Iğdır Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 14(3), 1031-1049, 2024
Journal of the Institute of Science and Technology, 14(3), 1031-1049, 2024

ISSN: 2146-0574, eISSN: 2536-4618

Biyosistem Mühendisliği / *Biosystem Engineering* **DOI: 10.21597/jist.1489821**

Araştırma Makalesi / *Research Article*

Geliş tarihi / Received: 25.05.2024 **Kabul tarihi / Accepted: 29.07.2024**

Atıf İçin: Altıkat, A. ve Alma, M.H. (2024). Farklı Buğday Çeşitlerinde Fiziko-mekanik, Renk ve FT-IR Özelliklerinin Kapsamlı Analizi. *Iğdır Üniversitesi Fen Bilimleri Enstitüsü Dergisi*, 14(3), 1031-1049.

To Cite: Altıkat, A. & Alma, M.H. (2024). Comprehensive Analysis of Physico-mechanical, Color, and FT-IR Properties in Diverse Wheat Varieties. *Journal of the Institute of Science and Technology*, 14(3), 1031-1049.

Farklı Buğday Çeşitlerinde Fiziko-mekanik, Renk ve FT-IR Özelliklerinin Kapsamlı Analizi

Alperay ALTIKAT[1*], Mehmet Hakkı ALMA[2]

Öne Çıkanlar:

- Müfitbey, Altay, Soyer ve Reis yüksek nem/fenolik içerik
- Bezostaja, Yunus, Dumlupınar ve Çetinel yüksek protein
- ES-26 ve Karaman 2000 yüksek lipid içeriğine sahiptir.

Anahtar Kelimeler:

- Buğday çeşitleri
- Fiziko-mekanik özellikler
- Renk analizi
- FT-IR
- Tohum boyutları

ÖZET:

Bu araştırmada, yoğun olarak üretilen 13 farklı buğday çeşidinin fiziksel ve mekanik özellikleri, renk değişimleri ve FT-IR analizleri incelenmiştir. Bu amaçla; Altay, Harmankaya, Çetinel, Yunus, Müfitbey, Soyer 02, Dumlupınar, Bezostaja, Sönmez, ES-26, Reis, Karaman 2000 ve Nacibey çeşitleri kullanılmıştır. Araştırma sonucunda, tohum genişliği ve kalınlığı en büyük olan çeşit Soyer-02 (3.42 mm ve 2.96 mm), en küçük olan ise Müfitbey (2.72 mm ve 2.36 mm) olarak belirlenmiştir. Tohum uzunluğu bakımından Dumlupınar en uzun (7.82 mm), Müfitbey ise en kısa (6.07 mm) olarak gözlemlenmiştir. Yüzey alanı en büyük Dumlupınar'da (53.35 mm²) ve en küçük Müfitbey'de (36.03 mm²) bulunmuştur. Aritmetik ve geometrik ortalama çaplar açısından en büyük değerler Dumlupınar'da (4.61 mm ve 4.12 mm), en küçük değerler ise Müfitbey'de (3.72 mm ve 3.54 mm) ölçülmüştür. Küresellik, Reis'te %61.22 ile en yüksek seviyede, Dumlupınar'da %52.67 ile en düşük seviyede bulunmuştur. Bin-tane ağırlığı açısından en ağır çeşit Reis (46.36 g), en hafif çeşit ise Altay (33.58 g) olarak kaydedilmiştir. Kırılma direnci bakımından en yüksek değerler Dumlupınar ve Bezostaja'da (10.89 N ile 11.3 N), en düşük değer ise Altay'da (5.89 N) bulunmuştur. Renk analizinde, L değerleri en yüksek Çetinel'de (63.77), en düşük ise Harmankaya'da (51.16) olarak belirlenmiştir. Tüm çeşitlerde pozitif 'a' değerleri kırmızı tonlarını, 'b' değerleri ise sarı tonlarını göstermiştir; en yüksek 'b' değeri Soyer-02'de (32.81) ve en düşük Harmankaya'da (24.68) bulunmuştur. FT-IR analizinde, Müfitbey, Altay, Soyer ve Reis'te geniş O-H gerilme titreşimlerinin (3270-3300 1/cm) yüksek nem veya fenolik içeriği gösterdiği düşünülmüştür. Bezostaja, Yunus, Dumlupınar ve Çetinel'de Amide I (1640-1650 1/cm) ve Amide II (1540-1545 1/cm) bantları yüksek protein içeriğine işaret etmiştir. ES-26 ve Karaman 2000'de alifatik C-H gerilme titreşimleri (2920-2925 1/cm ve 2850-2854 1/cm) yüksek lipid içeriğini gösterirken, Sönmez ve Harmankaya'da karbonhidrat spesifik C-O ve C-C gerilme titreşimleri (1000-1240 1/cm) yüksek nişasta içeriğini düşündürmüştür.

Comprehensive Analysis of Physico-mechanical, Color, and FT-IR Properties in Diverse Wheat Varieties

Highlights:

- Müfitbey, Altay, Soyer and Reis have high-moisture/phenolic content
- Bezostaja, Yunus, Dumlupınar and Çetinel have high protein
- ES-26 and Karaman 2000 have high lipid content

Keywords:

- Wheat varieties
- Physico-mechanical properties
- Color analysis
- FT-IR
- Seed dimensions

ABSTRACT:

In this research, physical and mechanical properties, as well as color changes and FT-IR analyzes of 13 different wheat varieties, which are intensively produced, were examined. For this purpose, Altay, Harmankaya, Çetinel, Yunus, Mufitbey, Soyer 02, Dumlupınar, Bezostaja, Sönmez, ES-26, Reis, Karaman2000, and Nacibey varieties were used. As a result of the research the Soyer-02 variety exhibited the largest seed width (3.42 mm) and thickness (2.96 mm), while the Müfitbey variety had the smallest width (2.72 mm) and thickness (2.36 mm). Dumlupınar showed the greatest seed length (7.82 mm), with Müfitbey having the shortest (6.07 mm). Surface area was greatest in Dumlupınar (53.35 mm²) and lowest in Müfitbey (36.03 mm²). Arithmetic and geometric mean diameters were largest in Dumlupınar (4.61 mm and 4.12 mm, respectively), with Müfitbey showing the smallest (3.72 mm and 3.54 mm). Sphericity ranged from 61.22% in Reis to 52.67% in Dumlupınar. The thousand-kernel weight varied significantly, with Reis recording the highest (46.36 g) and Altay the lowest (33.58 g). Fracture resistance was highest in Dumlupınar and Bezostaja (10.89 N to 11.3 N), with the lowest in Altay (5.89 N). Color analysis revealed L values ranging from 63.77 in Çetinel to 51.16 in Harmankaya, with all varieties showing positive 'a' values, indicating red tones, and 'b' values indicating yellow tones, with Soyer-02 having the highest (32.81) and Harmankaya the lowest (24.68). FT-IR analysis revealed broad O-H stretch vibrations (3270-3300 1/cm) in Müfitbey, Altay, Soyer, and Reis, suggesting high moisture or phenolic content. Amide I (1640-1650 1/cm) and Amide II (1540-1545 1/cm) bands in Bezostaja, Yunus, Dumlupınar, and Çetinel indicated high protein content. Aliphatic C-H stretch vibrations (2920-2925 1/cm and 2850-2854 1/cm) in ES-26 and Karaman 2000 suggested high lipid content, while carbohydrate-specific C-O and C-C stretch vibrations (1000-1240 1/cm) in Sönmez and Harmankaya suggested high starch content.

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INTRODUCTION

Wheat, Triticum spp., is an important staple food for billions of people around the world, providing an essential source of carbohydrates, proteins and various nutritient (Arzani & Ashraf, 2017). Recent research has increasingly focused on the physical and mechanical properties of different wheat varieties, which are critical for agricultural practices and the food processing industry (Hemery et al., 2007). These characteristics can significantly affect the milling, storage and bread-making quality of wheat, which in turn affects the overall productivity and quality of wheat-based products (Uthayakumaran & Wrigley, 2017). The sizes of wheat grains and their geometric properties are important factors in determining interspecific differences. Studies have shown that these features are effective not only on physical processing but also on color parameters (Yousefian et al., 2021).

Width, length and thickness ratios and arithmetic and geometric mean diameter values of wheat grains play an important role in agriculture, storage and processing processes (Unal et al., 2008). The size of wheat grains can affect post-harvest processes. For example, grain sizes can directly affect field productivity and harvester efficiency. Large grains generally mean high productivity, while homogeneity of grain sizes ensures consistency in harvesting and subsequent processing (Strelec et al., 2024). Grain sizes and proportions affect the quality and quantity of flour obtained during milling. Large and regularly shaped grains are ground more efficiently during the milling process and provide higher quality flour production (Yu et al., 2024). Arithmetic and geometric mean diameter values are used to determine the grinding behavior of the grains and the characteristics of the resulting flour (Hou & Komanduri, 2003). Grain sizes can affect air flow and aeration of grains during storage. Larger or irregularly shaped grains can obstruct air flow during storage, leading to moisture accumulation and spoilage (Ziegler et al., 2021). Grains with homogeneous sizes perform better under storage conditions. Grain sizes and ratios provide important information about the quality of wheat. For example, grains of a certain size and shape may be an indication that they meet a certain quality standard. These features also help determine the purpose for which wheat will be used (such as bread making, biscuit production) (Strelec et al., 2024). The physical properties of wheat grains are also important in terms of marketing and trade. Consumers and processors prefer wheat with certain size and quality standards. This is an especially important factor in international trade in wheat because buyers may seek specific grain characteristics for particular uses (Nuttall et al., 2017). For these reasons, measuring the size and shape characteristics of wheat grains is of critical importance in the general use and evaluation of wheat (Xu et al., 2023). Metrics such as arithmetic and geometric mean diameters standardize these measurements and are used to make important decisions in the processing, storage and evaluation of wheat (Thelwall, 2016).

The surface area of wheat grains determines how effectively moisture and air can penetrate into the grain (Al-Mahasneh & Rababah, 2007). Grains with large surface area can allow moisture to evaporate more quickly, which can help prevent mold and other microbial growth during storage (Batey, 2017). Additionally, in milling, the size and surface area of the grains can affect the energy consumption and material flow rate during the milling process (Chen et al., 2021). Grains with larger surface area can be more efficient in the grinding process and consume less energy (Chen & Öpöz, 2016). As it is known, the quality of bakery products varies depending on the properties of the wheat flour used (Nashat & Abdullah, 2016). The surface area of wheat grains can affect the water-holding capacity of flour and the development of the gluten network, which directly affects baking results (Pourmohammadi & Abedi, 2021). The surface area of seeds can affect the absorption of water and nutrients (Khan et al., 2024). Grains with a large surface area can absorb more water and nutrients during germination, which can increase the germination rate of the seed and the growth rate of young plants(do Nascimento et al., 2022). Surface area measurements of wheat grains can provide important data for genetic studies and plant breeding (Haghshenas et al., 2022). These measurements can help develop wheat varieties that are better adapted to certain environmental conditions or have higher yields and quality (Zahra et al., 2021).

Determining the breaking resistance of wheat grains is considered a factor that directly affects overall productivity, product quality and economic performance in the agricultural and food industries (Safdar et al., 2023). The breaking resistance of grains during wheat milling directly affects the efficiency and energy consumption of the milling process (Miskelly & Suter, 2017). Grains with higher breakage resistance may require more energy or special grinding settings. This is a critical parameter for optimizing grinding processes (Li et al., 2023). The quality of wheat flour used in baking and other food production processes is closely related to the breaking resistance of the grains. Wheat grains with low breaking resistance are easily milled, producing finer flour, which can have an impact on the texture and appearance of products (Wysocka et al., 2024). Breakage resistance is an important factor during storage and transportation of wheat. Grains with low fracture strength tend to be more damaged during handling and storage, which can lead to product loss and reduced quality (Kumar & Kalita, 2017). As plant breeders work to develop high-yielding wheat varieties that are resistant to various environmental conditions, traits such as fracture resistance are among the important selection criteria. Grains with high breakage resistance contribute to the development of more durable varieties with maximum yield potential (Qaim, 2020). Knowing the breaking resistance of wheat can increase economic efficiency by reducing losses during processing and transportation. Particularly for large-scale wheat processing businesses, these resistance measurements can reduce costs and increase operational efficiency (Dong et al., 2023).

The coloration of wheat grains serves as a critical parameter for both quality assessment and varietal classification, as noted in various studies (Feng et al., 2022). Different hues are associated with specific wheat varieties and their suitability for particular culinary applications. For instance, red wheat, renowned for its high protein content, is typically favored for bread production, whereas white wheat, characterized by a lower protein level, is often chosen for biscuits and cakes (Oyeyinka & Bassey). Further, darker wheat varieties are noted for their enriched phytochemical compositions, including elevated levels of anthocyanins (Adom et al., 2003). The color of wheat grains not only aids in determining the optimal harvest time by reflecting changes during the ripening process but also serves as an indicator of potential disease presence (Feng et al., 2022). Changes in grain coloration can signify the onset of fungal diseases, which may darken the grains and thereby offer an early warning system for disease management (Figueroa et al., 2018). Moreover, grain coloration can indirectly hint at the nutritional value of the wheat, further underlining its importance in agricultural and food science (Sharma et al., 2021). In summary, the diverse color spectrum of wheat grains is indispensable in both agricultural classification and food processing industries, as it influences decisions from field management to final product formulation (Khalid et al., 2023).

FTIR (Fourier Transform Infrared Spectroscopy) analysis is a critical method for examining different wheat varieties because it allows for the rapid and effective characterization of the wheat's chemical composition (Pandiselvam et al., 2023). FTIR can be used to detect chemical structures such as proteins, starch, lipids, and other macromolecules in wheat samples (Golea et al., 2023).This plays a crucial role in determining the nutritional value and potential uses of different wheat varieties. Additionally, it directly affects the quality of the wheat, processing methods, and the quality of the final products. Rapid and accurate analyses using FTIR enable effective monitoring of wheat quality parameters (Badaró et al., 2022). Furthermore, this analytical method can be employed to detect early signs of disease or deterioration in wheat grains. For instance, fungal diseases or chemical spoilage can lead to specific spectral changes, which can be identified through FTIR analysis (Shen et al., 2019). Wheat breeders can use FTIR analyses to study the effects of genetic variations on chemical components, aiding in the development of more efficient or disease-resistant wheat varieties (Qaim, 2020). FTIR analysis is also important for understanding the effects of environmental factors on the chemical structure of wheat (Mills et al., 2005). This is crucial for optimizing agricultural practices and facilitating adaptation to environmental changes. Therefore, FTIR analyses are an indispensable tool in wheat research and industrial applications. This method of analysis provides a better understanding and management of wheat in both research and commercial contexts (Pandiselvam et al., 2023).

In this study, the physical and mechanical properties, color changes, and FTIR analyses of 13 different wheat varieties, which are widely cultivated across the country, were examined. Detailed analysis of the physical and mechanical properties of these cultivated wheat varieties is critical for understanding their adaptation processes specific to agricultural management and production strategies. Determining the color characteristics is important for monitoring the ripening process and the effects of storage conditions on product quality. Additionally, color changes serve as a valuable indicator for consumer preferences and marketability. FTIR spectroscopy offers a rapid and precise method to detect the chemical composition of wheat. These analyses provide information about the quantity and quality of proteins, starches, and other bioactive components, thereby serving as a significant data source for shaping agricultural policies.

MATERIALS AND METHODS

In this study, we examined the physico-mechanical properties, color variations, and chemical compositions from 13 wheat varieties commonly grown throughout the country. These varieties include Altay, Harmankaya, Çetinel, Yunus, Mufitbey, Soyer 02, Dumlupınar, Bezostaja, Sönmez, ES-26, Reis, Karaman2000, and Nacibey. Figure 1 presents images of the wheat used in the research.

Figure 1. Wheat varieties analyzed in the study

Figure 1. Wheat varieties analyzed in the study (continued)

In the assessment of wheat's physical properties, parameters such as width, length, thickness, arithmetic mean diameter, geometric mean diameter, thousand kernel weight, surface area, and sphericity were considered. Mechanical properties were evaluated through fracture resistance values. Additionally, color properties were determined using L, a, b values along with Chroma and hue angle. The flours derived from these varieties were analyzed using Fourier Transform Infrared Spectroscopy (FTIR) to ascertain their chemical compositions.

A digital micrometer was employed to measure the dimensions of the seeds. The arithmetic mean diameter (Da) and the geometric mean diameter (Dg) of the seeds were calculated using Equations 1 and 2, respectively, where L, W, and T represent the length, width, and thickness of the seeds. The sphericity (Φ) of the seeds was determined using Equation 3, and the surface area (S) of the samples was calculated based on Equation 4 (Altıkat, 2020; Altıkat & Yasar, 2019).

$$D_a = \frac{L+W+T}{3}) \quad (1)$$

$$D_g = \sqrt[3]{L * W * T} \quad (2)$$

$$\emptyset = \frac{\sqrt[3]{L*W*T}}{L} \quad (3)$$

$$S = \pi * Dg^2 \quad (4)$$

A dynamometer mounted on a stand was utilized to measure the fracture strength of the samples. The device applied a consistent pressure at a rate of 60 mm per minute to horizontally positioned samples, and the puncture resistance was recorded in newtons (N). Subsequently, these values were analyzed. Figure 2 displays the dynamometer used in the research, and Table 1 provides its technical specifications. Color measurement in the study was conducted by the international Lab color system (Figure 3).

Dynamometer stand   Dynamometer

Figure 2. Dynamometer and stand utilized in the study

Table 1. Technical specifications of the dynamometer and its stand

Dynamometer stand	
Capacity	0-500 N
Resolution	0.1 N (0.01 kgf)
Lower and upper limit	Automatic
Measurement unit	N, kgf, lbf
Battery	NiCd
Dynamometer	
Loading capacity	5000 N (500 kg)
Tension-compression process	Motorized
Tension-compression speed range	0-240 mm/min

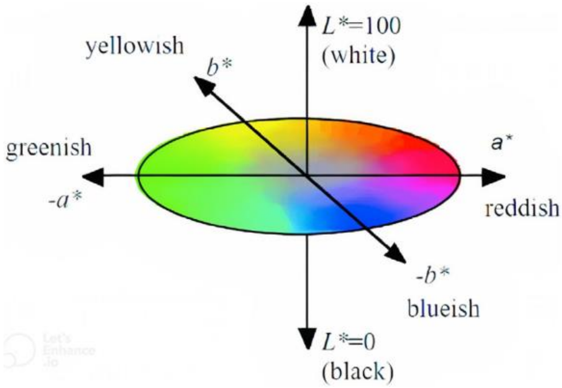


Figure 3. CIE L *a*b color space

The 'L' value quantifies brightness on a scale from 0 to 100, where 0 represents absolute black and 100 denotes absolute white. Additionally, the 'a' and 'b' values indicate chromaticity, with 'a' representing the red-green axis and 'b' the blue-yellow axis, both ranging from -90 to +90. Color measurements were conducted using a PCE-CSM4 color measurement device to determine the 'L', 'a', and 'b' values, as illustrated in Figure 4.

Figure 4. Color measurement device used in the experiments

RESULTS AND DISCUSSION

Variations in Physical and Mechanical Properties of Wheat Varieties

In the study, statistical analyses of average measurements were conducted, and Duncan's multiple range tests were used to identify significant variations in width, length, and thickness, as well as arithmetic and geometric mean diameters among the 13 wheat varieties, as detailed in Table 2. A review of the Table revealed statistically significant differences (P<0.001) across all examined varieties.

Table 2: Statistical analysis results of physical characteristics across wheat varieties

Varieties	Width (mm)	Length (mm)	Thickness (mm)	A.M.D. (mm)	G.M.D. (mm)
Altay	3 ^{bcde}	6.13 ^{de}	2.55 ^{de}	3.89 ^{ef}	3.60 ^{def}
Harmankaya	2.85 ^{cde}	6.50 ^{bcd}	2.42 ^{e}	3.92 ^{ef}	3.54 ^{ef}
Çetinel	3.18 ^{abc}	6.19 ^{cde}	2.63 ^{cd}	4 ^{de}	3.73 ^{cde}
Yunus	3.15 ^{abc}	6.32 ^{cde}	2.44 ^{de}	3.97 ^{de}	3.63 ^{cde}
Mufitbey	2.72 ^{e}	6.07 ^{e}	2.36 ^{e}	3.72 ^{f}	3.54 ^{f}
Soyer 02	3.42 ^{a}	6.79 ^{b}	2.96 ^{a}	4.39 ^{b}	4.09 ^{a}
Dumlupınar	3.27 ^{ab}	7.82 ^{a}	2.74 ^{bc}	4.61 ^{a}	4.12 ^{a}
Bezostaja	3.07 ^{bcd}	6.32 ^{cde}	2.42 ^{e}	3.93 ^{def}	3.60 ^{def}
Sönmez	3.05 ^{bcd}	6.42 ^{bcde}	2.79 ^{abc}	4.08 ^{cde}	3.79 ^{bcd}
ES-26	3.14 ^{abc}	6.59 ^{bc}	2.78 ^{abc}	4.17 ^{cd}	3.86 ^{bc}
Reis	3.41 $^{a\surd}$	6.53 ^{bc}	2.86 ^{ab}	4.27 ^{bc}	3.99 ^{ab}
Karaman2000	2.80 ^{de}	6.42 ^{bcde}	2.62 ^{cd}	3.95 ^{de}	3.61 ^{de}
Nacibey	3.13 ^{abc}	6.31 ^{cde}	2.50 ^{de}	3.98 ^{de}	3.67 ^{cde}
Stdsapma	*0.03*	*0.56*	*0.266*	*0.320*	*0.304*
F	*4.141*	*13.438*	*9.229*	*10.292*	*9.296*
P	*0.000**	*0.000**	*0.000**	*0.000**	*0.000**

*: statistically very significant, √: no statistical difference between groups with the same letter, A.M.D: Arithmetic mean diameter, G.M.D: Geometric mean diameter

The findings from the multiple comparison analyses reveal that the Soyer-02 variety has the largest seed width, measuring 3.42 mm, whereas the Müfitbey variety presents the smallest at 2.72 mm. This substantial discrepancy highlights the considerable heterogeneity in seed dimensions across the studied wheat varieties. Seed widths of the remaining varieties fall within this spectrum, illustrating the unique traits and agronomic properties inherent to each type. In terms of seed length, the Dumlupınar variety exhibits the greatest length at 7.82 mm, contrasted with the Müfitbey variety, which has the shortest seeds at 6.07 mm. Regarding seed thickness, the Soyer-02 variety displays the greatest thickness, measuring 2.96 mm, whereas the seeds of the Müfitbey variety are the thinnest at 2.36 mm. Additionally, the Dumlupınar variety demonstrates the largest arithmetic and geometric mean diameters, measuring 4.61 mm and 4.12 mm, respectively, which suggests pronounced seed robustness. Conversely, the Müfitbey variety exhibits the smallest values for both mean diameters, at 3.72 mm and 3.54 mm, respectively. These disparities underscore the varied physical properties that may influence the cultivation and application of these wheat varieties.

In the study, the thousand-kernel weight and sphericity of the analyzed wheat varieties were depicted in Figures 5a and 5b, respectively, along with the results of their statistical analyses. The Reis variety registered the highest thousand-kernel weight at 46.36 g, closely followed by the Soyer-02 and Dumlupınar varieties, which weighed 46.32 g and 42.28 g, respectively. The Yunus, Sönmez, and Bezostaja varieties were statistically grouped based on their thousand-kernel weights, as were the Karaman 2000 and Müfitbey varieties within their respective cluster. The Altay variety showed the lowest thousand-kernel weight at 33.58 g. Regarding sphericity, values ranged from 61.22% to 52.67%. The Reis variety exhibited the highest sphericity, succeeded by the Soyer-02 variety. The ES-26, Altay, and Sönmez varieties were categorized together in terms of sphericity, whereas the

Dumlupınar variety had the lowest sphericity at 52.67%. These results emphasize the marked variability in the physical attributes of the wheat varieties examined.

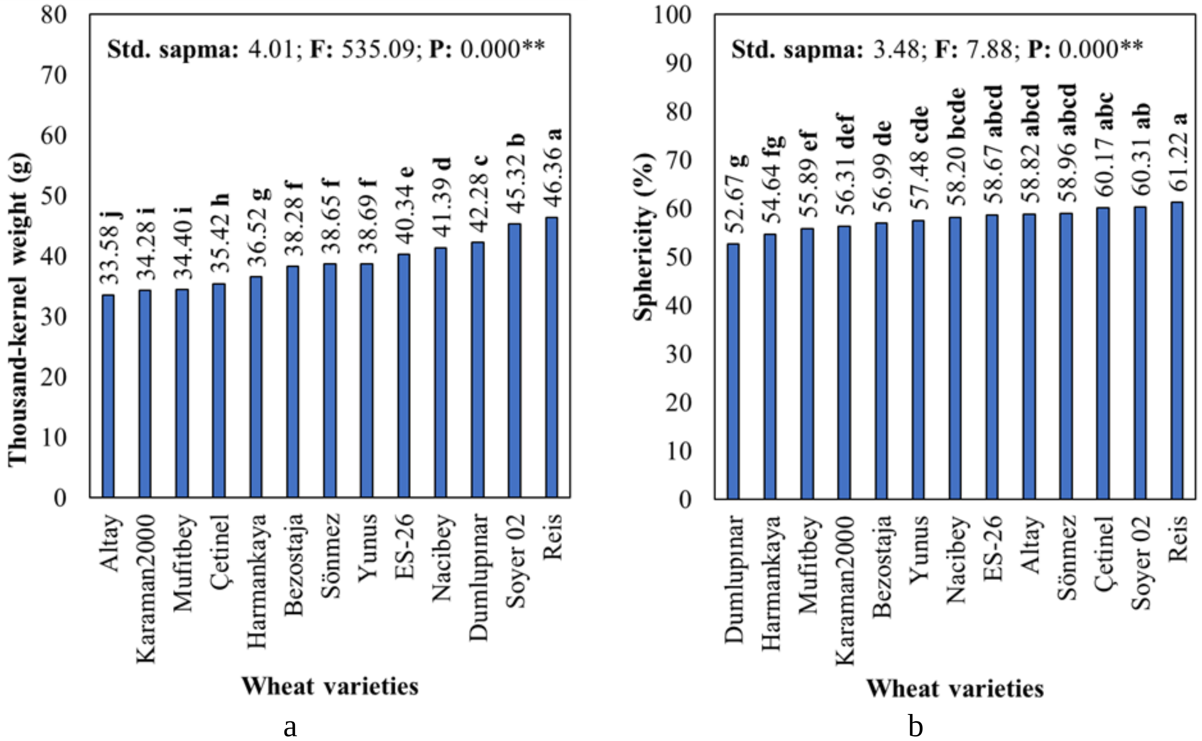


Figure 5. Values thousand-kernel weight of (a) and sphericity (b)

Upon evaluating the surface area metrics, the Dumlupınar and Soyer-02 varieties demonstrated the largest surface areas, with measurements of 53.35 mm² and 52.64 mm², respectively, as illustrated in Figure 6a. These were followed by the Reis and ES-06 varieties. The study grouped the Sönmez, Çetinel, and Nacibey varieties, along with the Karaman 2000, Bezostaja, and Altay varieties, into similar surface area categories. The smallest surface area was observed in the Müfitbey variety, recorded at 36.03 mm². Regarding fracture resistance, documented between 5.89 N and 11.3 N in Figure 6b, the values for the Dumlupınar, Nacibey, Reis, Sönmez, and Bezostaja varieties were categorized together, ranging from 10.89 N to 11.3 N. Additionally, the ES-26 and Müfitbey varieties formed another group, while the Harmankaya, Soyer-02, Çetinel, and Yusuf varieties were also similarly classified based on their fracture resistance. The Altay variety registered the lowest fracture resistance value at 5.89 N, highlighting significant variances in the mechanical robustness among the varieties studied.

The study of the physical and mechanical properties of wheat varieties is essential for several key aspects of cereal science and technology, directly impacting agricultural productivity, post-harvest processing, and food quality. These properties, which include kernel hardness, size, shape, and weight, critically influence the milling quality and the efficiency of flour production. For instance, the hardness of the wheat kernel is a fundamental trait that determines the energy required during milling and the type of flour produced. (Markowski et al., 2013) highlighted how the hardness and other mechanical properties vary significantly among wheat varieties, influencing not only milling efficiency but also the texture and quality of the final baked products.

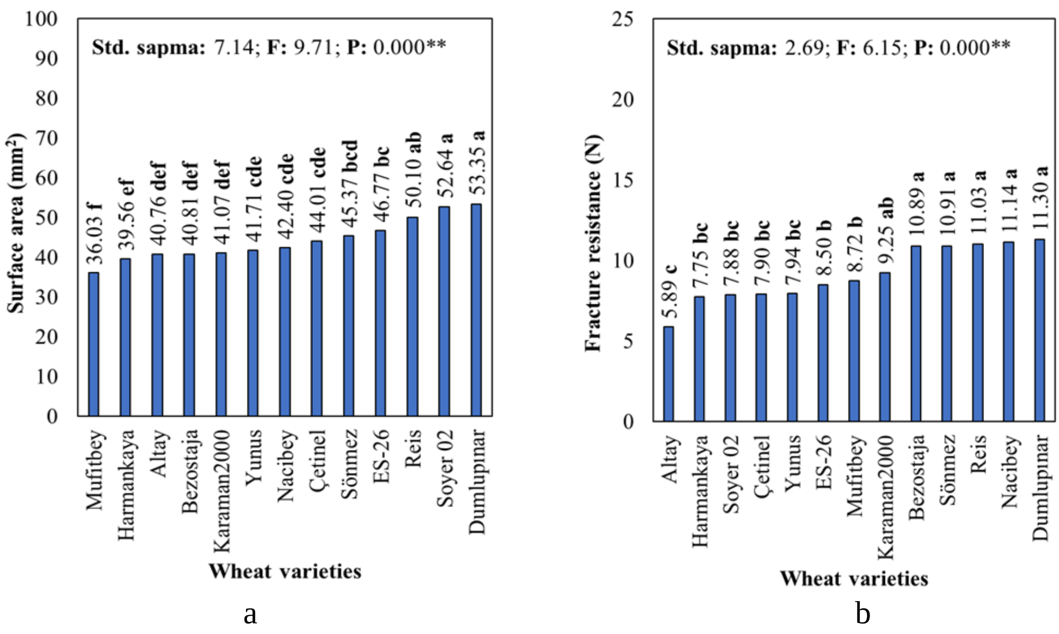


Figure 6. Surface area (a) and fracture resistance (b) values

Moreover, the dimensions and weight of wheat kernels, as studied by (El-Sheikha et al., 2010), affect their suitability for specific types of milling and processing. The researchers found that variations in moisture content significantly impact these physical properties, which in turn influence the handling and storage requirements of wheat grains. Additionally, the mechanical strength of wheat, particularly of the straw, has implications beyond grain production. (Kumar et al., 2020) examined the tensile and shear strengths of wheat straw, which are vital for developing sustainable uses for this agricultural by-product, potentially reducing waste and promoting environmental sustainability.

Variations in Color of Wheat Varieties

The statistical analysis results and multiple comparison tests performed to determine the color differences between varieties in the research are given in Table 3.

Table 3. Statistical analysis results of color change and multiple comparison tests

Varieties	L	a	b	Chroma (c)	Hue angle (h)
Altay	59.37 ^{bc}	11.23 ^{bcd}	31.40 ^{ab}	33.35 ^{abc}	70.32 ^{a}
Harmankaya	51.16 ^{f}	12.03 ^{abc}	24.68 ^{e}	27.50 ^{e}	64.16 ^{b}
Çetinel	63.77 ^{a}	10.09 ^{de}	30.86 ^{b}	32.48 ^{bcd}	71.92 ^{a}
Yunus	52.25 ^{ef}	12.05 ^{abc}	26.48 ^{d}	29.12 ^{e}	65.62 ^{b}
Mufitbey	55.8 ^{cde}	10.50 ^{cde}	29.03 ^{c}	30.89 ^{d}	70.09 ^{a}
Soyer 02	61.33 ^{ab}	11.58 ^{bcd}	32.81 ^{a}	34.74 ^{a}	70.56 ^{a}
Dumlupınar	55.11 ^{def}	9.63 ^{e}	26.06 ^{de}	27.80 ^{e}	69.71 ^{a}
Bezostaja	52.44 ^{ef}	12.87 ^{ab}	25.64 ^{de}	28.75 ^{e}	63.53 ^{b}
Sönmez	53.46 ^{def}	12.27 ^{ab}	25.69 ^{de}	28.50 ^{e}	64.57 ^{b}
ES-26	56.85 ^{cd}	11.69 ^{bcd}	32.09 ^{ab}	34.20 ^{ab}	69.91 ^{a}
Reis	52.79 ^{def}	13.52 ^{a}	28.50 ^{c}	31.56 ^{cd}	64.77 ^{b}
Karaman2000	52.88 ^{def}	11.97 ^{abc}	25.48 ^{de}	28.20 ^{e}	64.86 ^{b}
Nacibey	53.64 ^{def}	12.01 ^{abc}	25.28 ^{de}	28.02 ^{e}	64.63 ^{b}
Stdsapma	*5.46*	*1.87*	*1.179*	*3.126*	*3.90*
F	*8.58*	*4.35*	*29.03*	*17.87*	*13.96*
P	*0.000**	*0.000**	*0.000**	*0.000**	*0.000**

*: statistically very significant, √: no statistical difference between groups with the same letter, A.M.D: Arithmetic mean diameter, G.M.D: Geometric mean diameter

When examining the variation in L value, an indicator of brightness among varieties, it was determined that the Çetinel variety exhibited the highest L value at 63.77, while the Harmankaya variety had the lowest at 51.16. Additionally, the varieties Dumlupınar, Sönmez, Reis, Karaman, Nacibey, Yunus, and Bezostaja were classified within the same group based on their L values. The 'a' value represents a color component ranging from green to red. This value indicates the position of the color tone between green and red, where negative 'a' values denote green tones, and positive 'a' values indicate red tones (Cano-Lara & Rostro-Gonzalez, 2024). Upon analysis, all varieties were found to possess positive 'a' value, ranging between 9.63 and 13.52. The highest 'a' value was observed in the Reis variety, followed by the Bezostaja and Sönmez varieties. Furthermore, the varieties Harmankaya, Yunus, Karaman, and Nacibey, along with ES-26, Soyer-02, and Altay, were grouped based on the variation in their 'a' value.

The 'b' value of an object indicates the color component between blue and yellow within the color space (Al-Dairi & Pathare, 2024). This value specifies the position of the color tone between blue and yellow, with negative 'b' values representing blue tones and positive 'b' values indicating yellow tones. As expected, all varieties used in the study were found to have positive 'b' values. The statistical analysis divided the varieties into five distinct groups based on their 'b' values. The highest 'b' value was recorded at 32.81 in the Soyer-02 variety, followed by the Çetinel variety at 30.86 and the Müfitbey variety at 29.03. The lowest 'b' value was observed at 24.68 in the Harmankaya variety. Varieties such as Dumlupınar, Bezostaja, Sönmez, Karaman 2000, and Nacibey were categorized in the same group regarding their 'b' values.

The chroma (c) value of an object indicates the saturation or intensity of its color components, specifically how red/green and blue/yellow the object appears, aside from its brightness (L) value (Schweiggert, 2024). Colors with a high chroma value appear more vivid and distinct, while those with a low chroma value appear paler and duller. Upon analyzing the wheat varieties used in the study, it was found that the Altay variety exhibited the highest chroma value at 70.32, while the Bezostaja variety showed the lowest at 63.53. Based on chroma values, the varieties were grouped into two subcategories. Altay, Müfitbey, Soyer, Çetinel, Dumlupınar, and ES-26 formed one group, whereas Harmankaya, Yunus, Bezostaja, Sönmez, Reis, and Karaman2000 displayed statistically similar characteristics in terms of their chroma values.

The hue angle is considered a fundamental parameter for the characterization and application of colors (Li et al., 2024). This angle is calculated based on the a and b values, indicating the spectral position of colors and thus determining which primary tone or shade (e.g., red, blue, green, yellow, etc.) the colors belong to. In the study, the wheat varieties examined exhibited hue angles ranging from 63.53 to 71.92, categorizing them into two main groups. The varieties Altay, Çetinel, Müfitbey, Soyer-02, Dumlupınar, and ES-26 had higher hue angles compared to the Harmankaya, Yunus, Bezostaja, and Sönmez varieties, placing them within the same group.

The color properties of wheat kernels play a critical role in determining both the commercial value and consumer perception of wheat-based products. Color is a key quality attribute that influences the classification, processing, and marketing of wheat. The ability to measure and analyze these color characteristics accurately is therefore crucial for breeding programs aimed at improving these traits. (Horigane et al., 2003) developed innovative methods to assess the color characteristics of wheat kernels and flour without the need for milling, which not only preserves the germination potential of the kernels but also facilitates early selection in breeding programs. Their findings underscore the importance of kernel color as a breeding objective in Japan, highlighting the need for precise measurement techniques to support these efforts. Additionally, the variability in kernel color between hard white and hard red winter wheat varieties has been extensively studied by (Wu et al., 1999) their research detailed the significant differences in kernel color that exist between these varieties, which are critical for their market classification and ultimately, their processing and end-use qualities. Furthermore, (Zapotoczny & Majewska, 2010), conducted comparative analyses using various techniques to measure the color of the seed coat and endosperm of wheat kernels. Their study demonstrated high correlations between digital image analysis and spectrophotometry, providing valuable insights into the relationships between the color of the seed coat, endosperm, and overall grain quality, which are pivotal for processing and the quality of the final products.

FT-IR Analysis Outcomes for Wheat Varieties

O-H stretch vibrations (water and hydroxyl groups)

Upon analyzing the spectral data for the Müfitbey, Altay, Soyer, and Reis wheat varieties, broad stretch vibrations of O-H bonds were observed in the 3270-3300 1/cm range (Figure 6). These vibrations suggest that the seeds of these varieties either contain high levels of moisture or are abundant in phenolic components. The presence of phenolic compounds indicates a significant antioxidant capacity, which augments their health benefits. Antioxidants are vital for shielding cells against oxidative stress, thus playing an essential role in the prevention of numerous chronic diseases (El-Bahy, 2005; Radini et al., 2018).

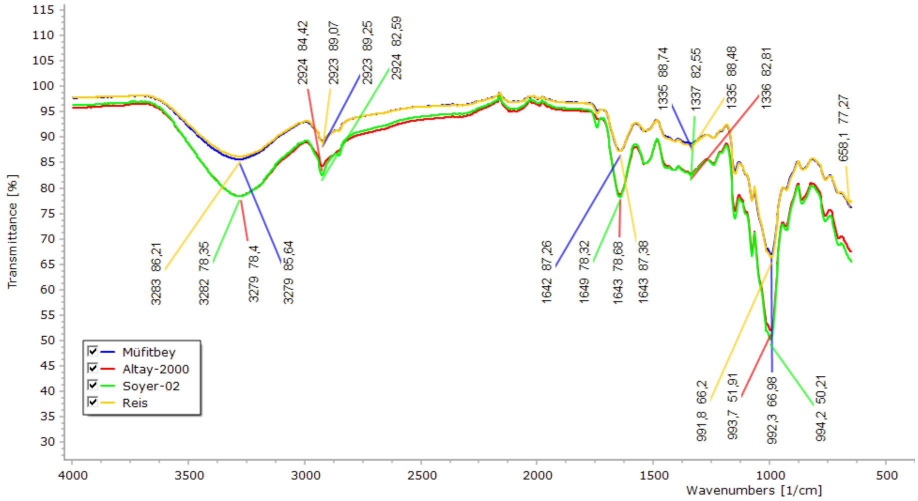
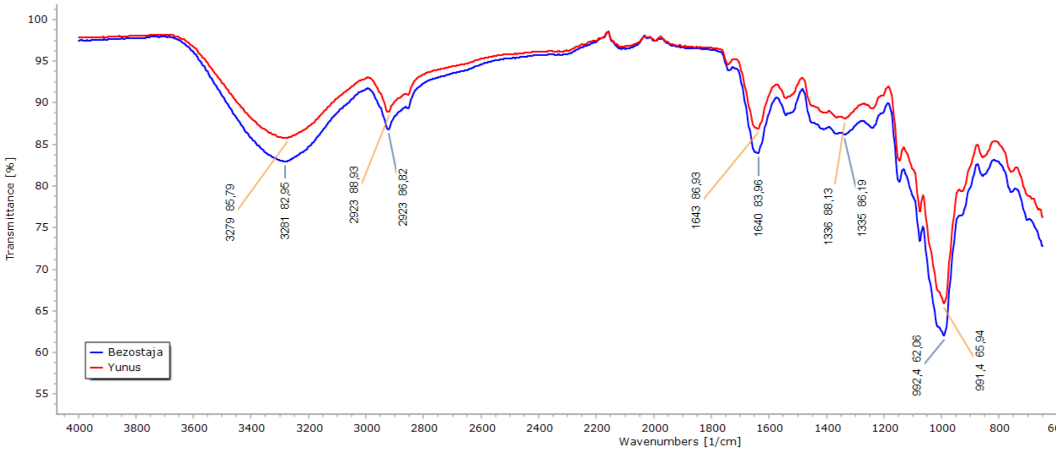


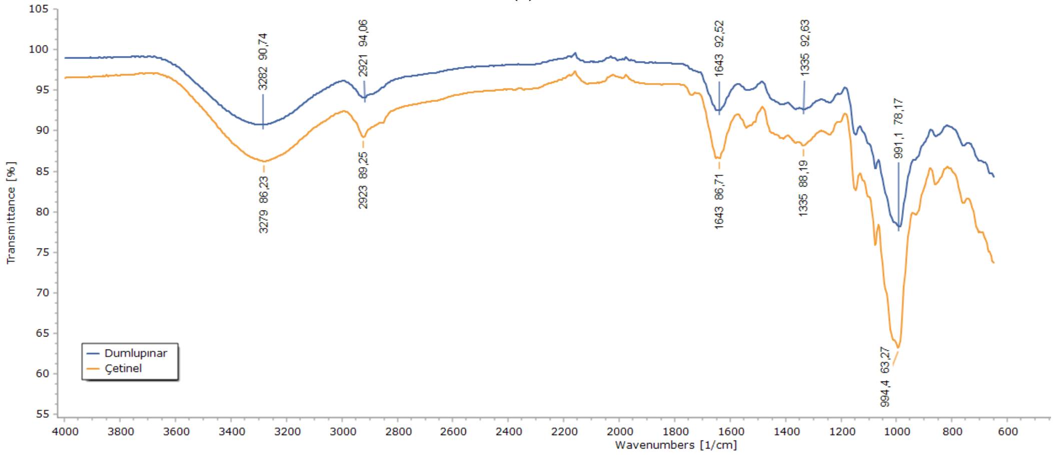
Figure 6. FTIR results of O-H Stretch Vibrations

Amide I and Amide II Bands (Protein Content)

In comprehensive spectral analyses of the Bezostaja and Yunus wheat varieties, distinct peaks, referred to as the Amid I band, were identified within the 1640-1650 1/cm range (Figure 7a). This specific wavelength is a hallmark indicator of wheat proteins, particularly those abundant in gluten (Stawoska et al., 2021). These proteins are crucial elements that substantially influence the structure and quality of wheat. Furthermore, peaks referred to as the Amide II band were observed within the 1540-1545 1/cm range in the pertinent varieties. These peaks are indicative of the vibrations of N-H and C-N bonds within the protein molecules, suggesting a high protein content (Fevzioglu et al., 2020). This is especially important in terms of the quality of the structure and quantity of the protein. Similar analyses performed on the Dumlupınar and Çetinel wheat varieties have shown that these seeds also possess rich protein profiles. The presence of Amide I and Amide II bands suggests that structures containing gluten proteins are prevalent in these seeds, as illustrated in Figure 7b. This finding is critically important for understanding the nutritional value and functionality of wheat (Makarenko et al., 2002). Gluten significantly influences the quality of bread and other wheat-based products by enhancing the elasticity and consistency of the dough.



(a)



(b)

Figure 7. FTIR results of Amide I and Amide II Bands

C-H stretch vibrations (lipid content)

Spectroscopic analyses conducted on the ES-26 and Karma 2000 wheat varieties revealed notable aliphatic C-H stretch vibrations in the ranges of 2920-2925 1/cm and 2850-2854 1/cm (Figure 8). These vibrations suggest that the seeds in question are rich in lipid components (Singh et al., 2024). Lipids are crucial macronutrients that enhance the energy value of wheat. The substantial lipid content in these wheat varieties enriches their energy density, making the seeds exceptionally nutritious. The detection of aliphatic C-H stretch vibrations in the ES-26 and Karma 2000 seeds highlights their potential as preferred choices for the production of high-energy food products and animal feeds (Osman et al., 2022). Additionally, these lipid profiles offer valuable insights for optimizing the utilization of these seeds as energy sources in wheat-based diets. Such findings are crucial for the development of agricultural products and the breeding of new wheat varieties. The high lipid content in the ES-26 and Karma 2000 varieties enhances their potential not only for food production but also as efficient alternative sources of biofuel.

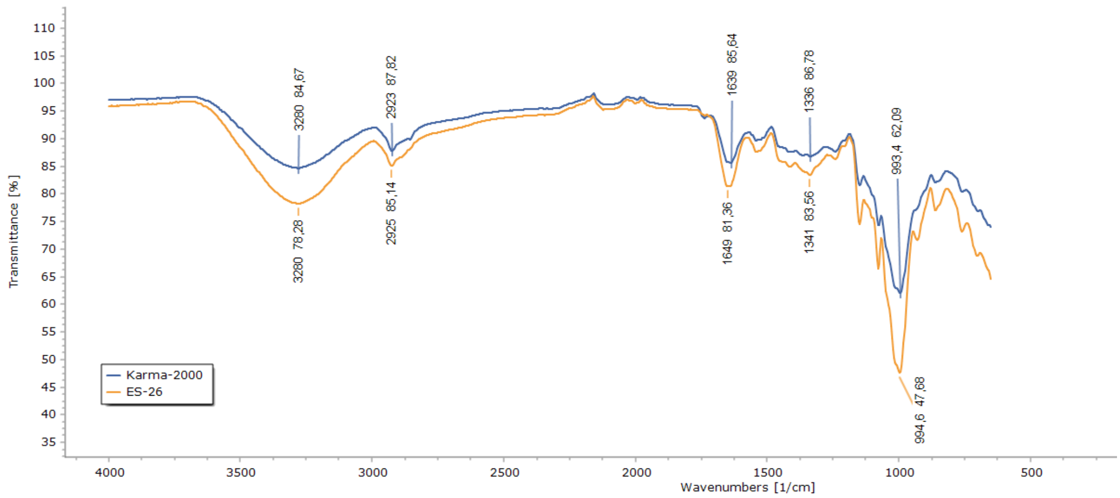


Figure 8. FTIR results of C-H stretch vibrations

C-O and C-C stretch vibrations (carbohydrate content)

Comprehensive spectroscopic analyses conducted on the Sönmez and Harmankaya wheat varieties have revealed clear C-O and C-C stretch vibrations, specific to carbohydrates, within the range of 1000-1240 1/cm (Fetouhi et al., 2019). These vibrations indicate that the seeds in question are particularly rich in starch, as shown in Figure 9. Starch, a fundamental carbohydrate found in wheat grains, is critically important for its role in energy storage (Cozzolino et al., 2014). This spectral signature demonstrates that the Sönmez and Harmankaya varieties possess high energy storage capabilities, making them energy-rich food sources. Additionally, the high starch content in these seeds not only renders them preferred varieties for bread making but also establishes them as ideal raw materials for other starch-based food products.

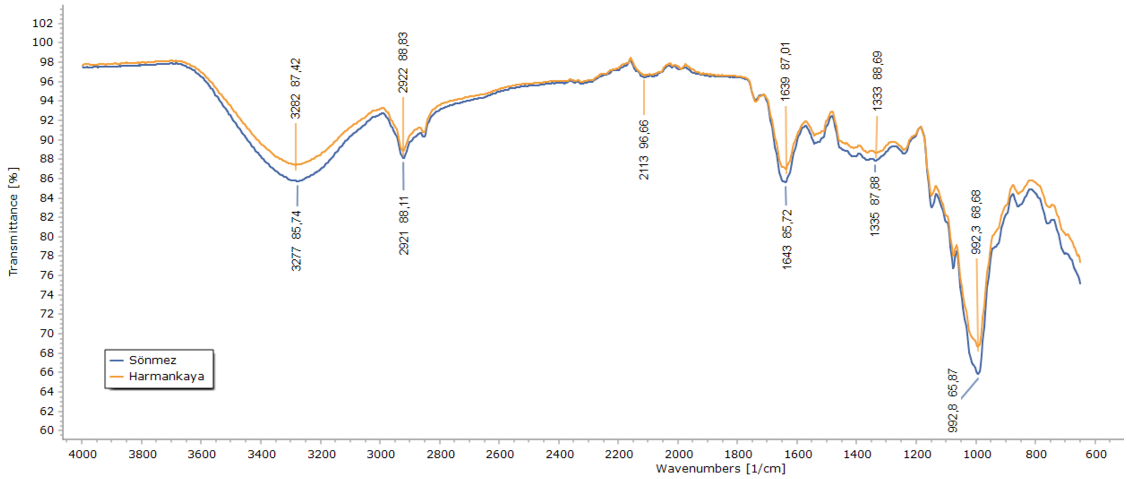


Figure 9. FTIR results of C-O and C-C stretch vibrations

The application of Fourier Transform Infrared (FT-IR) Spectroscopy in agricultural science, particularly in the analysis of wheat varieties, offers significant insights into their compositional and quality attributes. FT-IR spectroscopy is a powerful tool for rapid, non-destructive analysis, providing essential data that can help in understanding the molecular composition of wheat kernels, which is crucial for breeding, quality control, and food processing industries. One notable study by (Delwiche et al., 2002), explores the use of near-infrared (NIR) spectroscopy, closely related to FT-IR, to evaluate environmental effects on wheat development by analyzing mature grains. This study highlights how NIR spectroscopy can effectively predict quality-determining properties that are influenced by environmental conditions during the growth of various wheat cultivars. Further extending the scope of spectral analysis in agronomy, a study by (bigdeli et al., 2016) examined the spectral reflectance of Iranian wheat and barley varieties at different growth stages. Although primarily using field spectroradiometry, this research underscores the potential of spectral analysis techniques, including FT-IR, in distinguishing between different crop varieties and assessing their growth conditions and stages. Additionally, the feasibility of using Raman spectroscopy, a technique related to FT-IR, for detecting deoxynivalenol (DON) in wheat was explored by (Liu et al., 2009) they highlighted the advantages of this technique, including its insensitivity to water, which often hampers traditional IR and NIR methods. This study underscores the potential of FT-IR and related spectroscopic techniques for ensuring the safety and quality of cereals by detecting mycotoxins like DON. In another application, (De Girolamo et al., 2009) employed Fourier Transform Near-Infrared (FT-NIR) spectroscopy for the rapid and non-invasive analysis of DON in durum and common wheat. Their method effectively differentiated between contaminated and uncontaminated wheat samples, demonstrating the practical utility of FT-IR spectroscopy in mycotoxin detection and management within the food supply chain. Furthermore, the potential for FT-IR to detect adulteration in wheat flour was investigated by(Arslan et al., 2020), who developed chemometric models to identify barley flour adulteration in wheat flour. This study highlights the broader applications of FT-IR in maintaining the integrity and traceability of food ingredients.

CONCLUSION

In this research, the physico-mechanical properties, color properties and FT-IR properties of 13 different wheat varieties were examined and the results are listed below.

1. The Soyer-02 variety exhibited the largest seed width (3.42 mm) and thickness (2.96 mm), whereas the Müfitbey variety had the smallest width (2.72 mm) and thickness (2.36 mm). Dumlupınar showed the greatest seed length (7.82 mm) with Müfitbey having the shortest (6.07 mm). Surface area was greatest in Dumlupınar (53.35 mm²) and lowest in Müfitbey (36.03 mm²).
2. Dumlupınar had the largest arithmetic and geometric mean diameters (4.61 mm and 4.12 mm respectively), with Müfitbey showing the smallest (3.72 mm and 3.54 mm). The sphericity ranged from 61.22% in Reis to 52.67% in Dumlupınar.
3. The thousand-kernel weight varied significantly, with Reis recording the highest (46.36 g) and Altay the lowest (33.58 g). Fracture resistance was highest in varieties such as Dumlupınar and Bezostaja (10.89 N to 11.3 N), with the lowest in Altay (5.89 N).
4. Lightness (L values) ranged from 63.77 in Çetinel to 51.16 in Harmankaya. All varieties displayed positive 'a' values indicating red tones, with Reis having the highest (13.52). Yellow tones ('b' values) were highest in Soyer-02 (32.81) and lowest in Harmankaya (24.68). Chroma values and hue angles also showed significant variation among the varieties.
5. FTIR analysis revealed broad stretch vibrations of O-H bonds (3270-3300 1/cm) in Müfitbey, Altay, Soyer, and Reis, indicating high moisture or phenolic content. The presence of Amide I (1640-1650 1/cm) and Amide II (1540-1545 1/cm) bands in Bezostaja, Yunus, Dumlupınar, and Çetinel suggested high protein content, particularly gluten proteins.
6. Aliphatic C-H stretch vibrations (2920-2925 1/cm and 2850-2854 1/cm) in ES-26 and Karaman 2000 indicated high lipid content. Carbohydrate-specific C-O and C-C stretch vibrations (1000-1240 1/cm) in Sönmez and Harmankaya suggested high starch content.

ACKNOWLEDGEMENTS

We would like to thank Iğdır University Scientific Research Projects and Specialization Projects Unit for their support.

Conflict of Interest

The article authors declare that there is no conflict of interest between them.

Author's Contributions

The authors declare that they have contributed equally to the article.

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