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The Physicochemical and Technological Properties of Parboiled Durum Wheat (*Triticum* Durum Desf.) (Bulgur) Varieties during Drying

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ABSTRACT

The objective of this research was to assess the impact of drying temperature (50, 60, and 70 °C) and dryer type (natural convective air dryer, forced convective air dryer, and vacuum dryer) on moisture content, ash content, thousand-kernel weight, hectoliter weight, hydration capacity, and the L*, a*, b* color values of different durum wheat varieties following parboiling and drying. Significant variations ($P \leq 0.05$) were noted among the unprocessed wheat varieties regarding moisture content, ash content, thousand-kernel weight, hectoliter weight, hydration capacity and a*, b* color values. The moisture content of the wheat varieties increased to elevated levels during the parboiling (cooking) process due to moisture absorption. As the drying temperatures rose, the final moisture contents of all wheat samples diminished during the drying process across the three dryer types. The alterations in moisture contents of all wheat samples were found to be significantly different based on both the temperatures and the dryers used ($P \leq 0.05$). The most substantial reductions in moisture contents, thousand-kernel weight, ash content and hectoliter weight of all wheat samples after 8 hours of drying at all temperatures were achieved through vacuum drying. The hydration capacity of all bulgur wheat varieties exhibited a significant increase ($P \leq 0.05$) with rising drying temperatures, particularly when dried using the forced convective air dryer and vacuum dryer. In terms of color analysis results for bulgur wheat, an examination of the effects of wheat varieties, drying methods, and temperatures on color values revealed a decrease in L* and a* values, alongside an increase in b* values with the elevation of drying temperature. Vacuum drying was determined to be more effective than both the forced convective air dryer and the natural convective air dryer.

INTRODUCTION

Due to its ease of storage and the fact that its flour and fractions can be used to make a wide variety of food products, wheat is one of the main staple foods in the world. Wheat through the centuries has been intimately associated with human food. It is a major component of most diets of the world because of its agronomical adaptability, ease of sustained nutritional qualities in storage and the ability of its grits to produce a variety of palatable, interesting and satisfying food. A variety of food products, including bread, biscuits, cakes, pasta, fortified cereals, pet foods, and other specialized items, are derived from wheat. Although it grows in the winter, durum is spring wheat. Due to its distinct qualities and final output, durum wheat is a crop of economic importance despite its small acreage. (Elias, 1995). Since it is traditionally and commercially a durum wheat product, "bulgur" will refer to durum wheat

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bulgur (sometimes called "yellow bulgur") unless otherwise specified. Due to its amber hue and hardness, durum wheat (*Triticum* durum Desf.) is commonly used to make bulgur (Evlice & Özkaya, 2019). Bulgur, which is one of the oldest and most basic nutrients of Turkish cuisine, is a semi-ready-made food obtained by thoroughly cleaning and washing, then cooking (parboiling) and drying with two or three times the amount of water, separating the husk, breaking it and classifying it according to its size (Yıldırım et al., 2008a,b).

Parboiling of wheat involves a heat treatment during preparation that effectively kills the germ, thereby eliminating the potential for lipid hydrolysis due to the inactivation of the responsible enzymes. The parboiling treatment enhances the shelf life of products while also providing the necessary hardness. The process of parboiling causes a number of physico-chemical changes in the grain. Middle Eastern, North African, and Central Asian cuisines all use bulgur, a traditional dried wheat product that has been partially debranned (Miskelly, 2017).

Wheat grain is digested to produce bulgur, which gives it a number of beneficial qualities. This property is lost when wheat is processed; its microflora is almost completely destroyed, its enzymes become dormant, and it becomes more resilient to mold growth, rodent damage, and insect infestation. Furthermore, the raw wheat odor is removed, and a unique bulgur flavor and scent are released. The nutritional components of wheat bran are preserved by bulgur, which produces a semi-ready product that is inexpensive, quick to prepare, low in fat, high in protein, radiation resistant, more resilient than wheat in hot and humid environments, long-lasting, and a good source of folic acid. During the bulgur production process, proteins are denatured, and starch undergoes physicochemical changes including water absorption to become gelatinized. The grain's glassy, incredibly hard structure results from all of these changes, which fuse protein and starch gel (Bayram et al., 2004; Yılmaz & Koca, 2020; Yıldırım & Atasoy, 2020).

Like cracked wheat, bulgur is a highly nutritious product since it has been precooked to minimize the loss of vital water-soluble nutrients by absorbing the cook/soak water (Kadakal et al., 2007). The two most important processes in the production of bulgur are cooking and drying. One of the main factors affecting the quality of bulgur manufacturing is the drying process. Bulgur is typically sun-dried, but this can degrade the product's quality and lead to infestation (Kadakal et al., 2007). According to reports, the samples that were sun-dried and then hot-air oven-dried at 80 ^{o}C showed the biggest decreases in water-soluble vitamins. Hot air drying is frequently utilized in contemporary bulgur plants because of its enhanced capacity and advantages for sanitation (Hayta, 2001; Kahyaoglu et al., 2012). To support bulgur producers, however, more efficient drying techniques with extra advantages (shorter drying times, better product quality, etc.) need to be researched. The effects of various drying techniques (solar, sun, microwave, and tray drying) on the quality attributes of bulgur were examined in a study conducted by Hayta (2001). The lowest bulgur yield was obtained by sun drying. It was noted that the drying process had an impact on the water and oil absorption values as well as the protein extractability. It was discovered that the bulgur samples had comparable flavors, mouthfeels, and appearance. The physical characteristics of bulgur samples made with microwave-assisted spouted bed drying and spouted bed drying were compared by Kahyaoglu et al. (2010).

By ensuring that bulgur is produced in accordance with today's technology and on an industrial scale, it is necessary to obtain products with high nutritional value and superior quality. With new studies to be carried out, it is imperative to develop better quality and cheaper production methods. For this reason, in this study, it was aimed to determine the effect of different wheat varieties, drying methods and drying temperatures on bulgur quality and thus to reveal the most proper production method.

MATERIALS AND METHODS

Materials

Zenit, Svevo, Sarıçanak98, Güneyyıldızı and

Burgos durum wheat varieties were used as raw materials in this study. They were obtained from the Şanlıurfa Commodity Exchange in Türkiye. Before conducting experiments, the samples were manually cleaned to remove foreign materials and broken kernels.

Methods

Bulgur processing (Parboiling)

The precleaned wheat samples (Sarıçanak98, Zenit, Svevo, Burgos and Güneyyıldızı) were cleaned with distilled water for 1 min to remove any adhesive particles stuck to the surface of the kernels. Then, they were combined with distilled water (in at a ratio of 1:6 (weight basis) in to the volumetric flasks and cooked in boiling water (by a heater of IKA Model HP 30, Staufen, Germany)) at 98 ◦C for 45–60 min until the entire grain starch was gelatinized (Fig. 1).

Drying processing

The drying process for each wheat variety was carried out at 50, 60 and 70 °C for 8 h after parboiling process. Parboiled wheat samples were laid on each pan of dryers (1600 g/m2). Natural convective air dryer (NCAD) (Elektromag, M7040-R, Türkiye), forced convective air dryer (FCAD) (Elektromag, M7040-R, Türkiye) with air velocity of 1.2 m/s and vacuum dryer (VD) (WiseVen, WOV-70, Witeg, Germany) with the pressure of 10-750 mmHg were used for drying of parboiled wheat samples. Previously parboiled wheat samples were uniformly spread in single layer over the drying pans of dryers (Fig. 2). After drying the parboiled sample, intact bulgur was obtained. The moisture content (%, d.b.) of parboiled wheat samples after 8 h drying was figured out by lifting the drying pan and quickly weighing the sample with an electronic balance and calculated by Eq. 1 (Yıldırım, 2017).

$$M_t = \left[\frac{(M_o + 1) * W_t}{W_o} - 1\right] * 100 \qquad (1)$$

where W_o and W_t are the weights (g) of samples initially and at any drying time (t), respectively. Mo is the moisture content (%, d.b.) of samples initially and M_t is the moisture content (%, d.b.) at any drying time.

Figure 2. Illustration of drying process after parboiling of wheat samples for Bulgur production

Experimental analysis

The moisture contents of unprocessed and parboiled wheat samples were determined by the approved AACCI method no.44-15.02 (AACCI, 2010) and the results were expressed as precent dry solid (%, d.b.).

Ash contents of the samples (%, d.b.) were determined by AACC International approved method no 08-01.01 at 900 oC (AACCI, 2010).

Hectoliter weight (HLW) was obtained with a Shopper chondrometer equipped with a 250 mL cylinder and the results were expressed in kg/hL without reference to the moisture content (ISO 7971-2, 1995).

The surface color of sample kernels was measured using Ultra Scan VIS Color Quest XE HunterLab (Hunter Associates Laboratory Inc., Reston. VA. USA) after being standardized using Hunter Lab colour standards and 'L* (lightness), a*(redness to greenness) and b* (yellowness to blueness) values were measured (Yıldırım & Deger, 2021).

Thousand-kernel weight (TKW) in dry bases (d.b.) was found according to the procedure of Williams et al. (1983). The 20 g of cleaned unbroken kernels of each sample weighed. counted the kernels. and then converted to thousand kernels. The TKW (g. d.b.) of each sample for each wheat variety was calculated by Eq. 2.

$$TKW\ (g)\ (d.b.) = \frac{TKW * (100 - M)}{100} \qquad (2)$$

where, M is the moisture content (%) and TKW is the thousand-kernel weight.

The AACC International approved method was used to figure out moisture (44-15.02) and ash (08-01.01) contents of samples (AACCI, 2010).

Water absorption capacity (WAC) of samples was found by the method described by Hayta (2002). Wheat samples (10 g) were poured into 30 mL of water in the centrifugal tubes. They were kept in the water bath at 75 ^{o}C for 20 min and then centrifuged (Sigma2-16 PK. Germany) at 4000xg for 10 min. After draining the sample. water absorption capacity was calculated by the Eq.3.

$$WAC\ \left(\frac{g\ water}{g\ sample}\right) = \frac{W_2 - W_1}{W_1} \qquad (3)$$

where, W_2 is the weight (g) of wheat sample after centrifugation and W_1 is the initial weight (g) of wheat sample.

Statistical analysis

Statistical Package SPSS software (Version 22.0, SPSS Inc., Chicago, IL, USA) was used for statistical evaluation of data. Duncan multiple comparison test with ANOVA was used for comparisons at P≤0.05. All experiments were carried out in three replicates.

RESULTS AND DISCUSSION

Change in moisture content during parboiling (cooking) and drying of wheat samples

The average moisture content of unprocessed, parboiled and dried with natural convective air dryer, forced convective air dryer and vacuum dryer at 50, 60, 70 oC durum wheat varieties given in Table 1. The moisture content of unprocessed Burgos, Svevo, Güneyyıldızı, Sarıçanak98 and Zenit durum wheats were found to be 10.29, 10.07, 8.94, 9.04 and 9.34 (%, d.b.), respectively. According to the Codex Alimentarius International Food Standards CXS 178-1995, the maximum moisture content of durum wheat, semolina and wheat flour was 14.50 (%, w.b.) (CAIFS, 2019). Durum wheat with 15 and 16% moisture content can be stored for 12 weeks without any quality loss at 10 and 20 °C (Nithya et al., 2011). So, the moisture content values of 5 types of unprocessed durum wheat samples used in the present study were below these values.

Moisture contents of wheat varieties increased to higher levels during the parboiling (cooking) due to moisture absorption. The cooked wheat can be dried in industrial hot air-drying towers or in sunlight to decrease the moisture from 40–50% (w.b.) to roughly, 10–12% (w.b); nevertheless, the second approach presents clear quality concerns regarding contamination (Bayram et al., 2018). As shown in Table 1, the moisture contents of parboiled Burgos, Svevo, Güneyyıldızı, Sarıçanak98 and Zenit wheat varieties increased to 127.40, 121.07, 129.37, 123.30 and 125.07 (%, d.b.), respectively. These moisture contents are the first moisture contents of wheat samples before drying processes. Moisture contents after 8 h drying of parboiled Burgos, Svevo, Güneyyıldızı, Sarıçanak98 and Zenit wheat samples at 50 °C drying by the natural convective air dryer were found to be decreasing to 12.25, 11.62, 13.15, 11.87 and 12.12 (%, d.b.), respectively. Similarly, increasing of temperature to 60 °C decreased the final moisture contents to 11.75, 10.85, 12.32, 11.04 and 11.31 (%, d.b.). Also, drying at 70 °C temperature showed that the final moisture contents were found to be 10.28, 9.47, 11.30, 9.85 and 10.05 (%, d.b.) that were in the decreasing trend. As the drying temperatures increased the final moisture contents of all wheat samples decreased during drying with 3 dryers. As can be seen from these values, the temperature increases for the three dryers caused a decrease in the final moisture values. These decreases were found to be significant (P≤0.05) (Table 1). The change in moisture contents of all wheat samples was found to be significantly different for both temperatures and dryers (P≤0.05). The highest and lowest values of decrease in moisture contents of all wheat samples after 8 h drying at all temperatures were obtained by vacuum drying and natural convective air dryer, respectively. That means that the vacuum drying was more effective than the forced convective air and natural convective air dryers.

Table 1. Change in moisture content of durum wheat varieties during drying at different temperatures and processing

Process		Temp. (°C)	Moisture content (%. d.b.)				
			Burgos	Svevo	Güneyyıldızı	Sarıçanak98	Zenit
Unprocessed			10.29±0.03	10.07±0.04	8.94±0.02	9.04±0.01	9.34±0.05
Parboiled			127.40±0.11	121.07±0.25	129.37±0.12	123.30±0.08	125.07±0.10
Dried	NCAD	50	12.25^{bAX}±0.04	11.62^{eAX}±0.03	13.15^{aAX}±0.04	11.87^{dAX}±0.02	12.12^{cAX}±0.05
		60	11.75^{bBX}±0.01	10.85^{eBX}±0.02	12.32^{aBX}±0.03	11.04^{dBX}±0.05	11.31^{cBX}±0.04
		70	10.28^{bCX}±0.03	9.47^{eCX}±0.04	11.30^{aCX}±0.01	9.85^{dCX}±0.02	10.05^{cCX}±0.05
	FCAD	50	11.73^{bAY}±0.03	9.96^{eAY}±0.01	12.23^{aAY}±0.05	10.82^{dAY}±0.02	11.22^{cAY}±0.04
		60	10.47^{bBY}±0.02	9.14^{eBY}±0.0	10.89^{aBY}±0.03	9.93^{dBY}±0.02	10.18^{cBY}±0.03
		70	9.26^{bCY}±0.01	8.26^{eCY}±0.03	10.08^{aCY}±0.04	8.55^{dCY}±0.01	9.02^{cCY}±0.02
	VD	50	9.24^{bAZ}±0.05	8.30^{eAZ}±0.03	9.83^{aAZ}±0.02	8.85^{dAZ}±0.01	9.04^{cAZ}±0.04
		60	8.64^{bBZ}±0.01	6.84^{eBZ}±0.02	8.89^{aBZ}±0.04	7.93^{dBZ}±0.05	8.16^{cBZ}±0.03
		70	7.39^{bCZ}±0.02	6.13^{eCZ}±0.05	7.77^{aCZ}±0.04	6.83^{dCZ}±0.03	7.12^{cCZ}±0.04

NCAD: Natural convective air dryer, FCAD: Forced convective air dryer, VD: Vacuum dryer. Means followed by the different letters within the rows (a-e, wheat variety effect), the columns for each application (A-C, temperature effect) (X-Z, dryer effect) are significantly different at P ≤ 0.05. Results expressed as mean value ±SD (Standard deviation)

Ash content changes during drying

The ash level of various unprocessed durum wheat cultivars exhibits a significant difference (P≤0.05), ranging from 1.32% (d.b.) for Zenit to 1.76% (d.b.) for Svevo (Table 2). The variation in ash content may result from differences in variety, hardness, climate, location, soil characteristics and environmental factors. The analysis results of the ash for the raw material indicated a reduction in ash values after the parboiling and drying processes (Table 2). Similar ash content results of unprocessed

Durum and Einkorn wheat samples were found to be 1.81 and 2.22 % (d.b.), respectively. The ash content of several hard and soft wheat genotypes from different locales is reported to range from 1.18% to 2.32% (dry basis) (Dizlek et al., 2013). The Codex Alimentarius International Food Standards stipulate that the maximum ash level of whole durum wheat semolina should be 2.10% (d.b.) (CAIFS, 2019). The ash content observed for the durum wheat cultivars in this investigation conforms to established standards and previous research. Ash serves as a crucial chemical component for flour quality and indicates the purity of the flour. Ash content reflects the degree to which the endosperm has been fully and effectively separated from the kernel bran. The ash levels in the endosperm of durum wheat varieties surpass those of other wheat types (Morris, 2004).

The ash content of bulgur wheat was analyzed, revealing variations dependent on drying techniques (Natural convective air drying, Forced convective air drying and Vacuum drying) and temperature (50, 60 and 70 oC) differences. Özkaya et al. (1993) reported that the amount of ash in bulgur made from five different durum wheat under traditional and laboratory conditions decreased slightly while the wheat was processed into bulgur in both methods. The ash contents of the produced bulgur samples from different durum wheat varieties are shown in Table 2. The results revealed significant differences in the effects of cooking and drying methods on the ash contents of the bulgur samples. Parboiled followed by drying at different temperatures and different dryers resulted in lower ash contents in the produced bulgur compared to the raw materials (Table 2). This decrease in ash content likely occurred due to leaching of water-soluble components into the soaking and boiling water. These findings are consistent with those reported by Ukachukwu & Obioha (2000) and Obasi & Wogu (2008). Both boiled and autoclaved bulgur samples exhibited a significant decrease in ash content compared to the raw cereal grains (Marie & Gebreil, 2024). This decrease can be attributed to leaching, where water-soluble minerals are lost during the cooking process (Khan et al., 2013). Koca & Anıl (1996b) investigated the effects of different cooking methods and drying temperatures on bulgur quality and the effects of 50 °C and 70 °C drying temperatures on some physical and chemical quality properties of bulgur with traditional and two different levels of autoclave cooking methods. The ash content was found to be higher in bulgur cooked with the traditional method. Similar results of ash contents (1.04 and 1.81%) were found in the study of Ertaş (2017).

Hydration capacity change during drying

The cooking properties of parboiled durum wheat are characterized by the amount of water it takes in during the cooking process. The assessment of water absorption reflects the weight gain of the kernels after cooking and acts as an indicator of the grains' tendency to clump together and absorb broth and seasoning (Migliorini et al., 2016).

The water absorption capacities recorded for unprocessed Burgos, Svevo, Güneyyıldızı, Sarıçanak98 and Zenit wheats were 2.44, 2.42, 2.39, 2.47, and 2.31 (g water/g sample), respectively (Table 3). The hydration capacity of Sarıçanak variety was found to the highest while that of Zenit was the lowest value (Table 3).

When the results of the hydration capacity of bulgur wheat (Parboiled and dried) samples were examined, the hydration capacity of all bulgur wheat varieties increased significantly ($P \leq 0.05$) with the increase in drying temperature (from 50 °C to 60 °C and 70 °C), drying with forced convective air dryer and vacuum dryer.

Compared to the hydration capacity of the unprocessed wheat samples, the hydration capacity of parboiled plus dried wheat (intact bulgur) samples were found to be higher. The highest hydration capacity in bulgur wheat is in the drying performed in a vacuum dryer (50 °C; 4.28, 60 °C;

4.47, 70 ^{o}C; 4.83 g water/g sample) has been found in the Güneyyıldızı wheat variety. The effect of vacuum drying on the hydration capacities was the highest with vacuum drying and lowest with natural convective air drying of wheat samples (Table 3). As illustrated in Table 3, the hydration capacity of unprocessed and dried by different dryers after parboiling process of different durum wheat samples at different drying temperatures exhibited a significant variation ($P \leq 0.05$). This variation may be attributed to factors such as the size, hardness, variety, drying temperature and dryer type used in drying of the wheat samples. The hydration capacities of bulgur, a product derived from durum wheat, were observed to vary between 1.96 and 2.39 (g water/g bulgur) under different drying conditions (dryer type, 50, 70, 90 ^{o}C) (Kahyaoglu et al., 2010). Hayta (2002) also discovered that the hydration capacity of pilaf bulgur, which is produced from durum wheat, varied under different drying conditions, ranging from 2.33 to 2.56 g water/g bulgur.

Table 2. Change in ash content of durum wheat varieties during drying at different temperatures and processing

Process		Temp. (^{o}C)	Ash content (%, d.b.)				
			Wheat varieties				
			Burgos	**Svevo**	**Güneyyıldızı**	**Sarıçanak98**	**Zenit**
Unprocessed			1.60^{c}±0.03	1.76^{a}±0.02	1.49^{d}±0.04	1.73^{b}±0.01	1.32^{e}±0.08
Dried	**NCAD**	**50**	1.10^{dCY}±0.01	1.04^{eCY}±0.01	1.47^{aAX}±0.03	1.14^{cBZ}±0.01	1.25^{bCZ}±0.01
		60	1.32^{eBX}±0.02	1.36^{dBY}±0.02	1.40^{cBY}±0.01	1.47^{aAX}±0.01	1.43^{bBX}±0.02
		70	1.38^{cAX}±0.01	1.50^{bAX}±0.03	1.21^{dCY}±0.01	1.10^{eCY}±0.00	1.58^{aAX}±0.01
	FCAD	**50**	1.06^{eCZ}±0.01	1.43^{bAX}±0.03	1.28^{cBY}±0.00	1.17^{dCY}±0.01	1.64^{aAX}±0.02
		60	1.14^{eBY}±0.01	1.34^{aCY}±0.02	1.25^{cCZ}±0.01	1.23^{dBZ}±0.01	1.27^{bCY}±0.01
		70	1.23^{eAY}±0.02	1.39^{aBY}±0.02	1.33^{cAX}±0.01	1.27^{dAX}±0.00	1.36^{bBY}±0.02
	VD	**50**	1.40^{cAX}±0.02	1.44^{bBX}±0.02	1.25^{eBZ}±0.00	1.38^{dAX}±0.01	1.53^{aAY}±0.03
		60	1.11^{eCZ}±0.01	1.56^{aAX}±0.02	1.43^{bAX}±0.01	1.34^{cBY}±0.01	1.28^{dBY}±0.02
		70	1.17^{bBZ}±0.01	1.13^{cCZ}±0.01	1.07^{dCZ}±0.01	1.02^{eCZ}±0.00	1.21^{aCZ}±0.01

NCAD: Natural convective air dryer, FCAD: Forced convective air dryer, VD: Vacuum dryer. Means followed by the different letters within the rows (a-e, wheat variety effect), the columns for each application (A-C, temperature effect) (X-Z, dryer effect) are significantly different at $P \leq 0.05$. Results expressed as mean value ±SD

Table 3. Change in hydration capacity values of durum wheat varieties during drying at different temperatures and processing

Process		Temp. (^{o}C)	Hydration capacity (HC) (g water/g sample)				
			Wheat varieties				
			Burgos	**Svevo**	**Güneyyıldızı**	**Sarıçanak98**	**Zenit**
Unprocessed			2.44^{b}±0.02	2.42^{c}±0.01	2.39^{d}±0.01	2.47^{a}±0.02	2.31^{e}±0.01
Dried	**NCAD**	**50**	3.90^{eCZ}±0.01	4.03^{dCZ}±0.02	4.08^{cCZ}±0.01	4.12^{bCZ}±0.02	4.33^{aCZ}±0.03
		60	3.95^{eBZ}±0.02	4.17^{bBZ}±0.01	4.23^{aBZ}±0.03	4.25^{cBZ}±0.03	4.45^{dBZ}±0.02
		70	4.13^{eAZ}±0.04	4.42^{cAZ}±0.03	4.56^{aAZ}±0.02	4.48^{bAZ}±0.01	4.51^{dAZ}±0.02
	FCAD	**50**	4.06^{dCY}±0.01	4.12^{eCY}±0.02	4.22^{aCY}±0.02	4.28^{bCY}±0.01	4.41^{cY}±0.01
		60	4.15^{eBY}±0.03	4.26^{cBY}±0.03	4.54^{aBY}±0.03	4.44^{bBY}±0.02	4.49^{dBY}±0.02
		70	4.21^{eAY}±0.02	4.46^{cAY}±0.03	4.62^{aAY}±0.01	4.53^{bAY}±0.01	4.61^{dAY}±0.01
	VD	**50**	4.11^{bCX}±0.01	4.24^{eCX}±0.02	4.29^{aCX}±0.03	4.45^{dCX}±0.02	4.47^{cCX}±0.02
		60	4.23^{eBX}±0.01	4.35^{cBX}±0.01	4.67^{aBX}±0.04	4.58^{dBX}±0.01	4.54^{bBX}±0.02
		70	4.74^{bAX}±0.02	4.55^{eAX}±0.01	4.83^{aAX}±0.02	4.65^{dAX}±0.03	4.70^{cAX}±0.01

NCAD: Natural convective air dryer, FCAD: Forced convective air dryer, VD: Vacuum dryer, HC: Hydration capacity, Means followed by the different letters within the rows (a-e, wheat variety effect), the columns for each application (A-C, temperature effect) (X-Z, dryer effect) are significantly different at $P \leq 0.05$. Results expressed as mean value ±S

Damaged starch granules show an enhanced hydration capacity and an increased susceptibility to degradation by amylolytic enzymes when compared to their undamaged equivalents. Naturally, granular products derived from hard wheat possess a higher percentage of damaged granules than those obtained from soft wheat. Damaged starch is capable of rapidly absorbing water and expanding, showcasing a significant hydration capacity (Khan & Shewry, 2009). The hydration capacity of durum wheat and its flours play a crucial role in various processes related to bulgur, couscous, pasta, and noodles, which encompass dough formation, cooking, shaping, and drying. It was noted that the water absorption capacities of spouted bed dried wheat samples at lower air temperatures were significantly higher than those of microwave-assisted spouted bed dried samples. Additionally, dried parboiled wheat subjected to microwave-assisted spouted bed drying retained some hull portions attached to the cracked wheat following the dehulling process. This may result in a considerably lower water absorption capacity in microwave-assisted spouted bed drying in comparison to spouted bed drying (Kahyaoglu et al., 2010).

Hectoliter weight change during drying

One of the factors that affects the quality classification of wheat is the hectoliter weight; a greater weight is associated with a larger quantity of dry matter and, as a result, a higher flour yield (Manley et al., 2009) and bulgur yield. This weight is influenced by various factors including grain size, shape, hardness or softness, and density. Hectoliter weight may vary due to genetic makeup, environmental conditions, and farming practices (Protic et al., 2007).

The ANOVA results of the hectoliter weight analysis of 5 types of unprocessed, cooked and dried durum wheat samples at different dryers and temperatures used in the study are given in Table 4.

The hectoliter weights of unprocessed durum wheat samples were found to be statistically different ($P \leq 0.05$) in all wheat varieties. When unprocessed durum wheat varieties were compared in terms of hectoliter weight, the highest hectoliter weight was found for Zenit (86 kg/hL) variety and the least one was found for Svevo variety (81.75 kg/hL). The hectoliter weight of Zenit (86 kg/hL) was found to be significantly ($P \leq 0.05$) greater than that of the other four wheat varieties. Following Sarıçanak98, Burgos, Güneyyıldızı, and Svevo recorded a hectoliter weight of 84.05 kg/hL, 83.30 kg/hL, 83.10 kg/hL, and 81.75 kg/hL, respectively. The hectoliter values obtained in this study align with the findings of previous research conducted by Szumilo et al. (2010), Kılıç et al. (2012), Migliorini et al. (2016), and Öztürk et al. (2017). Given these results, it can be inferred that all the wheat varieties, characterized by their relatively high hectoliter weights, possess the potential to yield good semolina, bulgur, and couscous during milling. Furthermore, the hectoliter weights of durum wheat surpass those of other wheat varieties, as noted by Morris (2004). Wheat cultivars with a hectoliter weight of more than 82 kg/hL are classified as very good cultivar (Diepenbrock et al., 2005). Accordingly, except for the Svevo variety, other varieties were found to be above this value. According to Turkish wheat standards, wheat varieties with a hectoliter weight of more than 79 kg/hL are classified as the first-class wheats (Anonymous, 2001). In terms of hectoliter weight, all 5 wheat varieties exhibited good values according to Turkish wheat standards. When the hectoliter weight analysis of bulgur wheat samples was examined, a decrease in hectoliter weight values was observed in each of the 5 durum wheat cultivars with the increase in drying temperature and with the dryer types used (Table 4). This decrease in hectoliter weight values was due to the temperatures applied in drying, temperature differences and drying methods. When the hectoliter weights of samples were compared according to the drying methods used, the highest decrease in hectoliter weight value was observed in vacuum drying and the least decrease in hectoliters was found during drying with natural convective air dryer. While the hectoliter weight was observed in the Zenit variety with the highest value of 77.75 kg/hL in drying at 50 ^oC with forced convective air dryer, the highest decrease with the temperature increase was found in the Svevo, Güneyyıldızı and Burgos varieties, while the lowest value was observed in the Sarıçanak98 variety. The highest decrease in hectoliter weight in drying at 50 ^oC with a vacuum dryer was observed in the Burgos variety with a value of 62.28 kg/hL, while the highest decrease with the temperature increase was observed in the Burgos and Zenit varieties. On the other hand, when drying at 50 ^oC with a natural convective air dryer, the highest hectoliter weight value was observed for Burgos variety, also the highest decrease in hectoliter weight was observed for Burgos variety with the temperature increase. Similar results were reported by Koca & Anıl (1996b) in which it was determined that the hectoliter weight of unprocessed wheat was higher than the bulgur dried at 50 ^oC.

Table 4. Change in hectoliter weights of durum wheat varieties during drying at different temperatures and processing

Process		Temp. (^oC)	Hectoliter weight (HLW) (kg/hL)				
			Wheat varieties				
			Burgos	Svevo	Güneyyıldızı	Sarıçanak98	Zenit
Unprocessed			83.30^c±0.03	81.75^e±0.04	83.10^d±0.01	84.05^b±0.02	86.00^a±0.01
Dried	NCAD	50	70.09 ^{eAY}±0.01	73.57^{bAX}±0.02	72.91^{dAY}±0.01	73.08^{cAX}±0.01	73.90^{aAY}±0.03
		60	69.61^{eBX}±0.02	73.19^{bBY}±0.01	72.86^{dBX}±0.02	73.01^{cBX}±0.01	73.27^{aBY}±0.01
		70	65.78^{eCX}±0.03	70.85^{bCY}±0.02	70.42^{dCX}±0.01	70.67^{cCX}±0.02	70.93^{aCX}±0.01
	FCAD	50	70.19^{eAX}±0.01	72.52^{cBY}±0.02	74.91^{bAX}±0.02	71.64^{dAY}±0.03	77.75^{aAX}±0.02
		60	66.96^{dBY}±0.02	73.67^{bAX}±0.03	69.63^{cBY}±0.01	63.69^{eBY}±0.02	75.56^{aBX}±0.01
		70	64.50^{dCY}±0.03	71.80^{aCX}±0.01	66.43^{cCY}±0.02	63.14^{eCY}±0.01	69.77^{bCY}±0.02
	VD	50	62.28^{eAZ}±0.02	68.28^{aAZ}±0.01	67.33^{cAZ}±0.03	67.69^{bAZ}±0.02	65.74^{dAZ}±0.01
		60	56.09^{eBZ}±0.01	60.09^{bBZ}±0.01	60.51^{aBZ}±0.02	59.39^{cBZ}±0.01	57.86^{dBZ}±0.02
		70	54.76^{eCZ}±0.01	57.81^{bCZ}±0.02	58.71^{aCZ}±0.03	56.11^{cCZ}±0.02	55.54^{dCZ}±0.03

NCAD: Natural convective air dryer, FCAD: Forced convective air dryer, VD: Vacuum dryer, HLW: Hectoliter weight, Means followed by the different letters within the rows (a-e, wheat variety effect), the columns for each application (A-C, temperature effect) (X-Z, dryer effect) are significantly different at $P \leq 0.05$. Results expressed as mean value ±SD

Change in thousand kernel weight (TKW) during drying

The thousand kernel weight of durum wheat is crucial for understanding grain weight, fullness, slenderness, kernel size, grain yield, as well as the production of bulgur, couscous, and pasta. The fact that the grain is larger and harder in durum wheat was important in the thousand grain weight analysis results. The weight of a thousand grains fluctuates based on the growing conditions, climate, species, and varieties. For similar types, such as bread or durum wheat, the weight of a thousand grains is typically inversely related to the protein content, alongside the starch content. Hard wheat generally exhibits a higher thousand grain weight compared to soft wheat (Ünal, 2003).

Thousand kernel weights of unprocessed and parboiled then dried at different temperatures (50, 60 and 70 ^oC) in different dryers (natural convective air, forced convective air and vacuum dryers) were given in Table 5. In this research, the TKW values of unprocessed wheat samples showed a notable difference ($P \leq 0.05$) among various durum wheat varieties, with values ranging from 47.16 g (Güneyyıldızı) to 53.69 g (Burgos). Burgos variety yielded a high thousand-kernel weight value. Thousand kernel weight was found as highest in Burgos wheat while was lowest that of Güneyyıldızı wheat variety. Thousand kernel weights of durum wheat verities are higher than other wheat varieties (Morris, 2004). The variations noted in TKW among different unprocessed wheat varieties and genotypes may stem from the genetic composition of these varieties. The findings align with previous research conducted by Szumilo et al. (2010), Sayaslan et al. (2012), and Öztürk et al. (2017), who documented the TKW ranges of 25.90-51.40 g, 28.90-40.80 g, 42.30-56.20 g, and 31.40-47.10 g, respectively, across various unprocessed wheat varieties. The TKW values for durum wheat varieties are typically greater than those of other wheat varieties such as bread and soft wheat samples (Sissons, 2004).

When the thousand grain weight analysis results of bulgur wheat during drying were examined, a decrease in TKW of samples was observed in each of the 5 types of wheat samples with the increase in drying temperature. According to the drying methods used, the highest decrease in TKW was observed in the vacuum-dried durum wheat samples and the least decrease was observed in the natural convective air-dried ones. The effect of vacuum drying on the TKW was the highest and the effect of natural convective air drying was the least once. The TKW results of the raw material and the results of bulgur wheat after drying were found to be lower in all varieties and dryers. The difference in drying temperatures and drying methods was effective in this decrease in TKW analysis values

Table 5. Change in thousand-kernel weights of durum wheat varieties during drying at different temperatures and processing

Process		Temp. (°C)	Thousand-kernel weight (TKW) (g) – Wheat varieties: Burgos	Svevo	Güneyyıldızı	Sarıçanak98	Zenit
Unprocessed			$53.69^{a}\pm0.02$	$48.01^{c}\pm0.03$	$47.16^{e}\pm0.01$	$47.25^{d}\pm0.03$	$48.21^{b}\pm0.02$
Dried	NCAD	50	$53.53^{bAX}\pm0.03$	$47.81^{aAX}\pm0.04$	$45.63^{dAX}\pm0.02$	$46.77^{cAX}\pm0.02$	$43.56^{eAX}\pm0.01$
		60	$49.02^{bBX}\pm0.02$	$47.71^{aBX}\pm0.03$	$45.19^{dBX}\pm0.01$	$45.66^{cBX}\pm0.01$	$42.43^{eBX}\pm0.02$
		70	$48.62^{bCX}\pm0.03$	$47.59^{aCX}\pm0.02$	$44.79^{cCX}\pm0.02$	$44.20^{eCX}\pm0.02$	$42.21^{dCX}\pm0.01$
	FCAD	50	$53.23^{aAY}\pm0.04$	$46.88^{bAY}\pm0.02$	$44.55^{eAY}\pm0.02$	$46.27^{dAY}\pm0.03$	$42.86^{cAY}\pm0.02$
		60	$48.28^{cBY}\pm0.03$	$46.57^{aBY}\pm0.02$	$43.78^{eBY}\pm0.04$	$45.09^{dBY}\pm0.02$	$41.37^{bBY}\pm0.01$
		70	$46.93^{bCY}\pm0.01$	$45.89^{aCY}\pm0.03$	$42.27^{dCY}\pm0.02$	$44.76^{cCY}\pm0.03$	$40.89^{eCY}\pm0.02$
	VD	50	$49.70^{cAZ}\pm0.02$	$45.74^{aAZ}\pm0.01$	$43.33^{dAZ}\pm0.04$	$44.37^{bAZ}\pm0.02$	$41.17^{eAZ}\pm0.03$
		60	$48.10^{bBZ}\pm0.01$	$44.18^{aBZ}\pm0.02$	$41.61^{dBZ}\pm0.03$	$43.25^{cBZ}\pm0.02$	$40.14^{eBZ}\pm0.04$
		70	$46.82^{bCZ}\pm0.02$	$43.64^{aCZ}\pm0.01$	$40.56^{dCZ}\pm0.03$	$40.96^{cCZ}\pm0.04$	$37.58^{eCZ}\pm0.05$

NCAD: Natural convective air dryer, FCAD: Forced convective air dryer, VD: Vacuum dryer, TKW: Thousand-kernel weight. Means followed by the different letters within the rows (a-e, wheat variety effect), the columns for each application (A-C, temperature effect) (X-Z, dryer effect) are significantly different at $P \leq 0.05$. Results expressed as mean value ±SD

Color values (L, a* and b*) change during drying*

Wheat grains are generally white, light yellow, yellow-red, amber and brown in color. The color of wheat is very important for wheat products. The yellowish color of durum wheat, bulgur and semolina flour made from it is due to a carotenoid pigment called lutein, which can be oxidized to a colorless form by enzymes present in the grain. The most important carotenoids found in wheat are lutein and lutein-fatty acid esters from xanthophyl and ß-carotene from carotene. It has been reported that the color changes in bulgur resulted from a Maillard reaction between reducing sugars and amino acids as well as the destruction of naturally existing pigments (Marie & Gebreil, 2024). Color is accepted as an important quality criterion in durum wheats. In bulgur, which is desired to be bright yellow (high in b*) in color, the color in question is basically caused or affected by three factors (L*, a* and b*).

The color values (L*, a* and b*) of unprocessed, parboiled and dried (at different temperatures and by different dryers) durum wheat varieties were shown in Table 6 and significant differences (P≤0.05) was obtained between wheat varieties for all processing and drying temperatures. When the color values of the wheat samples used as raw material in bulgur production were examined, the highest L* (brightness) was found in Güneyyıldızı variety with 51.50 value and the lowest value was found in Svevo variety with 49.66 value. The highest a* (redness) value was found in the Burgos variety (8.64) and the lowest was found in the Zenit variety (7.99). The b* (yellowness) value that one of the most important quality characteristics for pasta, bulgur and other wheat products was found to be the highest in the Sarıçanak variety (22.12) and the lowest was found in the Zenit variety (20.77).

The L*, a* and b* values of parboiled Burgos, Svevo, Güneyyıldızı, Sarıçanak98 and Zenit wheat samples before drying process are given Table 6. There are significant differences between parboiled wheat varieties in terms of L*, a* and b* values. The L* and b* values of all wheat varieties increased after parboiling process while the a* value decreased. The increase in L* and b* values and the decrease in a* value during parboiling is important criterion for the bulgur quality which occurs because of the gelatinization of the starch in wheat during cooking.

According to the color analysis results of bulgur wheat, when the effect of wheat varieties, drying methods and temperature on color values was examined, a decrease was observed in L* and a* values and an increase in b* values with the increase in drying temperature.

When compared according to the color analysis values of the raw material, a decrease in L* and a* values and an increase in b* value was observed in the color results of bulgur wheat after drying. This change in color values after drying shows the effect of drying on color values of bulgur samples. With drying, the moisture content decreases, and as a result, darkening of the color occurs.

Table 6. Change in color (L*, a* and b*) values of durum wheat varieties during drying at different temperatures and processing

Process		Temp. (ºC)	Color	Wheat varieties				
				Burgos	Svevo	Güneyyıldızı	Sarıçanak98	Zenit
Unprocessed			L*	50.89^{b} ±0.02	49.66^{e} ±0.02	51.50^{a} ±0.03	50.55^{c} ±0.01	49.72^{d} ±0.01
			a*	8.64^{a} ±0.03	8.30^{c} ±0.01	8.36^{b} ±0.02	8.29^{c} ±0.03	7.99^{d} ±0.05
			b*	21.67^{b} ±0.01	20.87^{d} ±0.02	20.96^{c} ±0.01	22.12^{a} ±0.02	20.77^{e} ±0.03
Parboiled (Cooked)			L*	51.33^{d} ±0.01	51.53^{b} ±0.03	52.75^{a} ±0.01	51.10^{a} ±0.02	51.45^{c} ±0.01
			a*	6.94^{b} ±0.02	6.60^{d} ±0.01	7.26^{a} ±0.02	6.70^{c} ±0.03	7.25^{a} ±0.01
			b*	24.90^{d} ±0.02	24.82^{e} ±0.01	27.75^{a} ±0.02	25.10^{c} ±0.03	25.90^{b} ±0.04
Dried	NCAD	50	L*	47.25^{aCZ} ±0.02	46.59^{dCZ} ±0.03	47.18^{bCZ} ±0.01	44.13^{eCZ} ±0.02	46.95^{cCZ} ±0.01
			a*	8.20^{dAZ} ±0.01	8.24^{cCZ} ±0.02	9.38^{aAX} ±0.03	8.10^{eAY} ±0.03	8.51^{bAY} ±0.01
			b*	23.22^{dCZ} ±0.01	24.13^{aCZ} ±0.02	24.07^{bCZ} ±0.04	20.10^{eCZ} ±0.03	23.30^{cCZ} ±0.02
		60	L*	46.15^{aBZ} ±0.02	47.35^{bBZ} ±0.02	47.28^{cBY} ±0.01	44.84^{eBZ} ±0.02	47.01^{dBZ} ±0.03
			a*	8.17^{dBZ}	8.23^{cBZ}	9.36^{aBY}	8.06^{eBZ}	8.36^{bBY}

			±0.03	±0.01	±0.02	±0.01	±0.02
		b*	23.41^{dBZ} ±0.02	24.57^{aBZ} ±0.02	24.35^{bBY} ±0.01	21.33^{eBZ} ±0.02	23.47^{cBZ} ±0.01
	70	L*	45.75^{bAZ} ±0.02	48.87^{aAY} ±0.03	47.37^{dAZ} ±0.02	46.55^{eAZ} ±0.02	47.95^{cAZ} ±0.02
		a*	7.86^{eCY} ±0.01	8.37^{bAY} ±0.02	8.57^{aCZ} ±0.01	8.03^{dCY} ±0.03	8.14^{cCY} ±0.01
		b*	23.65^{dAZ} ±0.02	25.26^{aAY} ±0.03	24.60^{bAZ} ±0.02	22.73^{eAY} ±0.04	24.10^{cAX} ±0.03
FCAD	50	L*	47.73^{bCY} ±0.02	48.46^{aAY} ±0.04	47.53^{cBY} ±0.05	46.32^{eCY} ±0.01	47.43^{dCY} ±0.01
		a*	8.52^{cAX} ±0.01	8.43^{dAY} ±0.01	8.80^{aAY} ±0.03	7.92^{eBZ} ±0.04	8.64^{bAX} ±0.03
		b*	25.47^{aAY} ±0.04	25.42^{bAY} ±0.02	24.71^{cBX} ±0.02	23.63^{eBY} ±0.03	24.35^{dBY} ±0.05
	60	L*	49.47^{aBY} ±0.03	48.14^{cBY} ±0.03	46.79^{dCZ} ±0.02	46.73^{eBY} ±0.02	48.48^{bAY} ±0.02
		a*	8.28^{cBY} ±0.01	8.32^{bBX} ±0.01	8.37^{aCZ} ±0.03	8.16^{dAY} ±0.02	8.27^{cBZ} ±0.03
		b*	24.35^{cBY} ±0.02	25.01^{aCY} ±0.03	23.52^{eCZ} ±0.04	24.14^{dAY} ±0.03	24.50^{bAY} ±0.02
	70	L*	49.86^{aAY} ±0.01	47.96^{cCZ} ±0.02	47.58^{dAY} ±0.03	46.95^{eAY} ±0.05	48.15^{bBY} ±0.02
		a*	7.84^{cCZ} ±0.00	7.69^{dCZ} ±0.02	8.59^{aBY} ±0.01	7.54^{eCZ} ±0.02	8.01^{bCZ} ±0.05
		b*	24.36^{cBY} ±0.01	25.09^{aBZ} ±0.01	24.87^{bAY} ±0.04	22.38^{eCZ} ±0.02	23.88^{dCZ} ±0.06
VD	50	L*	51.24^{aCX} ±0.03	50.58^{bCX} ±0.03	49.76^{eCX} ±0.01	50.18^{cCX} ±0.02	49.99^{dCX} ±0.02
		a*	8.38^{eCY} ±0.02	8.50^{bBX} ±0.01	8.69^{aCZ} ±0.02	8.43^{cCX} ±0.01	8.41^{dCZ} ±0.01
		b*	25.54^{bCX} ±0.01	26.79^{aCX} ±0.02	24.52^{eCY} ±0.03	25.35^{cCZ} ±0.03	25.28^{dCX} ±0.02
	60	L*	54.51^{aAX} ±0.02	54.38^{bAX} ±0.02	54.09^{cAX} ±0.04	53.79^{dAX} ±0.02	52.88^{eBX} ±0.03
		a*	9.01^{bAX} ±0.03	8.27^{eCY} ±0.01	9.53^{aAX} ±0.02	8.73^{dBX} ±0.04	8.85^{cBX} ±0.02
		b*	28.85^{bAX} ±0.02	28.11^{dBX} ±0.02	29.66^{aAX} ±0.03	27.97^{eBX} ±0.01	28.54^{cAX} ±0.01
	70	L*	52.21^{eBX} ±0.01	53.56^{bBX} ±0.03	53.94^{aBX} ±0.02	53.35^{dBX} ±0.03	53.43^{cAX} ±0.02
		a*	8.72^{cBX} ±0.03	8.57^{dAX} ±0.02	9.32^{aBX} ±0.04	9.03^{bAX} ±0.01	9.00^{bcAX} ±0.01
		b*	27.24^{eBX} ±0.02	28.19^{bAX} ±0.01	28.49^{aBX} ±0.02	28.00^{dAX} ±0.01	28.11^{cBX} ±0.03

NCAD: Natural convective air dryer, FCAD: Forced convective air dryer, VD: Vacuum dryer. Means followed by the different letters within the rows (a-e, wheat variety effect), the columns for each application (A-C, temperature effect) (X-Z, dryer effect) are significantly different at $P \leq 0.05$. Results expressed as mean value ±SD (Standard deviation)

In the drying performed at 50 °C, the lowest L* value was found in the Sarıçanak98 variety with a value of 44.13 and the b* value was found in the Sarıçanak98 variety with a value of 20.10 in the natural convective air dryer. In the drying performed at 60 °C and 70 °C, the L* value was found to be the lowest by drying in the natural convective air dryer. The highest L* and b* values were found in vacuum drying at 70 °C. According to these values, the color of bulgur wheat was obtained darker in natural convective air drying and lighter color in vacuum drying. Similar results of color values were reported by Marie & Gebreil (2024) for cooked and dried bulgur samples produces from different cereals and Ertaş (2017) for comparison of industrial and homemade bulgur in Türkiye. Browning reactions can be responsible for color change in dried parboiled wheat. In general, browning reactions largely depend on moisture content, drying temperature and time. Thus, drying at higher temperatures promoted the formation of browning pigments. As a result of this, dried parboiled wheat became darker in color as temperature increased. Furthermore, β-carotenoid is the main pigment in durum wheat which is responsible for the yellow color. High temperature also enhances the pigment degradation. Reduction in b* value (yellowness) of dried parboiled wheat can be explained by increased β -carotenoid degradation due to high air temperature drying

CONCLUSION

In this study, parboiled five different durum wheat varieties (Svevo, Sarıçanak98, Zenit, Güneyyıldızı and Burgos) were dried by natural convective air, forced convective air and vacuum drying processes at drying temperatures of 50, 60 and 70 °C. Effect of dryer and drying temperature on moisture content, ash content, thousand kernel weight, hectoliter weight, hydration capacity, and color parameters L*, a*, and b* were researched. According to the results of the study, significant differences (P≤0.05) were observed among the unprocessed wheat varieties regarding moisture content, ash content, thousand kernel weight, hectoliter weight, hydration capacity, and color parameters L*, a*, and b*. The research findings indicated that all quality characteristics examined exhibited statistically significant (P≤0.05) differences among the wheat varieties, drying temperature and dryer type used. Furthermore, the temperature and drying methods employed resulted in notable variations in the drying rate of bulgur wheat samples. The desired reductions in moisture content, ash content, hectoliter weight, and thousand-kernel weight were achieved more rapidly through vacuum drying, followed by forced and natural convective air-drying methods. The color of bulgur wheat was obtained darker in natural convective air drying and lighter color in vacuum drying system. The use of vacuum drying methods in bulgur can be considered as a more effective drying method in terms of preserving the quality parameters of bulgur and will be important for the bulgur industry.

REFERENCES

AACC International. (2010). AACC International approved methods of analysis (11th ed.). St Paul, MN: AACC International. [Online] Retrieved from http://methods.aaccnet.org/

Anonymous. (2001). Turkish standards. Wheat standard. TS standard no: 2974.

Bayram, M., Bay Yilmaz, B. & Türker, N. (2018). Some critical deteriorations during the bulgur production. International GAP Agriculture & Livestock Congress, 954–957.

Bayram, M., Kaya, A., & Öner, M. D. (2004). Changes in properties of soaking water during production of soy-bulgur. Journal of Food Engineering, 61(2), 221-230.

CAIFS. (2019). Codex Alimentarius International Food Standards CXS 178-1995. Standard for durum wheat semolina and durum wheat flour.

Diepenbrock, W., Ellmer, F., Leon, J. (2005). Ackerbau, Pflanzenbau und Pfl anzenzüchtung. Stuttgart, Germany: Verlag Eugen Ulmer, Stuttgart.

Dizlek, H., Özer, M. & Gül, H. (2013). Farklı kükürt dozlarının ekmeklik ve makarnalık buğdayların nitelikleri üzerine etkileri. Journal of Food and Feed Science-Technology, 13, 19-30.

Elias, E. M. (1995). Durum wheat products. Durum wheat improvement in the mediterranean region: New challenges, Serie A: Séminaires Méditerranéennes, 40, 23-31.

Ertaş, N. (2017). A comparision of industrial and homemade bulgur in Turkey in terms of physical, chemical and nutritional properties. Chemical Industry and Chemical Engineering Quarterly, 23(3), 341-348.

Evlice, A. K. & Özkaya, H. (2019). Effects of wheat cultivar, cooking method, and bulgur type on the yield and color properties of bulgur. Quality Assurance and Safety of Crops & Foods, 11(4), 381-390.

Hayta, M. (2001). Bulgur quality as affected by drying methods. Food Engineering and Physical Properties, 67 (6), 2241-2244.

Hayta, M. (2002). Bulgur quality as affected by drying methods. Journal of Food Science, 67, 2241–2244.

ISO 7971-2. (1995). Cereals-Determination of Bulk Density, Called "mass per hectolitre"– Part 2: Routine Method. International Organization for Standardization. Geneva, Switzerland.

Kadakal, Ç., Ekinci, R., & Yapar, A. (2007). The effect of cooking and drying on the water-soluble vitamins content of bulgur. Food Science and Technology International, 13(5), 349-354.

Kahyaoglu, L. N., Sahin, S., & Sumnu, G. (2012). Spouted bed and microwave-assisted spouted bed drying of parboiled wheat. Food and bioproducts processing, 90(2), 301-308.

Kahyaoglu, L.N., Sahin, S. and Sumnu, G. (2010). Physical properties of parboiled wheat and bulgur produced using spouted bed and microwave assisted spouted bed drying. Journal of Food Engineering, 98, 159-169.

Khan, I., Yousif, A., Johnson, S.K. and Gamlath, S. (2013). Effect of sorghum flour addition on resistant starch content, phenolic profile and antioxidant capacity of durum wheat pasta. Food Research International, 54(1), 578–586.

Khan, K. & Shewry, P.R. (2009). Wheat chemistry and technology. AACC International, Inc. St. Paul, Minnesota, U.S.A. Fourth Edition. pp.88-112.

Kılıç, H., Aktas, H., Kendal, E. & Tekdal, S. (2012). İleri Kademe Ekmeklik Buğday (Triticum aestivum L.) Genotiplerinin Biplot Analiz Yöntemi ile Değerlendirilmesi. Türk Doğa ve Fen Dergisi, 1(2), 132-139.

Koca, A.F., & Anıl, M. (1996b). Farklı pişirme yontemleri ve kurutma sıcaklıklarının bulgur kalitesine etkileri. Ondokuz Mayıs Univ. Ziraat Fakültesi Dergisi, 11, 163e172.

Manley, M.G., Engelbrecht, M.L., Williams, P.C. & Kidd, M. (2009). Assessment of variance in the measurement of hectoliter mass of wheat, using equipment from different grain producing and exporting countries. Biosystems Engineering, 103(2), 176-186.

Marie, A. M., & Gebreil, S. (2024). Influence of Cooking and Drying Methods on Quality Characteristics of Different Cereals Bulgur. Food Technology Research Journal, 4(2), 107-122.

Migliorini, P., Spagnolo, S., Torri, L., Arnoulet, M., Lazzerinic, G. and Ceccarelli, S. (2016). Agronomic and quality characteristics of old, modern and mixture wheat varieties and landraces for organic bread chain in diverse environments of northern Italy. European Journal Agronomy, 79, 131-141.

Miskelly, D. (2017). Optimisation of end-product quality for the consumer. In Cereal grains (pp. 653-688). Woodhead Publishing.

Morris, S.R. (2004). Grain: Quality attributes. Encyclopedia of Grain Science, Eds: Wrigley, C. et al., Elsevier Ltd., Amsterdam, 238-254.

Nithya, U., Chelladurai, V., Jayas, D. S., & White, N. D. G. (2011). Safe storage guidelines for durum wheat. Journal of Stored Products Research, 47(4), 328-333.

Obasi, N.E., & Wogu, C.O. (2008). Effect of soaking time on the proximate and mineral compositions and antinutritional factors of yellow maize (Zea mays). Nigerian Food Journal, 26(2), 69-77.DOI:10.4314/nifoj.v26i2.47439

Özkaya, B., Köksel, H., & Özkaya, H. (1993). Bazı buğday çeşitlerinden farklı yöntemlerle üretilen bulgurların bazı vitamin ve mineral içerikleri ile proteinlerinin elektroporetik ve nişastalarının "birefringence" özellikleri üzerine araştırmalar. Tarla Bitkileri Merkez Araştırma Enstitüsü Dergisi, 2(4), 36-56.

Öztürk, İ., Kahraman, T., Avcı, R., Girgin, V.Ç., Çiftçigil, T.H., Tülek, A. & Tuna, B. (2017). Makarnalık Buğday (Triticum durum L.) Genotiplerinin Agronomik Karakterler ve Kalite Parametreleri Yönünden

Değerlendirilmesi. Journal of Bahri Dağdaş Crop Research, 6(2), 33-43.

Protic, R., Miric, M., Protic, N., Jovanovic, Z. & Jovin, P. (2007). The test weight of several winter wheat genotypes under various sowing dates and nitrogen fertilizer rates. Romanian Agricultural Research, 24, 43-36.

Sayaslan, A., Koyuncu, M., Yıldırım, A., Eserkaya-Guleç, A., Ateş-Sonmezoğlu, E., & Kandemir, N. (2012). Some quality characteristics of selected durum wheat (Triticum durum) landraces. Turkish Journal of Agriculture and Forestry, 36, 749-756.

Szumilo, G., Rachon, L. & Stankowski, S. (2010). The evaluation of grain and flour quality of spring durum wheat (Triticum durum Desf.). Polish Journal of Agronomy, 2, 78–82.

Sissons, M. (2004). Pasta. Encyclopedia of Grain Science, Elsevier Ltd., Amsterdam, 410-418.

Ukachukwu, S.N. & Obioha, F.C. (2000). Effect of time duration of thermal treatments on the nutritive value of Mucuna cochinchinensis. Global Journal of Pure and Applied Sciences, 6(1), 11-15.

Ünal, S. (2003). Buğday ve un kalitesinin belirlenmesinde uygulanan yöntemler. Nevşehir ekonomisinin sorunları ve çözüm önerileri: Un Sanayi Örneği, Nevşehir Ekonomi Sempozyumu 1, 27-28 Haziran, 15-29.

Williams, P. C., Nakoul, H. & Singh, K. B. (1983). Relationship between cooking time and some physical characteristics in chickpeas (Cicer Arietinum L.). Journal of the Science of Food and Agriculture, 34(5), 492–496.

Yıldırım, A. (2017). Hydration kinetics of some durum and bread wheat varieties grown in south-eastern region of Turkey. Journal of the Chemical Society of Pakistan, 39(5), 347-351.

Yıldırım, A., & Atasoy, A. (2020). Quality characteristics of some durum wheat varieties grown in Southeastern Anatolia Region of Turkey (GAP). Harran Tarım ve Gıda Bilimleri Dergisi, 24(4), 420-431.

Yıldırım, A., & Deger, Ö. (2021). Physical. physicochemical (technological) and chemical characteristics of common bread wheat (Triticum aestivum L.) varieties grown in Mardin region of Turkey. Harran Tarım ve Gıda Bilimleri Dergisi, 25(2), 151-162.

Yıldırım, A., Bayram, M., & Öner, M. D. (2008a). Ternary milling of bulgur with four rollers. Journal of Food Engineering, 84(3), 394-399.

Yıldırım, A., Bayram, M., & Öner, M. D. (2008b). Bulgur milling using a helical disc mill. Journal of Food Engineering, 87(4), 564-570.

Yılmaz, V. A., & Koca, A. F. (2020). Quality, sensorial and textural properties of einkorn and durum bulgur produced with several methods. International Journal of Gastronomy and Food Science, 22, 100263.