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EFFECT OF MOISTURE CONTENT ON WHEAT HARDNESS: AN SKCS-BASED STUDY

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ABSTRACT
This study aimed to analyze wheat hardness at varying moisture (10%–18%) using SKCS equipment and to establish regressions for relationship between moisture content and hardness index (HI). For this purpose, three bread wheat cultivars, Kınacı, Altay, and Selimiye, each with different hardness, were used. Differences between cultivars in terms of various physical and chemical properties were significant ($P < 0.05$). HI for Kınacı, Altay, and Selimiye decreased significantly from 18.7%, 31.5%, and 66.4% at 10% moisture to 10.9%, 16.5%, and 41.3% at 18% moisture, respectively ($P < 0.05$). In the regression equations, moisture content was used as the independent variable and HI as the dependent variable. Determination coefficients (R^2) of equations were 0.9669 for soft wheat Kınacı, 0.9906 for medium wheat Altay and 0.9278 for hard wheat Selimiye. Consequently, regression equations are feasible and can be used to determine HI based on moisture for different hardness groups in wheat.
Keywords: Wheat, hardness, SKCS, quality, tempering, regression

BUĞDAY SERTLİĞİ ÜZERİNE RUTUBET İÇERİĞİNİN ETKİSİ: SKCS TABANLI BİR ÇALIŞMA

ÖZ
Bu çalışma, SKCS cihazı kullanarak farklı nem içeriklerinde (%10–18) buğday sertliğini analiz etmeyi ve nem içeriği ile sertlik indeksi (HI) arasındaki ilişki için regresyon denklemleri belirlemeyi amaçlamıştır. Bu doğrultuda, farklı sertlik değerlerine sahip üç ekmeklik buğday çeşidi, Kınacı, Altay ve Selimiye kullanılmıştır. Çeşitler arasındaki bazı fiziksel ve kimyasal özellikler açısından farklar önemli bulunmuştur ($P < 0.05$). Kınacı, Altay ve Selimiye'nin HI değerleri, sırasıyla %10 nemde %18.7, %31.5 ve %66.4 iken, %18 nemde sırasıyla %10.9, %16.5 ve %41.3'e önemli derecede azalmıştır ($P < 0.05$). Regresyon denklemlerinde nem içeriği bağımsız değişken olarak, HI ise bağımlı değişken olarak kullanılmıştır. Eşitliklerin determinasyon katsayıları (R^2) sırasıyla yumuşak buğday Kınacı için 0.9669, orta sertlikteki buğday Altay için 0.9906 ve sert buğday Selimiye için 0.9278 olmuştur. Sonuç olarak, regresyon denklemleri uygulanabilir olup, buğdaydaki farklı sertlik gruplarına göre nem içeriğine dayalı olarak HI'yi belirlemek için kullanılabilir.
Anahtar kelimeler: Buğday, sertlik, SKCS, kalite, tavlama, regresyon

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INTRODUCTION

Wheat, along with rice, corn, barley, and oats, are grains cultivated worldwide for human consumption (Liu, 2007; Gani et al., 2012). These cereals, which are also rich in components called plant bioactive substances or phytochemicals with positive effects on health, are the main components of human nutrition and the main foods that meet the needs of people's carbohydrates, proteins, vitamins and minerals (Slavin, 2003; Madhujith et al., 2006; Goldberg, 2008). Wheat comes to the forefront among all cereals in terms of processing features and is used as the raw material of many products (Hrušková and Švec, 2009; Pasha et al., 2010).

Quality is a complex concept in wheat and is a phenomenon that can be defined as compliance with a specific purpose or use, which differs according to the soil structure and climatic conditions of the grown area and climatic conditions. (Finney et al., 1987; Pasha et al., 2010). In general, for flour, bread, and pasta industries, high protein content and good gluten quality are important, while for consumers, sensory and textural properties define quality wheat that produces a healthy final product (Çetiner et al., 2021).

Grain hardness or endosperm structure has a significant effect on technological properties such as milling and shelf life of wheat and is one of the key parameters that determine its quality (Nirmal et al., 2016). It is a feature that affects physical properties such as endosperm hardness, starch damage, particle size and distribution of flour and semolina and grinding efficiency (Brites et al., 2008). Therefore, grain hardness is one of the important distinctive factors in the evaluation of wheat for commercial purposes and plays an important role in the suitability of grinding in a commercial mill. Hardness and softness are related to the disintegration of the endosperm. In hard wheat, grain disintegration tends to occur along the cell boundaries. According to one view, grain hardness is related to the degree of adhesion between starch and protein, while another view suggests that hardness depends on the continuity of the protein matrix (Hrušková and Švec, 2009).

In wheat, grain hardness is largely controlled by genetic factors and is believed to be influenced by the presence of friabilin in the endosperm during the intermediate phase, as well as by water-soluble proteins. On the other hand, it may be affected by environmental factors and other factors such as fat, humidity and pentosane content. Friabilin, a sign protein that shows grain hardness, consists of two proteins: Puroindolin A (Pina) and Puroindolin B (Pinb) (Martin et al., 2006). Lipid binding proteins are defined as responsible for determining the differences between Pina and Pinb, hard and soft uniform properties (Szabó et al., 2016). Friabilin is present in large amounts in soft wheat, in small amounts in hard wheat, and at an almost negligible level in durum wheat (Szabó et al., 2016). The presence of friabilin in the wheat kernel weakens the bond between protein and starch, making the endosperm texture softer (Köksel et al., 2000).

Grain hardness is an important factor in determining the functional properties of wheat. Wheat is classified as soft, medium soft, hard, medium hard and extra hard according to grain hardness (Kent and Evers, 1994; Hansen and Poll, 1997; Pasha et al., 2010). In general, hard wheats are expected to be good in terms of bread quality depending on high gluten quality and protein amount. Baljeet et al., (2017) reported that hard wheat cultivars have higher dough stability and lower dough softening values. Hard bread wheat cultivars are the main source of flour used in bread production. Hard wheats generally use it in the production of breads and similar products with high quality requirements. Soft wheat varieties are a good raw material for the production of flour to be used in cookies and cakes (Delcour and Hoseney, 2010). Along with evaluating the quality of wheat, the hardness of the grain plays a crucial role in the grinding process and needs to be measured prior to milling. This feature affects the use of power during milling. Hard wheat cultivars consume more power than soft wheat types during grinding (Dziki and Laskowski, 2005). In the tempering process performed before the grinding, water is added to wheat samples according to the specified grain hardness. In the tempering, hard wheat should be given more water and more waiting time should be applied than soft wheats.

Grain hardness determination involves several methods, such as the Particle Size Index (PSI), Pearling Index (PI), and Single-Kernel Characterization System (SKCS), which are based on different principles. In the PSI method, the hardness value, wheat breaking is based on the percentage calculation of the amount that passes under the sieve as a result of shaking for a certain period of time in a fixed sieve. In the PI method, it is determined by determining the abrasion amount on the surface of the peeled grains in a special peeling (Çetiner et al., 2021). In the SKCS method, the hardness value is based on the determination of the resistance of the grains to crushing (Szabó et al., 2016). In addition to the grain hardness, the weight, size and moisture content of the grains are determined in the SKCS method (Sissons et al., 2000; Osborne and Andersen, 2003).

The objective of the present study was to determine the behavior of grain hardness values, determined using the SKCS equipment, for wheat samples with different hardness properties at varying moisture contents, and to establish the regression equations between the SKCS hardness index values and moisture content.

MATERIALS AND METHODS

Material

In the study, three bread wheat (*Triticum aestivum*) cultivars with different grain hardness, Kınacı-97, Altay-2000, and Selimiye were used. Cultivar (cv) Kınacı is a soft wheat with red kernel color, cv Altay-2000 is a medium hard wheat with white kernel color beside these cv Selimiye is a hard wheat with a red kernel color. The names of cultivars Kınacı-97, Altay-2000 were shortened as Kınacı and Altay respectively, in the text for convenience.

Methods

Firstly, wheat samples were first cleaned to eliminate broken and severely damaged kernels using laboratory-grade wheat cleaning equipment (Labofix 90, Brabender, Beilngries, Germany). The kernels remaining on 2.0 mm sieve were used in the study. For the purpose of eliminating the differences between wheat samples in terms of in the moisture content, samples were kept in the air circulation cabin (Protech, Ankara, Türkiye) at 45°C for 24 hours. Wheat samples were ground by using the sieve laboratory type mill (Retsch ZM 200, Germany) with a 500 µm eye opening for moisture, ash and protein analyses. Wheat samples were tempered to 10%, 12%, 14%, 16%, and 18% moisture content by adding water, according to the determined moisture content, to determine the SKCS hardness index at those moisture contents. Unless otherwise noted, all of the compounds employed in the investigation were analytical grade.

Physical and Chemical Characteristics

Thousand kernel weight of wheat samples were determined according to ISO 520 (2010) method using Tripette & Renaud Numigral II (Villeneuve, France) while the hectoliter weight of them were determined according to the ISO 7971-3 (2019) method using the nilemalitre device (Bastak, Ankara, Türkiye). The kernel size distribution of wheat samples was determined by weighing the samples in each range after the shaking of 100 g sample in the sieve device (Pfeuffer Sortimat, Kitzingen, Germany) for 180 second. The color values (L*, a* and b*) of wheat samples were measured by using a colorimeter (BYK Gardner Color-View, USA). The weight, length, moisture and hardness values of the samples were determined by a single characterization system (SKCS 4100, Springfield Illinois, USA) according to approved method 55-31.01 (AACC International, 2010). Pearling index (PI) of wheat samples was described as in Acar et al. (2019). Moisture, ash and protein contents of the samples were determined according to approved methods 44-15.02, 08-01.01 and 46-30.01, respectively (AACC International, 2010).

Statistical analysis

The results were expressed as the average of measurements of at least twice. In order to determine the significant differences between the results, variance analysis (ANOVA) was performed using JMP software (version 13.0.0, SAS Institute Inc., 2013). When significant differences ($P < 0.05$) were found, the least significant difference (LSD) method was used to determine the differences between the averages. Linear regression analysis was performed using the MS Excel (Microsoft Office Professional Plus 2016) was used for deriving the regression equations and coefficient of determination (R^2) values.

RESULTS AND DISCUSSION

Various physical properties of the wheat cultivars are presented in Table 1. The differences between the samples were significant in terms of thousand kernel weight (TKW), hectoliter weight (HLW), hardness index (HI), pearling index (PI), and sieve classes (2.8>, 2.8-2.5 and 2.5-2.0 mm). The cv Selimiye had higher HLW, HI, and lower PI than other cultivars ($P < 0.05$). The TKW of Kınacı and Selimiye were same and also significantly higher than that of cv Altay ($P < 0.05$). Furthermore, the highest ratio of kernels bigger than 2.8 mm was obtained from cv Kınacı (76.1%) while the lowest was obtained from the cv Altay (42.5%) according to the results of sieve analysis ($P < 0.05$). Besides these, cv. Altay had the highest ratio (50.3%) for the 2.8-2.5 mm kernel length, while cv. Selimiye had the highest ratio (7.9%) for the 2.5-2.2 mm kernel length, significantly ($P < 0.05$). In the present study, the hardness values of wheat cultivars were determined by SKCS whereas the PI values of those were determined by using grain pearling equipment as indicated. In wheat samples, the high HI value and the low PI value indicate that wheat is hard, while the low HI value and the high PI value indicate that wheat is soft (Acar et al., 2019). Therefore, cv Selimiye was the hardest wheat, with a significantly high HI and low PI, while cv. Kınacı was the softest wheat, with a significantly low HI and high PI ($P < 0.05$). The original HI distributions of wheat cultivars, before being placed in the air circulation cabin at 45°C for 24 hours to eliminate moisture content differences between the wheat samples, are also presented in Figure 1.

Table 1: Various physical properties of wheat samples

Cultivars	TKW (g, db)	HLW (kg/hl)	HI (%)	PI (%)	Sieve Analysis (%)		
					2.8> mm	2.8-2.5 mm	2.5-2.0 mm
Kınacı	37.6±0.2 a	78.8±0.1 c	20.6±0.1 c	36.1±0.1 a	76.1±1.1 a	23.2±0.7 b	0.7±0.1 c
Altay	36.7±0.2 b	79.1±0.1 b	36.9±0.0 b	27.6±0.1 b	42.5±0.6 c	50.3±7.1 a	7.1±0.1 b
Selimiye	37.6±0.2 a	81.4±0.0 a	73.7±0.3 a	20.9±0.0 c	69.9±0.1 b	22.2±7.9 b	7.9±0.1 a

TKW: Thousand kernel weight; HLW: Hectoliter weight; HI: Hardness index; PI: Pearling index, db: Dry basis; Means followed by different letters in columns are significantly different at $P < 0.05$.

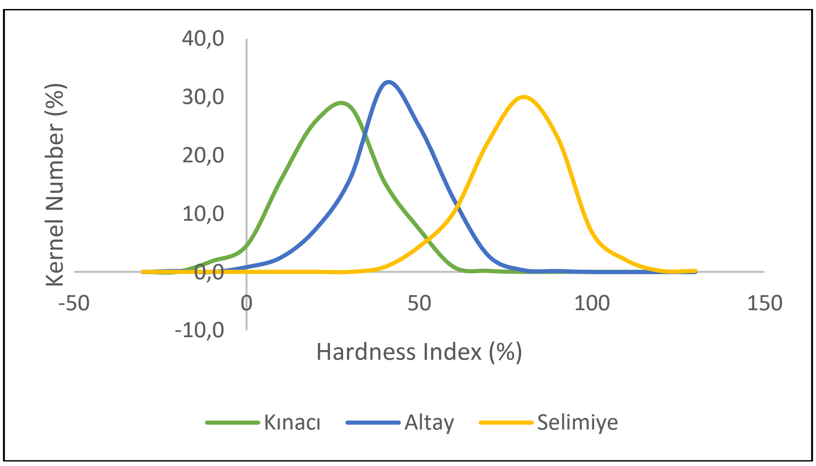


Figure 1. Hardness index distributions (%) of wheat cultivars

Several chemical properties and kernel color values of wheat cultivars are given in Table 2. The differences between the samples were significant in terms of moisture, protein and ash content, L* and b* (except a*) values. The moisture content of the cv Selimiye was the significantly highest while that of Kınacı was the significantly lowest ($P < 0.05$). The protein content of cv Kınacı was higher as compared to other cultivars while the ash content of cv Selimiye was higher and cv Altay was lower ($P < 0.05$). On the other hand, the L* and b* color values of cv. Altay was also the highest ($P < 0.05$). This means that the kernels of cv Altay were yellower and brighter than the other cultivars.

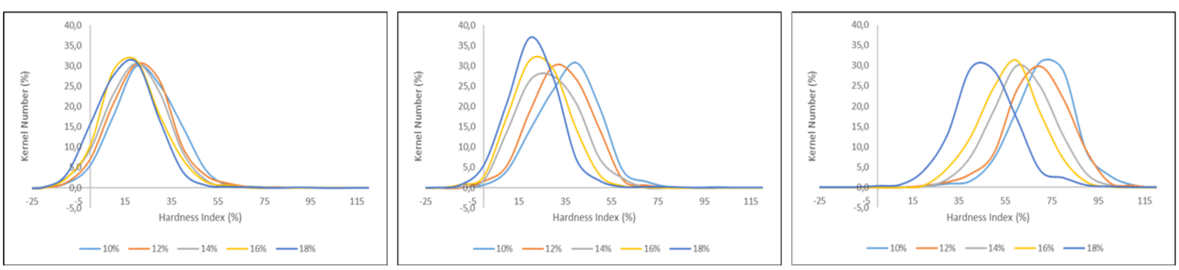
Table 2: Various chemical properties and color values of wheat samples

Cultivars	Moisture (%)	Protein (%, db)	Ash (%, db)	Color Values		
				L*	a*	b*
Kınacı	11.2±0.0 c	12.8±0.1 a	1.73±0.00 b	53.6±0.3 b	10.8±0.3 a	27.7±0.7 b
Altay	12.0±0.0 b	10.6±0.0 b	1.22±0.00 c	58.6±0.9 a	10.2±0.1 a	31.9±0.4 a
Selimiye	12.2±0.1 a	11.0±0.2 b	1.78±0.00 a	44.2±0.2 c	10.9±0.1 a	23.8±0.1 c

db: Dry basis; Means followed by different letters in columns are significantly different at $P < 0.05$.

The HI values of wheat cultivars according to the different theorical moisture content are given in Table 3. The cv Selimiye was the hardest wheat cultivar while the cv Kınacı was the softest and the Altay was the medium ones. According to the increasing moisture content the HI values were significantly decreased. The HI of cvs Kınacı, Altay and Selimiye were decreased from 18.7, 31.5 and 66.4 at 10% moisture content to 10.9, 16.5 and 41.3 at 18% moisture content, respectively. Therefore, the samples with 18% moisture content were softest, while those with 10% moisture content were the hardest for all wheat samples.

The Single-Kernel Characterization System (SKCS) assesses the crushing resistance of individual kernels. For this purpose, it analyzes 300 individual kernels by crushing them to determine the HI (Gaines et al., 1996; Osborne and Anderssen, 2003). The HI distributions (%) of these individual kernels of wheat samples at different moisture contents are also shown in Figure 2. The changes in grain hardness in different moisture content of the cv Selimiye were clearly realized as compared to the other cultivars. The reason for this was that the maximum decrease in grain hardness value with increasing moisture content occurred in cv Selimiye. The decrease in grain hardness values with the increase of moisture content from theoretically 10% to 18%, were determined as 7.8, 15.0 and 25.1 respectively for the cvs Kınacı, Altay and Selimiye (Table 3).



Kınacı Altay Selimiye

Figure 2. The changing HI distributions (%) of wheat cultivars according to the increasing moisture contents

Table 3: HI values of wheat samples in different moisture content

Moisture Content	HI (%)		
	Kınacı	Altay	Selimiye
10%	18.7±0.7 a	31.5±0.5 a	66.4±0.2 a
12%	17.2±0.5 a	28.0±0.7 b	63.9±0.6 a
14%	14.7±0.1 b	23.2±0.2 c	57.5±0.1 b
16%	13.2±0.3 b	19.5±0.2 d	52.1±0.6 c
18%	10.9±0.3 c	16.5±0.5 e	41.3±1.6 d

HI: Hardness index. Means followed by different letters in columns are significantly different at $P < 0.05$.

The regression analysis could help to understand the relationships among moisture as well as the kernel hardness of wheat samples. In the study, moisture content approved method 44-15.02 (AACC International, 2010) was the independent variable and hardness index (HI) was the dependent variable. The effect of wheat grain moisture content on HI for each wheat cultivar and the regression equations are given in Figure 3. Significant negative linear relationships were observed between HI and the moisture content of the samples, with coefficients of determination (R^2) of 0.9669, 0.9906, and 0.9278 for cvs Kınacı, Altay and Selimiye, respectively (Figure 3 and Table 4). Moreover, the correlation coefficients of regression equations were -1.1841, 2.4333 and -3,6981 while the standard errors of the slope of the regressions were 0.59, 0.57 and 2.71 for the same cultivars, respectively (Table 4). Windham et al. (1991), studied on the effect of wheat moisture content on hardness score and determined the coefficients of determination as 0.99, 0.98, 0.97 and 0.96 for the four wheat hardness classes. In another study (Qiao at al., 2022), the coefficient of determination overall regression model of hardness and moisture content for maize cultivars was determined as 0.9336. When the results of the present study are compared with relevant studies, similar results were obtained with Windham et al. (1991), but the results were higher than those of Qiao et al. (2022). This difference is considered to be due to the different product group studied. In the present study, cv Selimiye was the hardest sample, cv Kınacı was the softest, and cv Altay was the medium one (Table 1). Within each wheat cultivar, as moisture increased, HI decreased. However, with increasing moisture values, the highest decrease in HI was observed in cv Selimiye, while the least decrease of that was observed in cv Kınacı. This situation can also be understood from the differences in the slopes of the lines on the graph (Figure 3). According to the results, the HI values of wheat samples in different hardness classes can be determined according to their moisture content.

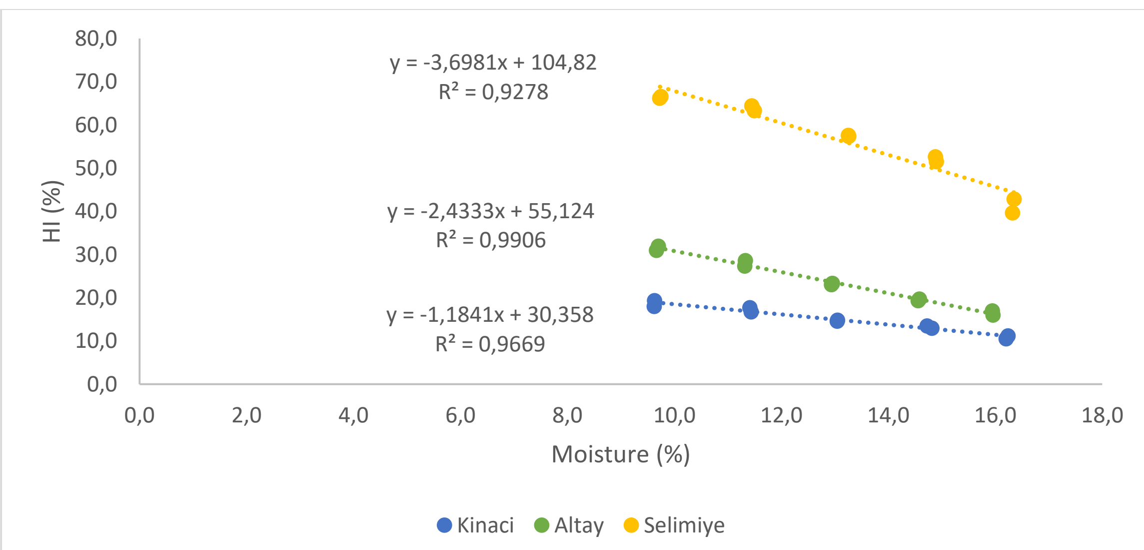


Figure 3. The regression equations of wheat cultivars between the hardness index (HI) and moisture content

Table 4: The coefficients of regression equations described the changes of HI in relation to moisture content for each sample

Cultivars	y = ax + b				
	a	b	R^2	r	Standard Error
Kınacı	-1.1841	30.358	0.9669	0.9833	0.59
Altay	2.4333	55.124	0.9906	0.9952	0.57
Selimiye	-3.6981	104.82	0.9278	0.9632	2.71

HI: Hardness index. a and b: Coefficients of regression. R^2: Coefficient of determination. r: Coefficient of correlation

CONCLUSION

One of the most important cereals cultivated all over the world for human nutrition is wheat. It stands out among all cereals due to its easy processability, which allows it to be used as a raw material in a variety of products. Furthermore, essential nutrients such as carbohydrates, proteins, vitamins and minerals can be obtained through the consumption of wheat and wheat-based products. Grain hardness, a crucial criterion for determining wheat quality, is a key factor in assessing its suitability for commercial use and milling. However, when the moisture content of wheat changes due to various reasons, a change in grain hardness is also observed. The Single-Kernel Characterization System for Wheat Kernel Texture is a method used to determine grain hardness, where the kernel texture (degree of hardness or softness) is assessed through instrumental measurement of the average force required to crush 300 individual kernels, and is reported as the hardness index (HI).

In the present study, the HI values of wheat cultivars in three different hardness classes were determined at varying moisture levels, and the regression equations between these two parameters were established. The findings demonstrated that there were significant variations in the hardness index (HI) values across the three wheat cultivars. Moreover, all cultivars showed a significant decrease in grain hardness with increasing moisture content and showed a significant negative correlation between HI and moisture content, according to the linear regression analysis.

Consequently, wheat hardness is highly influenced by moisture content, and these results help enhance the quality of wheat-based products and optimize milling procedures. The findings highlight the necessity of modifying processing variables, like water addition and tempering duration, according to grain hardness in order to improve product quality and energy efficiency. All results considered, better industrial utilization of wheat depends on an understanding of the link between moisture content and wheat hardness. The findings of this study may provide insightful information to help guide future studies in this area.

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CONFLICT OF INTEREST

The author declares that there is no any conflict of interest.

ETHICS REQUIREMENTS

This article does not contain any studies with human or animal subjects.

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