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Some Physical and Physicochemical Characteristics of Local Karakılçık Wheat Varieties Grown in Different Provinces of Türkiye

Kübranur ÖZKAN[1], Hülya GÜL[2]✍
[1,2] Süleyman Demirel University, Faculty of Engineering and Natural Sciences, Department of Food Engineering, Isparta/Türkiye
[1]https://orcid.org/0000-0002-2772-2463, [2]https://orcid.org/0000-0002-6791-817X
✉: hulyagul@sdu.edu.tr

ABSTRACT

Türkiye, one of the first places where wheat was cultivated, is the gene source of ancient wheat varieties that have attracted great interest in recent years. In this study, Karakılçık wheat varieties (KWV) grown by local producers in different provinces of Türkiye for the production of "Karakılçık Bread" were collected. Some physical (foreign matter, hectoliter and thousand kernel weight, grain hardness, kernel size distribution and homojenity, and colour) and physicochemical (wet and dry gluten, gluten index, falling number, zeleny sedimentation, and delayed sedimentation) characteristics of these KWV were determined and compared with a modern bread wheat variety (MBWV). The hectoliter and thousand kernel weights of KWV varied between 26.0-44.74 g and 60.43-70.80 kg hl-1, respectively. It was determined that the KWV of İzmir, Çanakkale, and Konya provinces had the largest and most homogeneous grain structure, while the Antalya KWV had the lightest and the Samsun KWV had the darkest grain color. The highest wet and dry gluten values were measured in the KWV of Antalya province, followed by MBWV and Konya province KWV. Significant differences were determined between MBW and KWV in terms of sedimentation and delayed sedimentation values ($p<0.01$). Falling numbers were observed between 499.7 and 372.0 seconds, the highest in Osmaniye and the lowest in Sakarya KWV. As a result, it has been concluded that KWV grown in different provinces of Türkiye have unique physical and physicochemical characteristics, with KWV grown in Konya province being comparatively superior to both MBWV and other KWV. The results of this study will be beneficial for the conservation, development, and sustainability of local varieties.

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Türkiye'nin Farklı İllerinde Yetiştirilen Yerel Karakılçık Buğday Çeşitlerinin Bazı Fiziksel ve Fizikokimyasal Özellikleri

ÖZET

Buğdayın ilk ekildiği yerlerden biri olan Türkiye, son yıllarda büyük ilgi görmeye başlayan atalık buğday çeşitlerinin gen kaynağıdır. Bu çalışmada; Türkiye'nin farklı illerinde yerel üreticiler tarafından "Karakılçık Ekmeği" üretiminde kullanılmak üzere yetiştirilen Karakılçık buğday çeşitleri (KBÇ) toplanmıştır. Bu KBÇ'nin bazı fiziksel (yabancı madde, hektolitre ve bin tane ağırlığı, tane sertliği, iriliği ve rengi) ve fizikokimyasal (yaş ve kuru gluten, gluten indeks, düşme sayısı, zeleny sedimantasyon ve gecikmeli sedimantasyon) özellikleri belirlenmiş ve modern bir ekmeklik buğday çeşidi (MBÇ) ile karşılaştırılmıştır. KBÇ'nin hektolitre ve bin tane ağırlıkları sırasıyla 60.43-70.80 kg hl-1 ve 26.0-44.74 g arasında değişmiştir. İzmir, Çanakkale ve Konya illerine ait KBÇ'nin en iri ve homojen tane yapısına, Antalya ili KBÇ'nin en açık, Samsun ili KBÇ'nin ise en koyu tane rengine sahip oldukları tesbit edilmiştir. En yüksek yaş ve kuru gluten değerleri Antalya KBÇ'de ölçülürken onu MBÇ ve Konya ili KBÇ takip etmiştir. Sedimantasyon ve gecikmeli sedimantasyon değerleri bakımından MBÇ ile KBÇ arasında önemli farklar belirlenmiştir

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($p<0.01$). Düşme sayısı değerleri 499.7-372.0 saniye arasında, en yüksek Osmaniye en düşük Sakarya KKBÇ'nde tespit edilmiştir. Çalışma sonucunda elde edilen veriler farklı illerde yetiştirilen yerel karakılçık buğdaylarının farklı fiziksel ve fizikokimyasal özelliklere sahip olduklarını, test edilen tüm özellikler bakımından Konya ilinde yetiştirilen karakılçık buğdayının nisbeten daha üstün olduğunu göstermiştir. Yerel çeşitlerin korunmasında, geliştirilmesinde ve sürdürülebilirliklerinin sağlanmasında elde edilen bulguların yararlı olacağı sonucuna ulaşılmıştır.

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INTRODUCTION

Wheat, the seeds of plants in the Graminaea family, is a significant crop used for both food and animal feed. It is the second most widely grown crop globally, following maize. The most recent statistics indicates that global wheat production stands at 761 million metric tonnes, with Türkiye contributing 20.5 million metric tonnes (FAO, 2023). *Triticum aestivum*, a hexaploid species called bread wheat, accounts for approximately 95% of the world's wheat production, while *Triticum turgidum durum*, a tetraploid species called durum wheat, constitutes the remaining 5% (Shewry & Hey, 2015a; Arzani & Ashraf, 2017).

Diploid (AA; 2n = 2x = 14) Einkorn (*Triticum monococcum L.*), the tetraploid (AABB; 2n = 4x = 28) emmer (*T. turgidum var. dicoccum*), and the hexaploid (AABBDD; 2n = 6x = 42) spelled wheat (*T. aestivum var. spelta*) are the ancient wheat varieties (Arzani & Ashraf, 2017). Currently, these varieties of wheat have limited usage and are cultivated only in small regions due to cultural considerations or to respond to the growing demand in health food markets (Cooper, 2015; Shewry & Hey, 2015a).

The archaeological record indicates that wheat originated in the Fertile Crescent, a geographic region encompassing Türkiye, Jordan, Palestine, Lebanon, Syria, Iraq, and Iran. Türkiye is the gene source of wild wheat varieties and is the region where wheat was first cultivated. Evidence of the domestication of Einkorn wheat, also known as siyez wheat, can be found in the southeast region of Türkiye and dates back to 9000 BC (Harlan & Zohary, 1966; Cooper 2015; Arzani & Ashraf, 2017; Atak, 2017). Cultural forms derived from their wild relatives spread all over the world from Anatolia (Karagöz, 2019).

The increasing consumer and commercial interest in ancient wheat cultivars can be attributed to their enhanced sustainability, better nutritional composition, and the commonly held belief that they offer superior health benefits (Arzani & Ashraf, 2017; Dinu et al., 2018; Mefleh et al., 2019). Acun and Gül (2022) reported that the amount of phenolic compounds and the antioxidant activity in 10 different local Karakılçık wheat samples cultivated in Türkiye ranged from 14.62 to 2329.67 µg GAE g^{-1} and from 0.04 to 23.92%, respectively.

Multiple studies in the literature indicate that ancient wheat varieties exhibit elevated levels of phenolics (Montevecchi et al., 2018; Balli et al., 2022), minerals such as zinc, iron, and copper (Golea et al., 2022), protein, lipids, tocotrienols, lutein, total tocol, and monounsaturated fatty acids (Hidalgo et al., 2009) when compared to modern wheat varieties. Additionally, they demonstrate a reduced rate of in vitro carbohydrate digestion, higher protein digestion, increased fibre content, better antioxidant activity, and a greater amount of resistant starch in regard to modern wheat cultivars (Čurná & Lacko-Bartošová, 2017). Sırakaya (2023) observed that emmer wheat (*Triticum dicoccum*) displayed a greater protein content in contrast with modern wheat. Conversely, there are also studies that hold a contrasting viewpoint, suggesting that there is minimal difference between modern and ancient wheat types in terms of biocomponents. In fact, certain components such dietary fibre are even lower in ancient wheat (Shewry & Hey, 2015b).

Modern or commercial wheat cultivars with improved yield and quality characteristics have been successfully developed through extensive breeding efforts over many years. Although modern wheat varieties have been beneficial in improving the technological quality of the product, there has been a growing interest in old wheat varieties in recent years. This is primarily due to their higher nutrient content, more adaptability to climate change, reduced input requirements, resistance to pests and diseases, and their suitability for organic farming (Dinu et al., 2018, Bencze et al., 2020).

Local wheat varieties that have been grown in Anatolia for centuries have been assigned several names depending on factors such as spike features, kernel colour, awn characteristics, sowing timing, and geographical origin. Kan et al. (2015) collected a total of 1587 wheat village cultivars and identified 162 unique local cultivar names. White Wheat, Yellow Wheat, Zerun, Karakılçık, Red Wheat, Siyez, Koca Wheat, Şahman, Kirik, Topbaş, and Üveyik wheat are the cultivars that have been reported to have higher cultivation areas among these varieties. Karakılçık wheat (KW) got its name from the black colour of its awns. The morphological, phenological, agronomic, and qualitative properties of KW genotypes grown in several areas in Türkiye have been found suitable for utilisation in breeding programmes (Alkan, 2022).

Both local and wild wheat are important genetic resources that have reached to this day, despite the fact that they have been exposed to many adverse conditions over the years, including drought, floods, disease and pest infestation (Aktaş et al., 2018). Researching all attributes (including physical, chemical, nutritional, etc.) of these genetic resources and uncovering their superiority is essential for protecting genetic resources and developing new genotypes. Hence, this study involved the collection of Karakılçık wheat varieties (KWV) cultivated by local farmers across several regions of Türkiye, followed by the assessment of the physical and physicochemical characteristics of these wheat samples. Even so, a comparison was made between the traits of KWV and a modern wheat variety (MBWV, Esperya) that is currently extensively utilised in the manufacture of bread.

MATERIAL AND METHODS

Materials

During the 2021 harvest season, KWV samples were collected in various rural areas in Türkiye, including Antalya, Adana, Osmaniye, Sakarya, Samsun, Isparta, Ankara, İzmir, Konya, and Çanakkale. A village with the highest production of Karakılçık wheat (KW) was chosen from each province. Specifically, the types of KW cultivated for making "Karakılçık Bread" were collected. Local cultivation of KWV in Türkiye is restricted to a limited number of provinces and a limited number of local producers. Therefore, KWV samples were collected from the village with the highest production in each province, as well as from the farmer with the highest production within that village. KWV were collected from local producers using a representative method of sampling to accurately represent the entire quantity of wheat. The samples were then transferred to the laboratory in cloth bags and stored under dry and cool conditions. The MBWV, known as "Esperya," was acquired from the Hediye Flour Factory in Isparta (Türkiye) for the purpose of comparing the features of the MBWV and KWV. For this study, a total of 11 (n =11) wheat varieties were used as materials. These included 10 different KWVs collected from ten different regions, as well as one MBWV.

Physical Properties

General characteristics: Following the TS (Turkish Standard) 2974 wheat standard (TSE, 2018), only a handful of wheat samples were gathered and tested for colour and smell during daylight by blowing strongly, rubbing, and smelling. Furthermore, an investigation was conducted to determine the presence of viable storage pests in the wheat samples (TSE, 2018).

Quantification of foreign materials: A 200 g sample of wheat, which represents the entire mass of the wheat, was taken. The amount of foreign matter in the sample was then measured and classified according to the TS 2974 wheat standard (TSE, 2018).

Measurement of hectoliter weight (HW): The mass of one litre of wheat was determined using a hectoliter measurement equipment, as specified in TS EN ISO 7971-3 (TSE, 2019). Subsequently, the samples were categorised in accordance with the TS 2974 wheat standard, with hectoliter weights as the basis (TSE, 2018).

Measurement of thousand kernel weight (TKW): TKW was computed on a dry matter basis after counting a total of five hundred kernels of wheat and multiplying the result by two (Uluöz, 1965).

Grain hardness measurement: After halving the wheat with the Grobecker cutting tool, cross-sectional views were examined. The relative amounts of vitreous (hard grain), floury (soft grain), and piebald (if the glassy area has any localized starch spots) wheat grains were ascertained (Elgün et al. 2002). Traditionally, vitreousness has been associated with hardness and opagueness (flouriness) with softness (Hoseney, 1986).

Testing for kernel size distribution and homogeneity: To find out about the distribution of kernel sizes and the homogeneity of wheat samples, 100 grams of clean wheat was put through sieves with openings of 2.8 mm, 2.5 mm, and 2.2 mm for 3 minutes (Williams et al. 1986). After the sifting period concluded, the quantity of wheat left on each sieve was measured, and the ratios were calculated. Homogeneity was defined as the quantity of wheat left on two consecutive sieves exceeding 75%.

Milling of wheat samples

Once the wheat samples were cleared of any foreign materials, they were rinsed with tap water and subsequently air-dried under ambient settings for a period of 36 to 48 hours. Subsequently, the grains were ground into whole-grain flour using a laboratory-grade flour mill (Ekin Gıda, Ankara). Following the milling process, the whole grain flours were kept at an ambient temperature for approximately one week. Subsequently, they were transferred to sealed bags and refrigerated at a temperature of +4 °C until further examination.

Analysis of colour

The colour of wheat samples and whole grain flours was assessed using a Minolta CR 410 chroma metre (MinoltaCo Ltd., Tokyo, Japan). Three measurements were taken at distinct locations, and the colour components were determined as follows: lightness L* (lightness-darkness: 100=white-0:black), a* (redness-greenness: (+) red, (-) green), and b* (yellowness-blueness: (+) yellow, (-) blue) (Peterson et al., 2001).

Analysis of the physicochemical properties

The whole grain flours obtained from milling were analyzed using physicochemical methods, which are briefly described below.

Wet and dry gluten content: The wet gluten content of wheat cultivars was measured using AACC Method 38-10.01 (AACC, 2010). This method involves physically combining a flour sample with water to form a dough ball, which is subsequently subjected to a washing process to separate starch and any soluble substances. The residual gluten was collected and then weighed to establish its wet gluten content. The wet gluten sample was transferred to the glutamatic system, where it was then dried until it reached a stable weight. Subsequently, the sample was subjected to cooling and then measured in terms of its weight as dry gluten.

Gluten index value: The gluten index was determined following the standards outlined in the AACC Method 38-12.02 (AACC, 2010). The wet gluten sample was subjected to automated centrifugation at a speed of 6000 revolutions per minute for a duration of one minute. The gluten index is a quantitative measure that determines the percentage of wet gluten that remains on the sieve after centrifugation. The gluten index was determined by multiplying the weight of the wet gluten retained on the sieve by 100 and subsequently dividing it by the weight of the total amount of wet gluten.

Zeleny sedimentation value: The Zeleny sedimentation test was carried out following the approved method defined in AACC Method 56-60.01 (AACC, 2010). In summary, a quantity of 3.2 grams of whole wheat flour was carefully placed inside a graduated cylinder with a glass stopper, which had a volume of 100 milliliters. Afterwards, the techniques outlined in the methodology were implemented, and the analyses were performed utilizing the sedimentation test equipment (Tekpa, Ankara, Türkiye). Following the time analysis, the sediment volume was quantified in milliliters using a cylinder. Afterwards, the sedimentation value was calculated using the appropriate factor, which corresponds to a moisture content of 14%.

Delayed Zeleny sedimentation value: The delayed Zeleny sedimentation value was determined using the methods published by Greenaway et al. (1965). The conventional hydration period, typically lasting 5 minutes, was extended to 120 minutes by incubating sedimentation tubes at 30°. The Zeleny sedimentation value and the delayed Zeleny sedimentation value were compared to identify any differences. If the difference exceeds a threshold of 5 ml, it indicates that the wheat has been affected by Sunn pest damage.

The measurement of the falling number: The falling number was determined using the standardized approach specified by the AACC Method 56-81.03 (AACC, 2010), and the findings were reported in seconds. To summarize, a quantity of 7 ± 0.05 g of whole wheat flour was measured and placed into a falling number tube. A volume of 25 milliliters of water at a temperature of 22 ± 2 °C was introduced into the tube and shaken until fully mixed. The entire slurry was removed by employing a viscometer-stirrer. Afterwards, the tube and viscometer-stirrer were carefully placed inside the water bath of the falling number device, and the equipment was immediately started. After the test is finished, the duration is observed and recorded in seconds.

Statistical analysis

The data collected on the attributes of the wheat samples were analyzed using the "SPSS" statistical software (SPSS, 2019) based on the random plots experimental design with three replications. Analysis of variance was performed on the obtained data. The averages were compared using the Duncan multiple test.

RESULTS and DISCUSSION

Physical properties

It has been established that both MBWV and KWV meet the general characteristics outlined in the TS 2974 (TSE, 2018) wheat standard. The wheat samples have been shown to possess unique colour and odour characteristics and lack the presence of any live pests commonly found in warehouses. Wheat should be free of any odors other than its natural odor. The presence of a fresh wheat odor or a warehouse odor is considered a typical grain odor; however, dampness and/or mold smells serve as indications of grain that is in a disordered state. Foreign odors such as grass, gas, onion, garlic, etc. are undesirable in wheat.

Upon analysis of the wheat samples for foreign matter content, in accordance with the TS 2974 Wheat Standard (TSE, 2018), it was found that the

MBWV and KW-Osmaniye were part of the second class, KW-Çanakkale was part of the third class, and the KWV grown in other provinces was classified as low-quality bread wheat. The producer directly obtained the KWV from the field in their harvested state, which is the main reason for the elevated presence of foreign matter in all samples. To clarify, the KWS did not undergo any preliminary cleaning procedures such as sifting or wind blowing. Another potential factor is that the production of KW is conducted by regional farmers in rural and small regions. Typically, manual labor is employed for harvesting in these limited regions instead of utilizing automated machinery for harvesting and cleaning. Manual harvesting results in a significant presence of foreign materials. Furthermore, KW is cultivated naturally with a careful approach, typically avoiding the use of pesticides. Hence, it is unavoidable that the product would experience a rise in the incidence of foreign substances, particularly those resulting from the presence of weeds.

HW, TKW, and glassy, floury, and piebald grain values of MBWV and KWV are given in Table 1. KWV are identified by the names of the provinces from where they are collected.

Table 1. Physical properties of wheat samples[a]
Çizelge 1. Buğday örneklerinin fiziksel özellikleri

Sample	Hectoliter weight (kg)	Thousand kernel weight (g)	Vitreous (%)	Floury (%)	Piebald (%)
MBWV[b]	71.2^{a}±1.05	29.37^{de}±0.01	6.00^{f}±0.00	65.33^{a} ±1.15	28.67^{b}±1.15
KW[c]-Çanakkale	70.53^{ab}±0.92	37.75^{b}±0.76	42.67^{b}±4.62	29.33^{de}±1.15	28.00^{b}±5.29
KW-Samsun	68.93^{bc}±0.49	31.19^{cd}±0.23	34.00^{c}±3.46	30.00^{cd}±6.43	36.00^{a}±5.03
KW-Antalya	60.43^{e}±1.39	33.00^{c}±2.75	30.67^{cd}±3.06	24.00^{de}±2.00	45.33^{a}±4.16
KW-İzmir	70.80^{ab}±0.26	39.52^{b}±0.32	42.00^{b}±0.00	29.33^{de}±3.06	28.67^{b}±3.06
KW-Isparta	69.10^{bc}±0.89	26.00^{f}±3.12	30.00^{cd}±2.00	22.00^{def}±2.00	48.00^{a}±4.16
KW-Adana	68.60^{c}±0.72	28.53^{def}±0.15	44.00^{b}±2.00	20.00^{ef}±6.93	36.00^{a}±2.00
KW-Ankara	70.73^{ab}±0.15	29.13^{def}±0.26	26.00^{d}±3.46	40.00^{c}±7.21	34.00^{a}±2.31
KW-Konya	68.63^{c}±0.46	44.74^{a}±0.25	29.33^{cd}±2.31	40.00^{c}±4.00	30.67^{b}±2.31
KW-Osmaniye	69.00^{bc}±0.44	26.72^{ef}±0.23	59.33^{a}±3.06	13.34^{f}±3.06	27.33^{b}±3.06
KW-Sakarya	66.53^{d}±0.47	28.44^{def}±0.28	17.33^{e}±3.06	55.33^{b}±3.06	27.34^{b}±3.06

[a]The mean values in the table for the same column and shown with the different superscript letters are significantly different $p<0.01$. [b]MBWV: Modern Berad Wheat Variety (Esperya variety), [c]KW: Karakılçık Wheat

There is no statistically significant difference ($p > 0.01$) in HW between MBWV and KW-Çanakkale, KW-İzmir, and KW-Ankara, as shown in Table 1. The HW of KWV ranged from 60.43 kg hl-1 in Antalya to 70.80 kg hl-1 in İzmir. The TS 2974 Wheat Standard classifies bread wheats according to their HW. Based on this criteria, bread wheat with a HW of 78.0 kg or more is classified as first class. If the HW falls between 76.0 and 77.9 kg, it is classified as second class. A HW between 73.0 and 75.9 kg is considered third class. Bread wheat with a HW of 73 kg or lower is defined as low-quality. According to the "TS 2974 Wheat Standard," both the MBWV and KWV were classed as low-quality bread wheat in terms of HW. The significant presence of foreign matter is one of the factors contributing to the low HW in all wheat cultivars. When comparing the MBWV with the KWV from various provinces, it was observed that there were variations in HW values ($p<0.01$). This is a result that was expected. The reason for this is that HW is significantly impacted by factors such as genotypes, locales, sowing rates, and interactions between genotype and environment (Marić et al. 2008). It is worth noting that there was no statistically significant difference ($p>0.01$) between the HWs of the MBWV and those of the Çanakkale, İzmir, and Ankara KWV. Similarly, in a study conducted in Italy, Stagnari et al. (2008) found that there was no distinction in the HW between durum wheat and ancient Khorasan wheat. However, the ancient emmer variety had a lower HW, measuring less than 78 kg hl^{-1}, compared to both durum and Horasan wheat. Csákvári et al. (2021) revealed varieties with higher HW than the KWV and MBWV examined in this study. The HWs were measured as 81.4 kg hl^{-1} in modern winter wheat, 75.7 kg hl^{-1} in old/traditional winter wheat, 77.3 kg hl^{-1} in modern einkorn, and 79.1 kg hl^{-1} and 80.1 kg hl^{-1} in two different ancient einkorn varieties.

KWS from the province of Konya had the highest TKW value with an average of 44.74 g, followed by İzmir with an average of 39.52 g and Çanakkale with 37.75 g. These were then followed by the Antalya sample with 33.0 g. It was found that the TKWs of the other KWS and MBW were lower. This low TKW may be due to the hot and dry climatic conditions.

Because seasonal climatic conditions are a very important factor in the grain yield and TKW of wheat, This problem can be solved by irrigation under certain conditions (Torrion & Stougaard 2017).

The samples collected from the province of Konya exhibited the highest TKW, averaging 44.74 g. This was followed by KW-İzmir with an average TKW of 39.52 g and KW-Çanakkale with an average TKW of 37.75 g. Subsequently, the KW-Antalya weighed 33.0 grams. The study revealed that the TKWs of the other KWV and the MBWV were comparatively lower. The low TKW could potentially be attributed to the dry and hot weather conditions. Seasonal climatic variables significantly affect grain yield and TKW of wheat, so irrigation can be used under certain conditions to solve this problem (Torrion & Stougaard, 2017).

The TKW of KW-Konya, which was measured to be 44.74 g, was found to be nearly equivalent to the TKW of the Emmer variety examined in Italy, with an average value of 45.05 g over a two-year period (Stagnari et al., 2008). Ertop and Atasoy (2019) found that the TKW of einkorn wheat was 27.94 g, which was lower than the TKW of durum wheat, which was 54.6 g. Our analysis revealed that the TKW of KW-Isparta was the only one that exhibited a lower value compared to MBWV.

Wheat varieties that have larger kernels also exhibit a higher TKW. According to Table 2 in the sieve study, the varieties KW-İzmir, KW-Çanakkale, and KW-Konya had the maximum quantity of wheat left on the 2.8 mm sieve, in that order. Conversely, it has been established that the KW-Isparta and KW-Osmaniye, which exhibit the lowest TKW, are characterized by their small size and heterogeneity. Furthermore, there was a significant proportion (about 16%) of these KW samples that had passed through the 2.2 mm screen. It is widely recognized that there is a direct relationship between TKW and the amount of flour produced. When the TKW and kernel size distribution and homogeneity tests are looked at together, they show that some KW samples are bigger than the MBWV, which means they will produce more flour. As previously stated, the impact of genotype-environment interactions on wheat quality is considerable. Theorem is supported by the fact that KWV grown in different provinces have different sizes, shapes, levels of homogeneity, and grain hardness, as well as different HW and TKW values.

The ratios of vitreous, floury, and piebald kernels for both MBWV and KWV are given in Table 1. According to Hoseney (1986), floury grains have a soft texture and a low protein content, whereas vitreous grains typically have a hard texture and a significant amount of protein. MBWV, as a variety of bread wheat, displayed a higher ratio of floury grains compared to KWV. The most similar result to MBW was discovered in KW-Sakarya, which had a floury grain rate of 55%. Following this were KW-Ankara and KW-Konya, both of which had a 40% floury grain rate.

The vitreous grain rate of KW-Osmaniye is higher than that of the other samples, measured at 59.33%. The MBWV and KW-Sakarya had the lowest vitreous grain ratios, respectively. It was noticed that both MBW and KWS had a relatively high percentage of piebald grain, which was an interesting observation. The development of grain piebald may differ from variety to variety, depending on the amount of protein present, the area of planting, and the weather conditions. It was found by Gül et al. (2012) that some bread wheat cultivars that were cultivated in the Lakes Region of Türkiye had a high piebald grain ratio. The authors were of the opinion that the climate conditions could be effective in this situation.

The mean values obtained through sieve analysis, which is used to evaluate the size and uniformity of wheat samples, are presented in Table 2. The KW-Izmir, KW-Konya, and KW-Çanakkale varieties exhibited the highest proportion of large grains ($\geq$ 2.8 mm), whereas the KW-Adana, KW-Isparta, and KW-Osmaniye varieties had the lowest proportion. The KW-Samsun and KW-Antalya had a similar grain size distribution to that of the MBWV. The greatest amount of medium-sized grains was found in KW-Ankara, KW-Adana, and KW-Samsun, while the lowest amount was recorded in KW-İzmir, KW-Çanakkale, and KW-Konya. The MBW, KW-Çanakkale, KW-Samsun, KW-Antalya, KW-İzmir, and KW-Konya samples were determined to be large and homogeneous, but the KW-Isparta, KW-Adana, KW-Ankara, KW-Osmaniye, and KW-Sakarya samples were found to be heterogeneous.

It is noteworthy that the grain size of the Karakılçık variety cultivated in İzmir, Çanakkale, and Konya provinces was considerably greater than that of the MBW variety. This outcome is in line with the findings of Larsson and Bergman (2023), who reported that different soil types and growing conditions have a significant impact on grain size. Researchers also determined that ancient wheats, such as einkorn, which are generally cultivated in nutrient-poor areas, exhibited an increase in grain size compared with modern wheat types that had not been treated with fertilizer. The presence of soil moisture during the grain maturation stage, as well as the presence of drought and irrigation, have an important effect on the size of the grain (Torrion & Stougaard, 2017). Hence, the presence of water in the soil is considered a crucial determinant for the reduced grain sizes observed in Isparta, Osmaniye, and Adana KWV, as compared to other types.

Characteristics of colour in wheat samples and their whole grain flours

The colour values measured in the grains and whole grain flours of the KWS and MBW can be seen in Table 3.

Table 2. Kernel size distribution and homogeneity of wheat samples[a]

Çizelge 2. Buğday örneklerinin tane büyüklüğü dağılımı ve homojenliği

Sample	Large (≥2.8 mm)	Medium (2.5–2.8 mm)	Small (2.2–2.5 mm)	Undersize (≤2.2 mm)	Size and homogeneity
MBWV[b]	44.92^{c}±1.38	30.50^{cd}±1.18	16.13^{e}±0.04	8.45^{b}±0.29	Large-homogeneous
KW[c]-Çanakkale	71.46^{b}±0.75	21.84^{f}±0.69	5.31^{g}±0.24	1.39^{de}±0.06	Large-homogeneous
KW-Samsun	47.67^{c}±5.18	41.33^{a}±3.81	10.17^{f}±2.04	0.83^{de}±0.11	Large-homogeneous
KW-Antalya	46.09^{c}±0.70	35.74^{b}±2.24	15.54^{e}±0.99	2.62^{cd}±0.67	Large-homogeneous
KW-İzmir	85.90^{a}±1.74	11.30^{g}±1.53	2.32^{g}±0.36	0.48^{de}±0.25	Large-homogeneous
KW-Isparta	16.53^{e}±0.80	27.26^{de}±0.96	39.81^{a}±1.73	16.40^{a}±2.22	Heterogeneous
KW-Adana	20.30^{e}±0.39	43.07^{a}±0.66	27.42^{c}±0.35	9.21^{b}±0.92	Heterogeneous
KW-Ankara	29.06^{d}±0.69	44.56^{a}±0.43	23.94^{d}±1.28	2.44^{cde}±0.86	Heterogeneous
KW-Konya	70.27^{b}±2.28	24.77^{ef}±1.51	4.66^{g}±0.88	0.30^{e}±0.07	Large-homogeneous
KW-Osmaniye	16.28^{e}±2.31	32.77^{bc}±0.79	34.94^{b}±2.94	16.01^{a}±0.63	Heterogeneous
KW-Sakarya	31.44^{d}±0.41	35.98^{b}±0.44	28.32^{c}±1.03	4.27^{c}±0.77	Heterogeneous

[a]The mean values in the table for the same column and shown with the different superscript letters are significantly different p<0.01. [b]MBWV: Modern Berad Wheat Variety (Esperya variety), [c]KW: Karakılçık Wheat

Table 3. Colour values of wheat samples and their whole grain flours [a]

Çizelge 3. Buğday örneklerinin ve tam tane unlarının renk değerleri

Sample	Colour values of wheat grains			Colour values of whole grain flours		
	L*	a*	b*	L*	a*	b*
MBWV[b]	41.3^{d}±0.1	7.4de±0.0	13.6f±0.0	64.9f±2.2	2.3b±0.1	10.0e±0.3
KW[c]-Çanakkale	44.5b±0.1	8.2b±0.2	16.6c±0.0	79.6bcd±1.7	1.7d±0.1	13.6b±1.4
KW-Samsun	36.2g±0.1	6.1f±0.2	11.7h±0.1	75.0e±0.5	1.8d±0.2	12.1cd±0.0
KW-Antalya	46.0a±0.7	7.5de±0.3	18.4a±0.3	82.7a±1.0	1.9cd±0.1	16.4a±0.3
KW-İzmir	45.0^{ab}±0.9	7.05e±0.3	17.3b±0.1	80.9ab±0.1	1.3e±0.0	15.7a±0.1
KW-Isparta	42.9^{c}±0.9	7.5cde±0.3	15.7d±0.1	80.1bcd±0.7	2.2bc±0.2	13.1bc±0.1
KW-Adana	38.8^{f}±0.6	8.7a±0.1	14.2e±0.2	78.2bcd±1.4	2.5ab±0.1	13.8b±0.1
KW-Ankara	40.8^{de}±0.7	7.9bcd±0.0	14.5e±0.4	80.7abc±0.4	1.7d±0.0	11.8d±0.3
KW-Konya	44.2^{c}±0.3	7.9bc±0.1	16.7c±0.1	77.8d±1.0	1.7d±0.3	13.7b±0.1
KW-Osmaniye	39.6^{ef}±0.5	7.5cde±0.2	13.2g±0.0	79.2bcd±0.4	2.8a±0.1	12.9bc±0.2
KW-Sakarya	39.5^{ef}±0.3	7.2e±0.0	14.1ef±0.1	77.9cd±0.2	1.6d±0.0	11.8d±0.2

[a] The mean values in the table for the same column and shown with the different superscript letters are significantly different p<0.01., [b]MBWV: Modern Berad Wheat Variety (Esperya variety), [c]KW: Karakılçık Wheat

The variety KW-Antalya showed the highest L* value, indicating it had the lightest colour among the KW varieties. KW-İzmir and KW-Çanakkale followed in that order. The KWS acquired from Adana, Osmaniye, and Sakarya provinces were found to have a much darker colour compared to the others. However, the Samsun KW grains had the darkest colour among all the samples.

Figure 1 displays representative images of three wheat samples: the MBWV sample (Figure 1A), the lightest coloured KW from Antalya province (Figure 1B), and the darkest coloured KW from Samsun (Figure 1C) province. The KW-Ankara is the one that most closely matches the brightness value of the MBWV.

The KW-Adana had the highest measured redness value (a*), while the KW-Samsun had the lowest. In terms of the a* value, the MBWV and KWs of Antalya, İzmir, Isparta, Ankara, Osmaniye, and Sakarya were statistically placed together in the same group. Among the wheat samples studied, KW-Antalya exhibited the greatest level of brightness and was also determined to have the highest level of yellowness, as shown by its b* value (Figure 1B). The highest b* values were measured in KW-İzmir, KW-Konya, and KW-Çanakkale, respectively, after KW-Antalya. The b* values were measured in KW-İzmir, KW-Konya, and KW-Çanakkale, respectively, after KW-Antalya. It was found that KW-Samsun had the lowest b* value, as well as the lowest L* and a* values (Figure 1C).

When the color values of whole grain flours were taken into consideration, it was found that the whole grain flours with the lightest colors were KW-Antalya, KW-İzmir, and KW-Ankara. On the other hand, the samples with the darkest colors were KW-Samsun and MBWV, as shown in Table 3. The remaining samples exhibited similar levels of brightness. The increase in L* values of the whole wheat flours indicates a significant lightening of the wheat colors following the milling process. Observations revealed an increase in the L* value and a notable decrease in the a* value throughout the milling process. The a* value of whole grain flours ranged from 2.8 to 1.3. Additionally, the b* value of KW-Antalya and KW-İzmir flours, which exhibit high levels of L* and b* in their grain colors, was found to be substantially higher. The samples presenting lower b* values compared to the others include KW-Ankara, KW-Sakarya, and KW-Samsun whole grain flours. The MBWV whole grain flour demonstrated the lowest b* value.

A B C

Figure 1. Representative images of three wheat samples; A:Modern Berad Wheat Variety (Esperya variety), B:Karakılçık Wheat-Antalya, C: Karakılçık Wheat-Samsun

Şekil 1. Üç farklı buğday örneğinin temsili görüntüleri; A:Modern ekmeklik buğday örneği (Esperya) B:Antalya ile Karakılçık buğday örneği, C: Samsun iline ait Karakılçık buğday örneği

Physicochemical properties

The physicochemical study was conducted to evaluate the technological features of whole grain flours derived from KW and MBW varieties. The results of this test can be seen in Table 4. The wet gluten and dry gluten values in the MBWV flour were measured to be 45.3% and 13.2%, respectively. In samples of Karakılçık wheat, the same values were found between 22.7% and 50.4% and 6.9% and 14.8%, respectively. The KW-Antalya showed the greatest wet and dry gluten values, with the MBWV and KW-Konya following slightly behind. This was followed by Karakılçık wheat from Osmaniye, İzmir, and Samsun provinces. The KW-Ankara and KW-Sakarya had the lowest wet and dry gluten levels. Comparatively, KW-Antalya exhibited significantly higher wet and dry gluten values in comparison to MBWV and other KWVs. There was no significant difference in these values between the MBW and the KW-Konya.

When the gluten index value, which is the indicator of gluten quality, is examined, it is determined that the MBW has the highest value, and there is no significant difference between the MBW and KW-İzmir and KW-Adana. After these three samples, KW-Antalya ranked fourth in terms of gluten index value.

Table 4. Physicochemical characteristics of whole grain flours of wheat samples[a]

Çizelge 4. Buğday örneklerinin tam tane unlarının fizikokimyasal özellikleri

Sample	Wet gluten (%)	Dry gluten (%)	Gluten index (%)	Sedimentation (ml)	Delayed Zeleny sedimentation(ml)	Falling number (second)
MBWV[b]	$45.3^{b}\pm1.6$	$13.2^{b}\pm0.0$	$96.7^{a}\pm0.5$	$32.0^{a}\pm0.0$	$29.0^{a}\pm1.0$	$424.0^{cde}\pm15.0$
KW[c]-Çanakkale	$28.7^{e}\pm0.9$	$8.9^{e}\pm0.1$	$70.6^{cd}\pm3.2$	$16.0^{e}\pm0.0$	$10.0^{g}\pm0.0$	$408.7^{e}\pm10.5$
KW-Samsun	$34.9^{cd}\pm1.4$	$10.4^{cd}\pm0.5$	$66.2^{cde}\pm6.7$	$13.7^{f}\pm0.5$	$12.0^{f}\pm0.0$	$446.3^{c}\pm18.1$
KW-Antalya	$50.4^{a}\pm1.7$	$14.8^{a}\pm0.4$	$85.4^{b}\pm1.0$	$22.7^{b}\pm0.5$	$24.7^{b}\pm0.5$	$423.0^{cde}\pm4.0$
KW-İzmir	$37.0^{c}\pm0.6$	$11.2^{c}\pm1.2$	$88.4^{ab}\pm4.7$	$17.0^{de}\pm0.0$	$24.7^{b}\pm0.6$	$445.0^{c}\pm10.0$
KW-Isparta	$32.2^{d}\pm0.3$	$9.9^{de}\pm0.1$	$61.0^{de}\pm4.3$	$18.0^{cd}\pm1.0$	$10.7^{fg}\pm0.6$	$420.0^{de}\pm6.0$
KW-Adana	$32.0^{d}\pm1.9$	$9.7^{de}\pm0.2$	$88.6^{ab}\pm3.7$	$17.0^{de}\pm0.0$	$19.0^{d}\pm0.0$	$441.0^{cd}\pm2.0$
KW-Ankara	$22.7^{f}\pm0.7$	$6.6^{f}\pm0.2$	$59.3^{e}\pm5.1$	$16.0^{e}\pm0.0$	$11.0^{fg}\pm0.0$	$348.7^{g}\pm3.5$
KW-Konya	$42.4^{b}\pm1.6$	$12.7^{b}\pm0.5$	$75.1^{c}\pm3.12$	$18.7^{c}\pm0.5$	$14.7^{e}\pm0.6$	$473.7^{b}\pm6.5$
KW-Osmaniye	$37.3^{c}\pm1.3$	$11.0^{c}\pm0.2$	$65.0^{cde}\pm6.1$	$19.0^{c}\pm0.0$	$11.7^{f}\pm0.5$	$499.7^{a}\pm4.5$
KW-Sakarya	$22.8^{f}\pm1.2$	$6.9^{f}\pm0.4$	$74.67^{c}\pm0.8$	$16.7^{e}\pm0.5$	$21.0^{c}\pm0.5$	$372.0^{f}\pm8.0$

[a] The mean values in the table for the same column and shown with the different superscript letters are significantly different p<0.01., [b]MBWV: Modern Berad Wheat Variety (Esperya variety), [c]KW: Karakılçık Wheat

Upon analyzing the gluten index value, which serves as an indicator of gluten quality, it is evident that MBW exhibits the greatest value. Furthermore, there is no notable distinction between MBW, KW-İzmir, and KW-Adana. KW-Antalya came in at number four in terms of the gluten index value after these three samples. As expected, the gluten index value of the KW-Ankara, which exhibited the least amount of wet and dry gluten content, was correspondingly the lowest among all the samples. However, the gluten index value of KW-Sakarya, which exhibited identical wet and dry gluten values as KW-Ankara, was determined to be better and fell within the same category as KW-Konya.

Karakılçık wheat samples had more gluten than the "Bozodi" einkorn variety (15.4%), which was studied by Csákvári et al. (2021), but less than the "Schiemann" variety (25.8%) in KW-Ankara and KW-Sakarya. The gluten content of the other Karakılçık wheat varieties, as assessed by Csákvári et al. (2021), was significantly higher than that of the modern einkorn variety (22.5%). Based on this information, it may be inferred that the locally cultivated karakılçık wheat in Türkiye shows potential as a promising variety.

In our study, we observed that the wet gluten content and gluten index values of Karakılçık wheats were greater than those of Kastamonu einkorn wheat, as reported by Ertop and Atasoy (2019) (6.75% and 42%, respectively). The dry gluten content for particular KWV and MBWV exhibited similarity to the findings of the investigation conducted by Gélinas and McKinnon (2016). In their study, Gélinas and McKinnon (2016) determined that the dry gluten content was 11.3% in tetraploid Khorasan wheat, 10.2% in emmer wheat, 10.4% in hexaploid spelt, and ranged from 9.2% to 15.7% in hexaploid modern wheat varieties. The dry gluten contents of KW-Antalya and KW-Konya were higher compared to the wheats examined in this study.

Significant differences were found between KWV and MBWV in terms of sedimentation and delayed sedimentation values, based on statistical analysis. The KW-Antalya sample, which had the highest wet and dry gluten ratios, showed a sedimentation value that closely approximated that of the MBW. The lowest sedimentation value was found in KW-Samsun. The sedimentation values of KW-Ankara and KW-Sakarya, which exhibited the lowest wet and dry gluten content, were also found to be the lowest. The TS 2974 wheat flour standard (TSE, 2018) classifies bread wheats based on their sedimentation value. A sedimentation value of 37 or more is categorized as 1st class, while a value between 31 and 36 ml is considered 2nd class. A number between 22 and 30 ml falls into the 3rd class category, while anything below 22 ml is regarded as as low-quality wheat flour. Based on this categorization, MBWV was classified as belonging to the highest class, KW-Antalya was classified as belonging to the third class, and the other KWV were classified as belonging to the low-quality bread wheat class.

The delayed sedimentation value indicates that the KW-Antalya and KW-İzmir samples were the most similar to the MBW. If the difference between the delayed sedimentation value and the normal sedimentation value exceeds 5 ml, the presence of sun pest damage can be mentioned in these wheat samples. It may be stated that the whole wheat flour from KW-Çanakkale, KW-Isparta, and KW-Osmaniye has been affected by pest infestation. While the wet gluten values of these samples were good enough, the low gluten index values may be attributed to the damage caused by sun pests. However, due to the absence of sun pest damage, the gluten index value of the KW-Sakarya was moderate despite the low levels of wet and dry gluten.

The falling number values of the whole wheat flour samples ranged from 499.7 seconds (at KW-Osmaniye) to 372.0 seconds (at KW-Sakarya), as shown in Table 4. The TS 2974 wheat flour standard (TSE, 2018) classifies wheats as first-class bread wheat if the Hagberg falling number is at least 250 or higher. In this case, all wheat varieties—including the MBWV—were in the first class in terms of falling numbers. To ensure high-quality bread flour, it is important to have adequate amylase activity, namely about 250 ± 25 seconds. None of the tested wheat samples, including the MBW, fell within this range, indicating that their amylase activity was inadequate. To achieve a falling number of 250 ± 25 seconds during bread baking from these flours, it is advisable to incorporate amylase in appropriate quantities.

CONCLUSION

Recently, there has been a growing interest among consumers, farmers, and researchers in local and ancient wheat types. One factor contributing to this rise is the public perception that products derived from ancient wheat are both more nutritious and more flavorful. The primary factors increasing attention towards old varieties among producers are the rising demand and the good adaptation of these kinds. Ancient varieties have survived and persisted to the present day by adapting to unfavourable weather conditions over an extended period of time. In today's day, characterised by rising threats like global warming, climate change, and drought, the protection and development of wheat cultivars that possess resilience to marginal cultivating and climatic conditions have assumed greater significance. This study examines the physical and physicochemical qualities of KWV grown by local producers in 10 different provinces in Turkey, which is known to have rich wheat genetic resources. These features are then compared to those of a MBWV called Esperya, highlighting the significance of the subject topic. Significant variations were observed among the Karakılçık wheats cultivated in various regions of Turkey. Climate and soil conditions have a big impact on the quality of Karaklçk wheat. The results of this study will contribute to future research on the preservation, utilisation in cultivar development, cultivation, and sustainability of ancient Karakılçık wheat.

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Contribution Rate Statement Summary of Researchers

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

Conflict of Interest Statement

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