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Bulgur milling using roller, double disc and vertical disc mills

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Abstract

In the present study, roller, double disc and vertical disc mills were used to determine their effects on the quality of bulgur (surface characteristics, shape, dimension (x, y, z), particle volume (V), bulk density, one-thousand particles weight and size). Eighteen kilowatt motor was used and gap width was fixed at 2.50 mm for the mills.

The roller mill had the highest milling yield (99.19%). Smooth and glassy particle surface was obtained due to the sharp-to-sharp operational principle of the roller mill (cutting effect). The quantity of coarse (/2.20) bulgur particle was higher than that of middle (2.20/2.00) and fine (2.00/0.50) bulgur particles. One-thousand particles weight and bulk density were found as 6.93 g and 63.76 g/100 mL, respectively. However, uniform particle shape was not obtained from the roller mill. It could be due to the irregular cutting of the particles between teeth of the roller mill.

The coarse, middle and fine bulgur were obtained using the double disc mill at the percentage of 22.30, 34.60 and 37.94, respectively. The double disc mill caused low surface quality in contrast to obtained ovoid or elliptical shape. Moreover, its yield was 94.84%.

Vertical milling position of the vertical disc mill decreased the retention time of bulgur particles in the milling zone therefore, ellipticity (ovoid) of bulgur particles was lower than that of the double disc mills. The milling yield of vertical disc mill was 97.60%, which was higher than the double disc mill (94.84%).

Keywords: Bulgur; Milling; Roller mill; Double disc mill; Vertical disc mill; Size reduction

1. Introduction

Due to the lack of extra-ordinary potentials of the well-known commercial products, i.e., pasta, biscuit, rice, flour etc., food producers, distributors and market directors investigate new commercial food products to place with them in markets. R&D departments also spend too much money and time to develop new commercial and acceptable food products to generate new shelves. Perhaps the most difficult R&D activity is the design of a new food product due to unacceptability risk of consumers. Therefore, a good procedure may be investigate the ancient traditional and regional products, which is cheap and high potential acceptable.

Due to above objectives, the investigators and researchers pay attention to bulgur, recently. The trials have been showing that the result is always great when bulgur is experienced for the first time by a person.

Bulgur is main ingredient presently used in more than 250 delicious meals. Bulgur is a whole grain product, which is generally produced from *Triticum durum* using cleaning, drying, tempering, peeling, milling, polishing (optional) and classification operations. It is semi-ready-to-eat and ready-to-eat food product, having long shelf-life, resistant to insect, mites and microorganisms. Bulgur is also important as a dietary fibre source, having 18.3 g dietary fibre per 100 g. Its dietary fibre content is 3.5, 6.8, 1.1, 1.8, 7.0, 15.3, 9.2, 2.3, 1.3 and 4.3 times higher than rice, wheat flour, barley, oat meal, spinach, tomato,

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turnip, whole wheat bread, soybean and pasta, respectively (Dreher, 2001). The detailed nutritional properties of bulgur were given in literature (Bayram, 2000, 2005a, 2005b, 2005c; Bayram, Öner, & Eren, 2004a, Bayram, Öner, & Kaya, 2004b).

Bulgur is the one of ancient food products. The first historical knowledge about bulgur was found in the Çatalhöyük (Anatolia) archaeological studies (the history of Çatalhöyük goes back to 7000–8000 years ago). The production of this ancient grain product recently reached to important level around the world. For example, one million ton of bulgur (~$ 800 million) is produced in Turkey by 500 plants. About twenty percent of bulgur production is exported. Out of Turkey, there is also important amount of bulgur production. In addition, 250,000–300,000 tonnes (15–20 bulgur plants) in the United States plus Canada, 60,000–80,000 tonnes (4–6 bulgur plants) in the EU and 100,000–120,000 tonnes (10–15 bulgur plants) in the Arabic countries are produced.

The consumption of bulgur is also important to understand its economical and nutritional properties. It is approximately 2.5 and 2.0 times higher than that of pasta and rice in Turkey, respectively. The average annual consumption of bulgur is about 12 kg/person. This consumption is amazingly huge in the East and South Parts of Turkey (~25 kg/person) and in Syria, Iraq, Iran, Israel, Lebanon, Arabia, i.e., Middle East countries (~30–35 kg/person) (Bayram, 2000, 2005a, 2005b, 2005c; Bayram & Öner, 1996, 2002, 2004a, 2004b; Bayram, Kaya, & Öner, 2003). The amount of bulgur for food-aid programs annually reached to 60,000–80,000 tonnes and gradually increase each year, which is made by United Nation and WFP. The same amount of bulgur is additionally supplied from USA to the developing countries.

Due to the significant trend to produce bulgur in developing and developed countries, some technological upgrades are required. Therefore, each step in the bulgur production system should be strictly controlled and adapted with new technologies.

In the literature, there are too many studies related to the milling of semolina and flour (Campbell & Webb, 2001; Campbell, Bunn, Webb, & Hook, 2001; Pasikatan, Milliken, Steele, Spillman, & Haque, 2001; Peyron, Chaurand, Rouau, & Abecassis, 2002). However, there is no enough study related to the milling properties of bulgur (Bayram & Öner, 2005; Özboy & Köksel, 2002). Moreover, the milling operation of bulgur is different from the milling of the uncooked wheat products, such as flour and semolina due to the processing properties of bulgur (its cooked and dried whole-kernel form and final granular particle sizes (3.5–0.5 mm)).

Granular materials are commonly produced by compression, impaction, attrition or rubbing and cutting. Generally, compression reduces hard solids to coarse particles with relatively few fines; impaction gives coarse, medium or fine products; attrition yields very fine particles from soft and non-abrasive materials. Cutting gives particles of a uniform size, sometimes with a defined shape (McCabe, Smith, & Harriott, 1985). Mills utilizing attrition or shear forces for size reduction play a major part in fine grinding. Since much of milling carried out in the food industry is for the production of very small particle sizes and this type of mill finds extensive application.

In a roller mill, the solid particles are caught and crushed between rolling members, i.e., face of a ring or casing. In the roller mill, cylindrical rollers press outward with great force against a stationary anvil ring or bull ring with the cutting effect of tooth. It is extensively used in the production of flour and semolina.

Two types of disc mill (single and double disc mills) are also used in the milling industry (Brennan, Butters, Cowell, & Lilly, 1976). In the single disc mill, the feedstock passes into a narrow gap between a high speed, rotating grooved disc and the stationary casing of the mill. Intense shearing action results in comminution of the feed. The gap is adjustable, depending on feed size and product requirements (Brennan et al., 1976). The disc mills may be roughly grouped as (i) a vertical-spindle machine having the disc rotating in a horizontal plane and (ii) a horizontal-spindle machine with the disc rotating in a vertical plane. The vertical-spindle disc machine is ideal for grinding flat surfaces that can readily be placed manually on the disc. Hence, it is used for surface-grinding components as they come from the foundry and forge. Small particles are held against the disc by hand; larger particles are often permitted to float on the disc, due precautions being taken by means of a retaining plate or fixture to prevent the work piece from being thrown of the machine. To ensure even wear of the abrasive and a flat surface the components should be moved across the surface of the disc (wear is a function of the linear speed). In the horizontal-spindle machine, the work done with this class of machine is much the same as that outline for the vertical-spindle design mentioned above. With the working surface of the disc rotating in a vertical plane, the machine is suitable for a wide range of articles. Perhaps the widest known use for this type of grinding machine is the sharpening of the many single point tools used on lathes, planers and shapers.

In the present study, the different mills, i.e., roller, double disc and vertical disc were investigated to determine their effects on the milling quality of bulgur and to find the optimum mill type.

2. Materials and methods

2.1. Materials

Cleaned, classified, cooked, dried and peeled *T. durum* was obtained from Arbel Legumes and Bulgur Co. (Mersin, Turkey) (Turkish cultivar of Ege-88, winter wheat, harvesting year 2003, m.c. = 12.05% (w.b.), protein content = 11.8% (d.b.).

2.2. Methods

2.2.1. Milling operations

The roller (Tanmak Milling Ind. Co., Gaziantep, Turkey), double disc (Günmak South Milling and Screw Conveyor Ind. Co., Gaziantep, Turkey) and vertical disc (Toprakcıoğlu Mills Co., Karaman, Turkey) mills were used for the milling operation. The each mill had an 18 kW motor and operated at 400 rpm. The teeth depth and drall of the roller mill were 2.5 mm and 5.0 cm, respectively. The alpha and beta angles were 30° and 65°, respectively. The roller mill was run at sharp-to-sharp position.

The gap between discs was 2.5 mm for the double and vertical disc mills. The double disc milling operation was carried out by passing bulgur two times throughout a single disc mill. The vertical disc mill had same properties but it was installed at vertical position to use potential energy and minimize the retention time of product.

The main shared properties in the mills were gap, power and rpm as 2.5 mm, 18 kW and 400 rpm, respectively. These similarities supplied the comparison of the mills with each other.

2.2.2. Moisture and protein contents

The moisture (w.b.) and protein (d.b.) contents of cooked, dried and peeled intact wheat were determined using the oven drying (105 °C) and Kjeldahl methods, respectively (AOAC, 1990).

2.2.3. Imaging of samples

Bulgur was imaged before and after the milling operations using a Digital Jenoptik 4.1 Exclusiv camera (4.1 MPixels, 2× digital and 3× optical zoom lens, Jenoptik Co., Germany). The surfaces of bulgur particles after the milling operation were viewed at 400× magnification using an Olympus Photo Microscope (Olympus BH, Japan).

2.2.4. Measurement of dimensions

The dimensions of one hundred bulgur particles were measured using a micrometer (Mutitoyo No. 505-633, Japan). Ellipsoidal particle volumes (V "mm^3") were calculated using the following equation (Bayram et al., 2004a, 2004b):

$$V = 4/3 \times \pi \times (\text{radius of width}) \times (\text{radius of thickness}) \times (\text{radius of length})$$

2.2.5. Measurement of one-thousand particle weight, bulk density and sieve analysis

The weight of one-thousand of bulgur particles were measured using an analytical balance (sensitivity ±0.0001, Shimadzu, Japan). Bulk densities (hectolitre-weight) were determined using a graduated cylinder and an analytical balance. Sieve analyses were performed using 2.20, 2.00 and 0.50 mm sieves. Bulgur was classified into three sizes after the milling, such as pilaf (coarse), midyat (middle) and köfte (fine). The coarse bulgur was collected over a 2.20 mm screen (/2.20). The middle and fine bulgur were obtained between 2.20 and 2.00 mm (2.20/2.00), and 2.00 and 0.5 mm (2.00/0.50) screens, respectively. Bulgur below 0.5 mm of screen (0.50/) was classified as 'by-product' and used to calculate the overall milling yield (TSE, 2003).

2.2.6. Statistical analysis

Maximum, minimum, mean values, standard deviations and coefficient of variances (CV, %) of the dimensions of bulgur particles were determined. An ANOVA analysis was performed for the mean values of dimensions ($p = 0.05$). Duncan's multiple range test was performed to determine the effect of milling system on the particle dimensions.

3. Results and discussion

Main problems during the bulgur milling operation can be classified as follows: (i) deformation, scratching and formation of burrs on the surface of particles (especially for abrasive type mills), (ii) the formation of sharp edges on the particles (the loss of ovoid shape causes adhesiveness, breakage, flour formation and loss of quality during preparation of pilaf and köfte from bulgur), (iii) the loss of translucency, smoothness and appearance, (iv) decrease in yield due to flour formation (particles < 0.50 mm), and (v) the creation of different sized bulgur particles.

Some particles obtained from the roller mill was long, which were ground along the crease of the wheat particles (Fig. 1) due to random falling down (sideways position) into the grinding zone of the roller mill. The particle surface was smooth and glassy due to cutting effect of the roller mill (sharp-to-sharp configuration) (Fig. 2). The

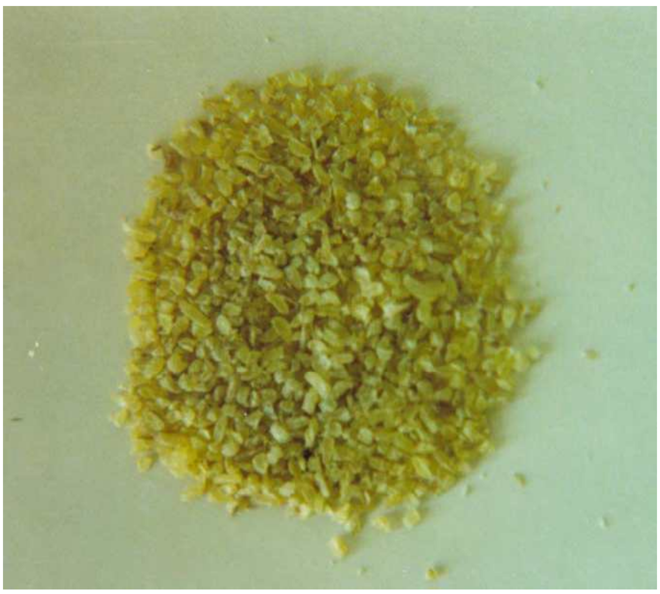

Fig. 1. Roller milled bulgur.

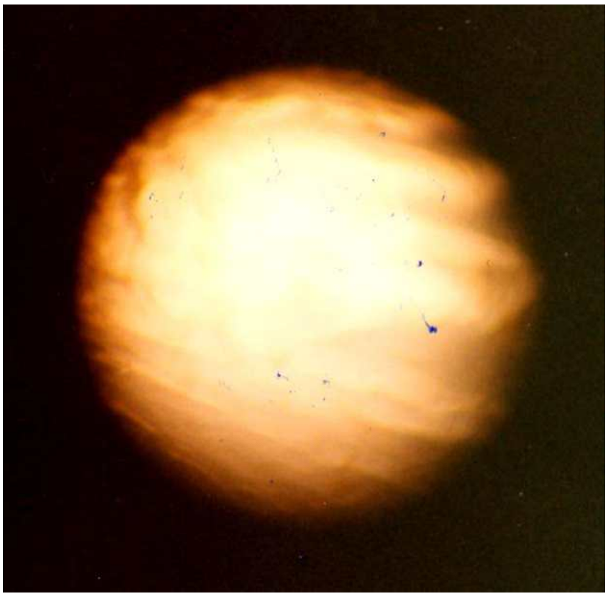

Fig. 2. Microscopic view of a roller milled bulgur particles (×400).

Fig. 4. Microscopic view of a double disc milled bulgur particles (×400).

roller mill cut the wheat particles as slice, so that the sharp edges were observed. The smooth and polish surface (glassy and transparency) was good, but sharp edges could cause some problems (crumble) for meals preparation.

During the double disc milling operation, the bulgur particles lost their surface appearances due to the deformation with abrasion. Cracking, scratching, burr formation and splitting on the bulgur particles were observed. However, the abrasion effect prevented the existing of long bulgur particles, therefore extreme sharp edges were not obtained (nearly ovoid) (Figs. 3 and 4).

The objective of the use of double disc mill was to obtain the uniform size and shape (ovoid shape like an ant-head). However, double milling increased the quantity of by-product (flour). It might be acceptable because of its ovoid shape production.

Due to the vertical working principle of vertical disc mill, the vertical disc milled bulgur was more elliptical than the roller milled bulgur; however it was less elliptical than the double disc milled bulgur (Fig. 5). The vertical position also decreased the deformation of the bulgur particle surface due to short resistance time in the grinding zone, therefore good surface appearance was obtained in contrast to the formation of some sharp edges (Fig. 6). The vertical disc mill produced more smooth particles than the roller mill due to mixing or abrasion effect during the revolution

Fig. 3. Double disc milled bulgur.

Fig. 5. Vertical disc milled bulgur.

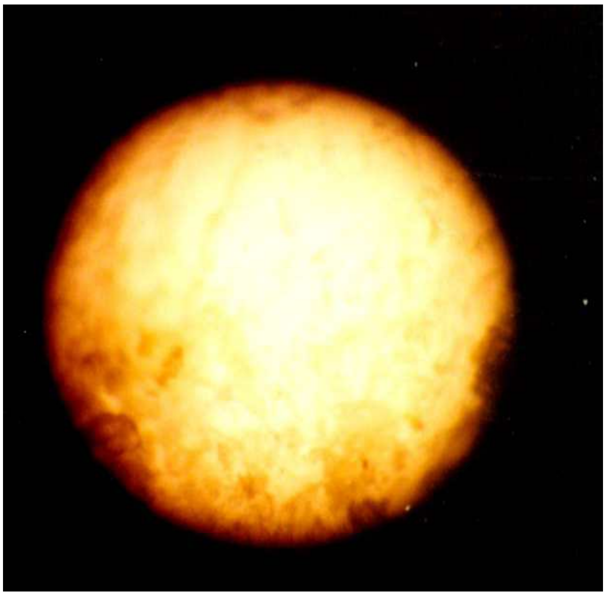

Fig. 6. Microscopic view of a vertical milled bulgur particles (×400).

of discs. In addition, long bulgur particles were not obtained from the vertical disc mill.

The changes in the dimensions were illustrated in Table 1. The mean *x*-side value (length) of the bulgur particles obtained from the roller mill was bigger than the other mills. Also, its maximum, standard deviation and CV values were huge. These results correlated the previous explanation (Fig. 1). The mean, standard deviation and CV values of the *x*-side of the bulgur particles obtained from the double disc mill were the lowest, so that the abrasion effect caused homogeneity and uniformity. Also, the smallest value for the standard deviation and CV of particle volume (V) correlated the uniformity of the double disc milled bulgur particles.

The mean values of the *y*-sides (width of particle) of the bulgur particles obtained from three mills were nearly identical ($p > 0.05$). But, the *z*-side (across crease side) value of the double disc milled bulgur particles was the biggest due to its low cutting effect ($p < 0.05$). The standard deviations of the *y*- and *z*-sides of the roller milled bulgur particles were the smallest in contrast to the biggest *x*-side values due to the sideways feeding position of the intact wheat kernels and slicing effect of the roller tooth.

The overall yield (/0.50) for the roller, double disc and vertical disc mills were 99.19%, 94.84% and 97.60%, respectively. Due to the cutting effect of roller mill, its yield was greater than the others. Also, the vertical position of disc mill, i.e., short residence time increased the milling yield (97.60%) compared with the double disc mill.

Maximum amount of coarse bulgur (/2.20) was obtained from the roller mill (88.56%) due to its cutting effect. Middle (2.20/2.00) and fine (2.00/0.50) bulgur were 5.96% and 4.65%, respectively (Fig. 7). In the present study, this corrugation in the roller mill was enough to obtain the high amount of coarse bulgur but not for the other sizes bulgur.

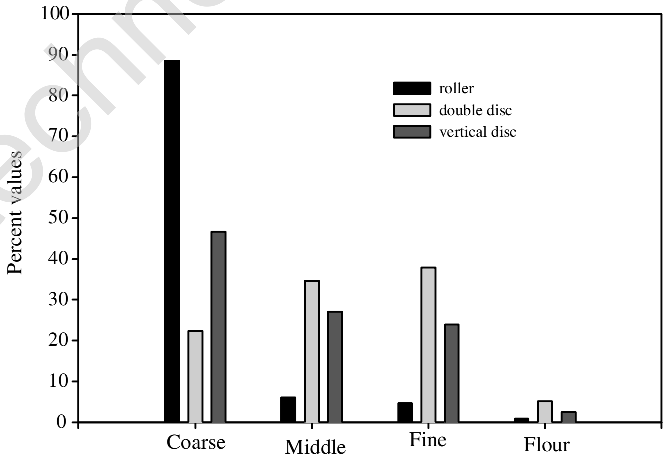

Fig. 7. Particle size (sieve analysis) distribution of bulgur from three mill types.

Table 1
Dimensions of bulgur particles

Responses	Milling systems	Minimum (mm)	Maximum (mm)	Mean (mm)	Std. deviation	Coefficient of variance (%)
x	Roller	2.11	3.68	2.698^{a}	0.458	16.98
	Double disc	2.08	2.25	2.158^{b}	0.049	2.27
	Vertical disc	2.00	3.25	$2.454^{a,b}$	0.421	16.54
y	Roller	1.58	1.73	1.639^{a}	0.057	3.48
	Double disc	1.21	2.15	1.574^{a}	0.268	17.03
	Vertical disc	1.09	1.95	1.536^{a}	0.257	16.73
z	Roller	0.76	0.95	$0.855^{b,c}$	0.062	7.25
	Double disc	0.81	1.25	1.008^{c}	0.144	14.29
	Vertical disc	0.70	1.25	$0.898^{a,b,c}$	0.185	20.60
V	Roller	1.10	2.78	$1.790^{b,c}$	0.459	25.64
	Double disc	1.43	1.86	1.583^{c}	0.147	9.29
	Vertical disc	1.47	2.72	$2.155^{a,b}$	0.435	20.19

Different letters indicate statistically significant differences exist at $\alpha = 0.05$ for each column and response.
Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares.
Duncan test was applied.

They might be produced by decreasing the depth of teeth and gap between the rolls.

The amount of coarse, middle and fine bulgur in the double disc mill were 22.30%, 34.60% and 37.94%, respectively. The double milling operation increased the amount of middle bulgur, fine bulgur and by-product in contrast to decrease in the coarse bulgur due to abrasion effect.

The coarse, middle and fine bulgur were obtained from the vertical disc mill as 46.61%, 27.05% and 23.94%, respectively. By-product was 2.40%. The quantity of coarse bulgur in the vertical disc mill was greater than the double disc mill. Similar to the double disc mill, the high amount of middle and fine bulgur was obtained from the vertical disc mill.

The bulk densities of bulgur obtained from the roller, double disc and vertical disc mills were 63.76, 74.12 and 70.70 g/100 ml, respectively. Due to ovoid shape and smoothness (no sharp edge), double disc milled bulgur had the biggest bulk density.

The 1000-particle weights of the bulgur particles obtained from the roller, double disc and vertical disc mills were 6.93, 1.91 and 5.04 g, respectively. These results were parallel to the results of sieve analysis.

As a result, in the present study, the roller mill (sharp-to-sharp) had cutting effect due to the tooth of rolls. The double disc mill had compression, rubbing and cutting effects. The vertical disc mill had also compression, rubbing and cutting effects, but forces were lower than the single or double disc mills due to the position of disc. Vertical position caused the gravitational force and short residence time. Therefore, bulgur particles were less affected from the available forces. The residence time in the disc mill installed horizontally was controlled by centrifugal force and conveying capabilities of the tooth corrugations (there was additionally gravitation force in the vertical disc mill).

The advantages and disadvantages of the mills used in this study were compared in Table 2. The roller mill was the best for the milling economy, i.e., high yield and low quantity of flour. Another most important property of the roller mill was the gaining good surface characteristics to the bulgur particles (glassiness, transparency, smoothness etc.). This is a perfect result for the bulgur milling technology. According to obtained results the roller mill can be famous and leader in the bulgur industry with small re-arrangements in the next time.

However, the roller mill caused the formation of long bulgur particles. This problem could be solved using different feeder over the rolls, or recycling screen to separate and re-feeding into the mill, or double or triple roller mills, or a hard polisher etc.

The roller mill is a famous mill used in flour and semolina industries. Due to its wide-use in the industry, its maintenance and arrangements could be made easily, and also it is easily installed into flow-diagrams and plant designs.

Table 2
Evaluation of mills for bulgur

Properties of bulgur		Roller	Double disc	Vertical disc
Dimensional uniformity	x	*	***	**
	y	***	*	**
	z	***	**	*
	V	*	***	**
Amount of coarse bulgur		***	*	**
Amount of middle bulgur		*	***	**
Amount of fine bulgur		*	***	**
Amount of flour (if desired)		*	***	**
Loss (by-product, if flour is undesired)		***	*	**
Overall milling yield		***	*	**
Surface characteristics (appearance etc.)		***	*	**
Ovoid/ellipsoidal shape		*	***	**

[*], Bad.
[**], Acceptable.
[***], Good.

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