Effects of several production methods on technological, textural and sensorial properties of emmer (*Triticum turgidum* ssp. *dicoccum*) bulgur

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Abstract In recent years, the interest in primitive wheat species including emmer (*Triticum turgidum* ssp. *dicoccum*) wheat and their characteristics have increased due to natural food trends. Bulgur is a nutritious and healthy product with long shelf life, produced from hard wheat species without the need for any additives. The basis of this study was to reveal the potential for bulgur production by the six production methods, combinations of three cooking (traditional, autoclave, microwave) and two drying (hot-air, microwave) methods of emmer wheat. In addition to some physical, chemical and technological properties of emmer wheat, yield, color, cooking time and textural and sensorial properties of the bulgur samples were investigated and statistically significant differences ($p < 0.05$) were recorded among the bulgur samples. Autoclave cooking had a negative effect on color and got the lowest sensorial acceptability scores. Microwave drying increased fine bulgur formation and shortened the cooking time. The volume and weight increase indexes were increased more than hot-air drying thanks to physical effects of microwave drying on the structure. According to the texture analysis results, microwave cooking increased the adhesivity, and microwave drying increased hardness and springiness. In conclusion, emmer wheat have great potential for bulgur production, and traditional cooked + hot air dried samples had better bulgur properties in overall.

Keywords Emmer · Bulgur · Process · Technological

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Introduction

Ancient wheat species were originated in the Fertile Crescent zone and were the significant food source of humanity for several thousand years and the ancestors of modern wheat species (Serpen et al. 2008; Unal 2009). Ancient wheat species are also known as “primitive wheat”, with hulled, low harvest index, mostly adaptable to poor soil, water and climate conditions and characterised by high resistance to diseases (Giambanelli et al. 2013; Hlisnikovsky et al. 2019). Cultivation of primitive wheat species was decreased radically in the middle of the twentieth century and substituted by modern wheat species because of easy cleaning, operating and high yield properties (Giuliani et al. 2009). In the last decade, the interest of scientists on both the technological and nutritional properties of ancient grains has increased. As the recognition of these grains increased, the interest of producers, industrialists and consumers started to increase. Non-genetically modified foods, which are thought to be more natural and healthy, has begun to see more demand from consumers. However, the attention on ancient grains and the amount of production is not at the expected level. As an ancient grain, emmer (*Triticum turgidum* ssp. *dicoccum*) is one of the good examples of this situation.

Emmer is a tetraploid ($2n = 28$), hulled primitive wheat, which is not subjected to any modern breeding or selection. Cultivation of emmer is continuing in South European and Black Sea area countries, generally in marginal areas of low economic communities (Giambanelli et al. 2018). Today, in Turkey, emmer can be found in a small zone in Kastamonu and Sinop provinces, in the Black Sea region (Giuliani et al. 2009). There are many studies suggesting that emmer wheat, like other ancient wheat species, is richer in terms of some nutritional and functional

components than modern wheat species (Abdel-Aal and Rabalski 2008; Arzani and Ashraf 2017; Benincasa et al. 2015; Dhanavath and Rao 2017; Yilmaz et al. 2015). Emmer wheat is known to have a remarkable amount of protein, fiber, resistant starch, minerals, carotenoids and antioxidant components (Curna and Lacko-Bartosova 2017).

Emmer is still used for animal feeding and human consumption in rural. Bulgur is one of the most consumed product types for emmer wheat just like einkorn (*Triticum monococcum* L.), and with the rising interest, it becomes a favourite product for niche markets. Bulgur is an ancient, nutritious, tasty product commonly produced from durum wheat (*Triticum turgidum* ssp. *durum*) with the steps of cleaning, cooking, drying, tempering, cracking, debranning and sizing (Yilmaz and Koca 2017). Cooking and drying steps are crucial in bulgur processing (Bayram et al. 2004). Traditionally, cleaned wheat kernels are cooked in boiling water and dried under the sunlight. Industrially, cleaned kernels are preferably soaked in water, cooked in pressurized boilers (autoclave like) and dried with air flow in drying towers. Microwave cooking and drying can be accepted as a novel method for bulgur production, which have been used in scientific studies but not yet an industrial scale. Cooking and drying type, time and temperature are the most critical parameters in terms of bulgur quality.

In this first part of the study, the aims were; to demonstrate the potential of emmer wheat in respect to technological, textural and sensorial properties in bulgur production and to determine the best emmer bulgur production method according to the results of the analyzes.

Materials and methods

As the raw material, Emmer (*Triticum turgidum* ssp. *dicoccum*) was obtained from a farmer in Sinop province (Turkey). Emmer wheat was dehulled, dry cleaned and the grains over 2.5 mm sieve were used for bulgur production. All samples were stored with double layer polyethene bags at 4 °C until the analysis.

Grain characteristics

The dehulling yield of emmer was performed with the method described below; a hundred grams of hulled emmer was separated from hulls by hand, the removed hulls were weighted, and the ratio of kernels was given by % of the total amount of the initial sample. To determine foreign material content (FMC) of emmer wheat, hundred grams of uncleaned wheat sample was sifted through 3.5 and 1.7 mm sieves and separated from its impurities by the help of the pincer. The FMC was calculated as a percentage of

the initial amount sample. Thousand kernel weight (TKW) of the emmer wheat was performed by weighting randomly selected 500 kernels, and TKW was calculated as g/1000 kernels on dry matter (DM). The determination of hectoliter weight (HW) of the wheat sample was done with the help of 1-L measuring cylinder (40 cm/8.8 cm height/diameter) and results were given as kg/100 L on DM.

Composition analysis of wheat

AACC 44-15.02 method (AACC 2000) was used to determine the water content of the wheat and bulgur samples. Total ash content of the wheat samples was detected using the AACC 08-01.01 method (AACC 2000) with some modifications. 5 g of wheat flour in porcelain ash dishes were pre-incinerated with ethanol. After samples were incinerated at the furnace at 900 °C until the grey ash was obtained. According to the AACC 46-30.01 method (AACC 2000), the nitrogen contents of the samples were determined with the Kjeldahl method (K-355, BÜCHI Labortechnik AG, Switzerland). AACC 30-25.01 method (AACC 2000) was used to determine the crude oil content of the samples, using a soxhlet distillation system.

Bulgur production

Dry cleaned and size sorted wheat grains were used for bulgur production. With the combination of three cooking (traditional, microwave, autoclave) and two drying (microwave and hot air) methods, six different bulgur samples were produced in triplicate. The devices used for cooking and drying processes are the same as the previous study (Yilmaz and Koca 2017). Parameters of production methods were given in Table 1. For all cooking and drying techniques, parameters were determined by pre-trials. Cooked and dried samples were tempered with 3.5% water about 10 min, and they were ground with laboratory scale hammer mill (Cengiz, Ankara, Turkey). Bran layer was separated with the help of a fan. Bulgur samples were divided into three fractions with the help of 2.5–2–0.5 mm sieves.

Color analysis of bulgur

Color properties of the samples were performed with a colorimeter (CR-400, Konica-Minolta, Osaka, Japan). L^* (brightness, 100 white, 0 black), a^* (+ 120 red, – 120 green) and b^* (+ 120 yellow, – 120 blue) values of wheat, uncooked and cooked bulgur samples were determined with five parallel measurements. Color difference (ΔE) was calculated according to following equation (Eq. 1), where the L_0 , a_0 and b_0 are the parameters of raw wheat and L , a and b are the parameters of the calculated sample.

Table 1 Bulgur production parameters

Method	Soaking parameters (up to 60% water absorption)			Cooking parameters (until full gelatinization)			Drying parameters (until $\leq 10\%$ water)	
	WWR	Temp	Time	WWR	Temp or power level	Time	Temp or power level	Time
TC + HD	–	–	–	1:3	100 °C, 1 atm	25 min	60 °C	16 h
TC + MD	–	–	–	1:3	100 °C, 1 atm	25 min	500 W	70 min
MC + HD	1:2	60 °C	2 h	–	500 W	9 min	60 °C	14 h
MC + MD	1:2	60 °C	2 h	–	500 W	9 min	500 W	50 min
AC + HD	1:2	60 °C	2 h	–	121 °C, 2.1 atm	7 min	60 °C	15 h
AC + MD	1:2	60 °C	2 h	–	121 °C, 2.1 atm	7 min	500 W	55 min

TC traditional cooking, MC microwave cooking, AC autoclave cooking, HD hot air drying, MD microwave drying, WWR wheat: water ratio, Temp Temperature

$$\Delta E = \sqrt{(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2} \quad (1)$$

Yield analysis of bulgur

Tempered, ground, debranned and size sorted bulgur samples were classified into two groups; fractions over 2 mm was classified as coarse bulgur, and fractions between 0.5 and 2 mm sieves were classified as fine bulgur. Removed bran layer and materials under the 0.5 mm sieve were not classified as bulgur, and they were calculated as a loss in the yield calculation. Coarse, fine and total bulgur yield was calculated as a percentage of the total amount.

Cooking analysis

Optimum cooking time

Two grams of bulgur samples were cooked with 50 ml of boiling water in a beaker. Five pieces of bulgur were chewed with 30-s intervals and the cooking time (min) was determined according to the feeling of cooked product in the mouth (Bajaj and Sidhu 1989).

Weight increase index

Two grams of bulgur samples were cooked with 50 ml of boiling water in a beaker for an optimum cooking time as determined before. Cooked samples were drained and dried with the help of filter paper for about 5 min, and samples were weighted. Weight increase index was expressed as a percentage of the weight increase per gram of the samples.

Volume increase index

Two grams uncooked bulgur samples were taken to 50 ml measuring cylinder, 20 ml of water was added to the

cylinder, and the volume of the uncooked samples was recorded. Same samples were cooked up to their optimum cooking times, drained, and the volume increase index was determined with the same method. The volume increase index was given as the percentage of the volume difference between uncooked and cooked samples.

Texture profile analysis (TPA)

TPA was performed by the method for the cooked rice in Champagne et al. (1998) with some modifications. TA.XT2 Plus (Stable Micro Systems, England) texture analyzer with 50 mm aluminium probe was used for this analysis. 1 g of optimum cooked and drained bulgur samples were placed to the center of the platform of the analyzer with the aid of a spatula without overlapping. The method was applied to the device as a two-cycle compression. Pre-test, test and post-test speeds were adjusted to 1 mm/sec. The samples were compressed up to 80% of their heights at both cycles. The time between compressions was 5 s. Trigger force was taken 5 g. Hardness (g), adhesiveness (g × sec), cohesiveness, springiness, chewiness and resilience results of the bulgur samples was measured with five parallel.

Sensory analysis

Sensory analysis was performed to both uncooked and cooked bulgur samples according to the procedures explained by Hayta (2002) with slight modifications. Optimum cooking times were considered and used for cooked samples. Samples were cooked in boiled water without adding any other ingredient which may have act on panellist's evaluation. In uncooked samples; "odor", "color and appearance" parameters, in optimum cooked bulgur samples; "odor and taste", "mouthfeel", "color and appearance" and "overall acceptability" parameters were

evaluated in terms of 5 total points (1; lowest, 3; acceptable, 5; highest point) with the ten experienced and well informed panellists.

Statistical analysis

The results are expressed as mean values $\pm$ standard deviation of triplicate analysis. Production techniques were considered a factor for the one-way analysis of variance (ANOVA) and Duncan's multiple range test were performed to data at $p < 0.05$ significance level with SPSS software version 21 (SPSS Inc. Chicago, IL, USA).

Results and discussion

Grain characteristics

Physical properties of emmer wheat like dehulling yield, FMC, TKW and hectoliter weight are given in Table 2. Hulls are the main reason for the low yield of hulled grains while comparing with modern wheat species. The dehulling yield of Italian emmer was found 66% by Messina et al. (2012), which is a similar result to this study ($68.96 \pm 0.83\%$). TKW of three emmer varieties were reported as 29, 33 and 40 g on DM by Mayer et al. (2011). TKW of emmer was found 30.73 ± 0.42 g on DM, which is in the range of that study. Hectoliter weight of emmer was determined as 80.31 ± 0.36 kg/100L on DM. De Vita et al. (2006) studied with 20 emmer accessions cultivated in Italy, and they reported that the test weight (hectoliter) of the accessions were between 69.9–77.4 kg/100 L, which are lower than emmer of this study. Variety of wheat, climate, location and soil characteristics are the main parameters affecting the physical properties of the grain (Hlisnikovsky et al. 2019). Factors as given above and the result of that study without considering dry matter content are thought to cause this difference.

Compositional properties of emmer

Water, ash, protein and crude oil contents of the emmer are shown in Table 2. Water content of bulgur samples are given in Table 3. Arzani and Ashraf (2017) reviewed the

nutritional properties of ancient wheat species, including emmer. They reported that the protein content was in the range of 13.5–19.05% on DM and the mean of lipid and ash content were 2.16% and 2.3% on DM, respectively for emmer. Similarly, Brandolini et al. (2015) were reported 15.8% protein and 2.4% ash. Curna and Lacko-Bartosova (2017) reviewed the emmer studies about chemical composition and nutritional value, and they summarized the protein and lipid content of emmer varieties between 10–21.9% and 1.02–3.80%, respectively. The ash content in emmer was usually reported higher ($> 2.0\%$ DM) than in durum and soft wheat (1.7–1.8% DM) (Curna and Lacko-Bartosova 2017). As shown in Table 2, the compositional properties of emmer are consistent with literature findings. It can be concluded that the amount of protein which has a significant effect on grain quality is quite high in emmer wheat.

Yield

Fine, coarse and total yield results of the bulgur samples are given in Table 4. It is known that bulgur can be used in the production of many foods. Fine bulgur is generally preferred in the production of foods, such as köfte, kısır and salads like tabbouleh (Bayram and Oner 2005). The highest fine bulgur yield ($0.5 \text{ mm} < x < 2 \text{ mm}$) was calculated in TC + MD and AC + MD samples ($p < 0.05$), and their fine bulgur yields are statistically not different from MC + MD samples ($p > 0.05$). Both three samples were subjected to microwave drying resulted as an increase in the fine bulgur yield than others. With the effect of microwaves, size reduction at the grinding process increases due to larger pores formed in drying. Kahyaoglu et al. (2010) studied the impact of spouted bed and microwave-assisted spouted bed drying of parboiled wheat. They reported that, with the effect of microwaves, puffing effects occurred in microwave assisted samples so the apparent density decreased and pore sizes of that samples were found higher as a result of this effect. Bulgur is mostly used for pilav making and in general coarse bulgur was preferred for this dish. TC + HD, MC + HD and MC + HD samples had the highest coarse bulgur yield ($p < 0.05$). The common point of these three methods is the drying technique. Hot air drying resulted in a higher

Table 2 Physical and chemical properties of emmer wheat

Dehulling yield (%)	Foreign material (%)	HW (kg /100L) DM	TKW (gram) DM	Water (%)	Ash (%) DM	Protein (%) DM	Crude oil (%) DM
68.96 ± 0.83	4.23 ± 0.08	80.31 ± 0.36	30.73 ± 0.42	11.78 ± 0.32	2.32 ± 0.08	15.40 ± 0.17	2.34 ± 0.07

HW hectoliter weight, TKW thousand kernel weight, DM dry matter

Table 3 Water content and color properties of the samples

Method	Water content (%)	Color parameters			
		L^*	a^*	b^*	ΔE
Raw wheat	11.78 ± 0.32a	36.38 ± 1.09a	6.24 ± 0.31b	12.13 ± 0.64ab	–
TC + HD	8.77 ± 0.14b	31.72 ± 0.67b	6.67 ± 0.15ab	11.85 ± 0.20b	4.70 ± 0.66b
TC + MD	8.74 ± 0.36b	31.16 ± 0.49b	6.83 ± 0.15ab	12.01 ± 0.02b	5.26 ± 0.50b
MC + HD	9.40 ± 0.41b	31.22 ± 0.79b	6.95 ± 0.39a	11.72 ± 0.15b	5.24 ± 0.83b
MC + MD	8.94 ± 0.24b	32.17 ± 0.98b	6.95 ± 0.17a	12.60 ± 0.26a	4.31 ± 0.94b
AC + HD	9.28 ± 0.36b	28.50 ± 0.13c	6.29 ± 0.35b	10.75 ± 0.08c	8.01 ± 0.13a
AC + MD	8.95 ± 0.29b	29.24 ± 1.40c	7.04 ± 0.28a	11.68 ± 0.24b	7.21 ± 1.41a

Different letters indicate significant differences among samples in the same column ($p < 0.05$)

TC traditional cooking, MC microwave cooking, AC autoclave cooking, HD hot air drying, MD microwave drying

Table 4 Yield and cooking properties of the bulgur samples

Method	Yield			Cooking properties		
	Fine bulgur yield (%)	Coarse bulgur yield (%)	Total yield (%)	Optimum cooking time (min)	Weight increase index (%)	Volume increase index (%)
TC + HD	21.14 ± 3.91bc	71.95 ± 3.01a	93.09 ± 1.06a	7.33 ± 0.29bc	177.67 ± 11.06	178.33 ± 5.77b
TC + MD	29.14 ± 3.01a	63.24 ± 0.55b	92.38 ± 3.23a	8.00 ± 0.00a	167.83 ± 17.29	186.67 ± 10.41ab
MC + HD	20.53 ± 2.49c	72.53 ± 3.47a	93.06 ± 1.01a	7.93 ± 0.40ab	164.17 ± 9.24	188.33 ± 7.64ab
MC + MD	26.27 ± 3.54ab	62.36 ± 3.49b	88.64 ± 1.81b	7.33 ± 0.29bc	174.33 ± 10.75	196.67 ± 5.77a
AC + HD	21.52 ± 0.90bc	69.10 ± 0.51a	90.61 ± 0.42ab	7.50 ± 0.50abc	167.67 ± 5.01	180.00 ± 5.00b
AC + MD	30.94 ± 3.06a	56.65 ± 1.45c	87.59 ± 1.91b	7.17 ± 0.29c	179.33 ± 3.25	191.67 ± 7.64ab

Different letters indicate significant differences among samples in the same column ($p < 0.05$)

TC traditional cooking, MC microwave cooking, AC autoclave cooking, HD hot air drying, MD microwave drying

coarse bulgur yield than microwave dried ones. It is seen that the drying method rather than the cooking method is more effective on the bulgur fractions because of longer process times than cooking. Among bulgur samples, MC + MD and AC + MD were found to have lower total yield results than other samples but similar to AC + HD sample.

Color

Color parameters, such as L^* , a^* , b^* and ΔE of the wheat and bulgur samples are shown in Table 3. Color is accepted as the most significant property that influences to appearance and consumer preference. Color parameters have an important effect on bulgur's visual acceptability, especially bright yellow color is the desired feature by consumers (Balci and Bayram 2015). Due to consumer demands, yellow colored bulgur production has increased in recent years (Ertas 2017). Durum wheat is the most used raw material in bulgur production, and it is characterised with bright yellow color, mainly due to the presence of pigments

such as carotenoids. Emmer wheat is known to have a reddish-brownish color. The color parameters of emmer wheat (L^* ; 36.38 ± 1.09, a^* ; 6.24 ± 0.31, b^* ; 12.13 ± 0.64) also demonstrate that it has darker and less yellow color while comparing with two durum wheat cultivars which were chosen for bulgur production (Mean of L^* ; 59.55, a^* ; 7.25, b^* ; 18.60) (Savas and Basman 2016). Lower L^* (14.2) and a^* (0.6), but similar b^* (12.2) value was also expressed for pearled emmer wheat by Messina et al. (2012).

During the transformation of wheat to bulgur, significant changes were observed in color properties ($p < 0.05$). In all bulgur samples, L^* value decreased while comparing with raw wheat, which means a darker product than emmer. Autoclave cooked (AC) bulgur samples were determined to have a lower L^* value than other bulgur samples ($p < 0.05$). MC + HD, MC + MD and AC + MD samples were found to have higher a^* value ($p < 0.05$), which means to have more red color than emmer. b^* value, an indicator of desired yellow color, did not change in bulgur samples compared to emmer ($p > 0.05$), except for

AC + HD bulgur. MC + MD bulgur has the highest b^* value among the bulgur samples ($p < 0.05$). Due to the lower cooking and drying times, it is thought that pigments and also yellowness of MC + MD bulgur can be better protected than other bulgur samples. Ertas (2017) reported the color properties of 34 industrially produced and homemade bulgur samples in the range of; L^* : 52.48–75.16 and 45.52–80.44, a^* : -0.52 to 4.59 and 0.68 – 4.33 , b^* : 21.81–29.97 and 13.89–23.18. As a result, emmer bulgur samples were found darker, redder and less yellow color than the durum wheat bulgur samples.

ΔE can be defined as an overall color change of the samples, compared with unprocessed material (raw wheat) and calculated with L^* , a^* and b^* parameters. ΔE values of the AC + HD and AC + MD samples were found higher than other samples ($p < 0.05$), which means autoclave cooking caused more color changes than other cooking methods. Savas and Basman (2016) studied with two durum and two bread wheat cultivars for bulgur production in two cooking (atm pressure and autoclave) and three drying (sun-dried, oven-dried and infrared) methods. They reported lower L^* , a^* and b^* values in autoclave cooked bulgur than atmosphere pressure cooked ones, which resulted in higher ΔE values, as like emmer bulgur samples. They also stated that autoclave cooking could induce more degradation in color because of higher temperature and pressure.

Cooking properties

To determine the cooking behaviours of the bulgur samples, optimum cooking time, weight increase index and volume increase index analysis were performed (Table 4). Significant differences were recorded between the cooking time of the samples, but intervals of required times to cook were about 7–8 min in all samples. The longer cooking time was found in TC + MD sample, but similar to MC + HD and AC + HD samples. As a result of optimum cooking times, it is hard to evaluate the effects of cooking or drying methods on this parameter, but if there is any effect, it is minimal. Messia et al. (2012) studied with reference (not treated), parboiled hulled and dehulled emmer with and without precooking to determine some cooking parameters. They reported the cooking time of the samples between 18–21 min, which are quite higher than the examples of this study probably due to differences between parboiling parameters versus bulgur production. Cooked and dried wheat were ground and sieved to obtain homogenous bulgur. With the effect of grinding, the surface area of the bulgur grains was increased and since the heat and water are easier to reach to the centre of the grain, the cooking time was shortened. Savas and Basman (2016) reported that the optimum cooking time was 8 min for all

bulgur samples produced with different wheat cultivars, cooking and drying methods as given above. It could be accepted as similar despite different wheat cultivars and processing methods.

Weight increase index of cooked bulgurs were in the range of 164.17–179.33%, and the differences in weight increase indexes were found insignificant ($p > 0.05$). Savas and Basman (2016) reported the weight increase of the bulgur samples, produced with several wheat cultivars, cooking and drying methods, in the range of about 190–290%. These findings are higher than emmer bulgur samples probably with the effect of different wheat cultivars with different technological properties and because of different production methods. The weight increase index of parboiled hulled and dehulled emmer was reported in the range of 119–132% by Messia et al. (2012), which is significantly lower than the bulgur samples. As explained above, in addition to the different process parameters, smaller bulgur grains could uptake more water because of increased surface area than parboiled emmer samples.

The volume increase index values of the bulgur samples were determined between 178.33–196.96%. The highest volume increase was identified in MC + MD sample, and except for TC + HD and AC + HD samples, the rest of the samples were statistically not different from it ($p > 0.05$). In MC + MD sample, with the effect of both cooking and drying with microwaves, the number of pores and pore sizes on grains have become more than other samples. More and bigger pores enlarged the grains and allowed water to penetrate the grain better, so it might have resulted in a higher volume increase in the last product. Bayram et al. (2004) stated that the volume increase was higher than the weight increase due to the high swelling capacity of wheat during the production of bulgur. Similar findings were also observed in emmer bulgur results.

Texture profile

Textural properties of bulgur samples like hardness, adhesiveness, springiness, cohesiveness, chewiness and resilience were measured with texture analyzer (Table 5). Except for cohesiveness, in all parameters, significant differences were observed among bulgur samples ($p < 0.05$).

Hardness is the force applied by the sample to the probe at the first compression. The highest hardness was determined in TC + MD, MC + MD and AC + MD samples and they are not statistically different from AC + HD sample. The lowest hardness was determined in TC + HD samples. In general, microwave dried samples had a higher hardness value than hot air dried ones. The reasons of this difference are; with microwave drying, samples are drying faster than hot air dried samples and the temperature rise to 140 °C (checked with a thermocouple), which is quite

Table 5 Texture profile of the bulgur samples

Method	Texture profile analysis					
	Hardness (gram)	Adhesiveness (gram × sec)	Cohesiveness	Springiness	Chewiness	Resilience
TC + HD	24,752 ± 3392c	− 7.06 ± 3.27c	0.69 ± 0.05	0.64 ± 0.05c	11,099 ± 2766b	0.51 ± 0.07ab
TC + MD	33,812 ± 1163a	− 8.12 ± 1.24c	0.72 ± 0.01	0.78 ± 0.05a	18,950 ± 734a	0.58 ± 0.02a
MC + HD	29,310 ± 1271b	− 77.06 ± 11.34a	0.68 ± 0.03	0.63 ± 0.06c	12,548 ± 1604b	0.48 ± 0.03b
MC + MD	34,015 ± 1322a	− 52.78 ± 8.78b	0.71 ± 0.03	0.75 ± 0.01ab	18,057 ± 806a	0.55 ± 0.05ab
AC + HD	33,435 ± 1181ab	− 18.23 ± 6.52c	0.73 ± 0.02	0.69 ± 0.04bc	16,853 ± 1345a	0.54 ± 0.02ab
AC + MD	34,111 ± 1613a	− 9.24 ± 1.37c	0.70 ± 0.08	0.75 ± 0.05ab	17,210 ± 1357a	0.57 ± 0.04a

Different letters indicate significant differences among samples in the same column ($p < 0.05$)

TC traditional cooking, MC microwave cooking, AC autoclave cooking, HD hot air drying, MD microwave drying

higher than hot air drying (60 °C). Microwaves directly effect the water molecules in the structure as it is known and it was resulted to very high temperatures due to the longer time compared to cooking in drying process. As a result of this high temperature and fast mass (water) transfer, microwave dried samples have particularly lower water content than hot air dried ones, and they may become harder than the hot air dried ones due to structural effects of very high temperature on starches and proteins. Yuksel et al. (2017a) investigated textural properties of couscous-like product using bulgur flour as a by-product, and they did not report a significant difference in hardness values of microwave (180 W) and packed bed (60 °C) dried couscous samples. The power level of microwaves has directly affect the physical properties of the sample, especially temperature. Low power level microwave application (180 W) compared to emmer bulgur samples (500 W), different raw materials, production methods and also end products may be the reasons for these different findings.

Adhesiveness is defined as a negative force to pull the probe from the sample (Yuksel et al. 2017a). The highest adhesiveness was recorded in MC + HD sample, followed by MC + MD sample ($p < 0.05$). Microwave cooked samples were recorded more adhesive than other samples. Gelatinized starch properties might be modified with the effect of microwaves during cooking so the cooked kernels might become sticky than other samples. However, higher adhesivity is not a preferred textural property for the end product by consumers. Adhesiveness of the microwave (180 W) dried couscous samples were reported lower than packed bed dried (60 °C) ones by Yuksel et al. (2017a). As stated before, the main reasons for the different results of this study are; different end products and the high power level applied in microwave drying of emmer bulgur (500 W) which is thought to have a great impact on the product structure.

Springiness value is calculated by the ratio of the time (distance) passed during the second and first compression operations. As like in hardness values, springiness value of the microwave dried samples were found higher than the rest of the samples, except for AC + HD sample. Due to many more and larger pores formed by the effect of microwave drying, the elastic properties of the samples are thought to be slightly increased.

Chewiness can be defined as the energy needed to chew samples and derived by multiplying hardness, cohesiveness and springiness values. TC + HD and MC + HD samples had the lowest chewiness value among bulgur samples ($p < 0.05$) and the rest of the samples had similar chewiness value ($p > 0.05$). The lower chewiness value indicates the easier chewing ability, so the TC + HD and MC + HD samples can be accepted as more chewable than other bulgur samples. In addition, the hardness and springiness characteristics of these bulgur samples were found to be lower than the other bulgur samples. It can be concluded that lower hardness and springability would improve the chewability of the bulgur samples.

Resilience is defined as the ability of the samples to take their original shape after the first compression and calculated with the ratio of the area before the peak force of the first compression and the area after the peak force of the first compression. According to the results, TC + MD and AC + MD samples resilience results were found higher than MC + HD samples ($p < 0.05$) and they were similar to the rest of the samples ($p > 0.05$).

Sensorial properties

Sensory characteristics are more effective than nutritional characteristics in consumers' decision to buy and consume a product. No matter how good the nutrient properties of a product are, it must have a certain level of sensory acceptability. Otherwise, it will not be preferred by

consumers. The results of the sensory analysis are given in Table 6.

No significant difference was found between the odor characteristics of uncooked bulgur. When the color and appearance properties were compared, AC + MD sample was taken the lowest score, and no statistical difference was found between AC + HD sample. According to these results, the color and appearance scores of the bulgur samples prepared by using autoclave cooking were evaluated lower by the panellists. Yuksel et al. (2017b) evaluated sensory properties of uncooked couscous samples produced from bulgur flour, and there was no significant difference reported between samples using different drying (packed bed 60–80° C and microwave 180–360 W) methods.

When the sensory properties of the cooked bulgur samples were examined, no significant differences were found in the odor and taste properties among the samples ($p > 0.05$). The same result was also obtained in the color and appearance properties ($p > 0.05$). Bilgicli (2009) studied the changes in sensory properties of common bean and chickpea bulgur prepared with different cooking (autoclave and microwave) and drying (microwave and oven) methods. The researcher reported that there was no significant difference in appearance scores between cooking and drying methods and no difference in odor, taste and overall acceptability scores between drying methods of common bean bulgur samples. However, appearance, smell, taste and overall acceptability scores of microwave applied chickpea bulgur samples were reported lower than the other cooking and drying methods.

Mouthfeel is a parameter to determine the textural characteristics of the sample while eating. Panellists gave feedback with significant differences among samples ($p < 0.05$). TC + HD and TC + MD samples had higher mouthfeel points than other samples. Traditionally cooked

samples were found to be better by the panellists, according to the mouthfeel evaluation.

Although the overall acceptability scores of the bulgur samples were close to each other (3.31–3.68), statistical differences were determined among samples ($p < 0.05$). It can be seen that the cooking method is more influencing on scores than drying method. Similar statements were reported in a study to evaluate different drying conditions (tray, solar, sun and microwave) on bulgur quality (Hayta 2002). No significant difference between drying methods was reported by the researcher, in terms of flavour, mouthfeel and overall acceptability scores. Traditionally cooked bulgur samples got higher scores than autoclave cooking ones ($p < 0.05$) and not different from microwave cooked samples ($p > 0.05$). In general, traditionally cooked bulgur samples were evaluated better in terms of sensorial characteristics by the panellists, followed by microwave cooked bulgur samples. Besides, all of the samples were scored above the middle point and evaluated as acceptable.

Conclusion

As a sum of the analysis and evaluations made in this research; Emmer wheat is a highly nutritious food thanks to its high protein, fat and mineral content, and it is evident that emmer is a preferable raw material for bulgur production with good bulgur yield and cooking characteristic. As a result of six different bulgur production methods, significant differences were determined in terms of technological, textural and sensorial properties. Although many process stages will affect the quality and various characteristics in the production of bulgur, the most decisive ones are cooking, drying, and debranning if applied. As well as the effects of the combination of cooking and drying

Table 6 Sensorial properties of the bulgur samples

Method	Uncooked bulgur		Cooked bulgur			
	Odor (1–5P)	Color and appearance (1–5P)	Odor and taste (1–5P)	Mouthfeel (1–5P)	Color and appearance (1–5P)	Overall acceptability (1–5P)
TC + HD	3.73 ± 0.23	3.70 ± 0.17a	3.57 ± 0.06	3.76 ± 0.11a	3.63 ± 0.25	3.68 ± 0.06a
TC + MD	3.93 ± 0.35	3.53 ± 0.15a	3.80 ± 0.55	3.63 ± 0.23a	3.47 ± 0.21	3.67 ± 0.12a
MC + HD	3.85 ± 0.35	3.70 ± 0.10a	3.70 ± 0.10	2.95 ± 0.45b	3.48 ± 0.28	3.54 ± 0.13ab
MC + MD	3.83 ± 0.15	3.67 ± 0.38a	3.73 ± 0.06	3.05 ± 0.18b	3.37 ± 0.35	3.53 ± 0.14ab
AC + HD	3.62 ± 0.28	3.36 ± 0.38ab	3.40 ± 0.00	2.83 ± 0.29b	3.37 ± 0.31	3.31 ± 0.21b
AC + MD	3.53 ± 0.21	3.06 ± 0.32b	3.73 ± 0.15	2.90 ± 0.36b	3.13 ± 0.38	3.39 ± 0.17b

Different letters indicate significant differences among samples in the same column ($p < 0.05$)

TC traditional cooking, MC microwave cooking, AC autoclave cooking, HD hot air drying, MD microwave drying

methods on these properties, the different temperature, pressure and microwaves applications that the samples were exposed during these methods were also very effective. Microwave application for cooking, drying or both had negative effects on coarse bulgur yield and textural properties of the final product like higher hardness and lower chewiness. Autoclave cooking could be considered as the worst method according to sensory analysis and color results. TC + HD method can be selected for emmer bulgur production, thanks to its better yield, cooking, textural and sensorial properties.

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