et al. 2002, Pasha et al. 2010), although the correlation of rupture force and energy absorbed with protein content is not clearly known. In this study, a strong correlation was obtained. In reality, wheat texture is primarily influenced by a hardness gene, but is also influenced by secondary factors such as protein (Morris 2002). Protein content is an important factor affecting the hardness. Wheat having a high protein content is generally hard because of the strong interaction between carbohydrates and proteins (Preston 1998, Dobraszczyk et al. 2002, Pasha et al. 2010). However, according to Kalkan (2009), it can also be said that moisture content is a more important parameter than protein content in regard to wheat hardness.

In conclusion, the rupture force, energy absorbed, and hardness values of wheat varieties Daphan, Nenehatun, Doğu-88, Lancer and Kunduru-1149 at the X-X load orientation were lower than those at the Y-Y load orientation for the entire range of protein content. A strong correlation was found between protein content and rupture force, energy absorbed, and hardness for all varieties at both load orientations. In other words, the higher the protein content, the harder the grain. This correlation may be important for millers and end-users of wheat for milling and post-milling processes.

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