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Ternary milling of bulgur with four rollers

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Abstract

In this study, the effect of ternary roller mill (four rolls and three gaps) on the selected quality parameters of bulgur was researched. Particle size, colour (*L*, *a*, *b* and YI-values), ash content, hectolitre-weight, yield and loss were evaluated for the roller mill. The first (between first and second rollers: 1.9 mm), second (between second and third rollers: 1.2, 1.0 and 0.8 mm) and third (between third and fourth rollers: 0.4, 0.5 and 0.6 mm) gaps were arranged to determine the optimum parameters. The products obtained were classified as coarse (+/3.5), pilaf (3.5/2.0), medium (2.0/1.0), fine (1.0/0.5) and undersize (0.5/−) using 3.5, 2.0, 1.0 and 0.5 mm circular sieves.

The fine bulgur obtained from the roller mill had brighter yellow colour than coarse one. The yield values of samples from the roller mill were obtained between 87.86% and 99.75% at different gap adjustments. When the particle size decreased, the percent ash was decreased from 2.28% to 1.46% due to increase in abrasion effect. The hectolitre-weight values were determined between 70.08 and 81.08 hl/kg. In the ternary roller milling system, coarse, pilaf, medium and fine bulgur could be produced simultaneously. A high production yield and capacity (3500 kg/h) were obtained with low energy consumption (0.00514 kW h/kg). It also supplied uniform particle sizes due to multiple milling stages by preventing the escape of kernels from the gaps.

Keywords: Bulgur; Roller mill; Milling; Size reduction; Ternary milling

1. Introduction

Bulgur is a whole grain product, which is generally produced from durum wheat using cleaning, drying, tempering, peeling, milling, polishing (optional) and classification operations. It is classified as semi-ready-to-eat or ready-to-eat food. Bulgur is main ingredient pleasantly used in more than 250 delicious meals due to its long shelf-life, low cost, ease of preparation, high nutritional value, taste and resistant to radiation, insect, mites and microorganisms (Bayram, 2000, 2005; Bayram & Öner, 2005, 2006). Therefore, it is an important wheat product due to its high dietary fibre content, 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, turnip, whole wheat bread, soybean and pasta, respectively (Dreher, 2001).

Bulgur is an ancient wheat product and its history goes back to 4000 BC. Recently, archaeological studies have revealed that bulgur was used in Neolithic and Bronze Eras (Valamoti, 2002). Recently, there are two basic processing methods to produce bulgur i.e. Antep and Karaman (Mut) (Bayram & Öner, 2005). Milling techniques (stone, disc, roller, etc.) used in both methods affect the significant properties of bulgur (colour, shape, taste and size).

The production of bulgur reached to important level around the world. For example, over one million ton of bulgur (~$ 800 million) is produced in Turkey by 500 plants. About 20% of bulgur production is exported. There is also important amount of bulgur production at different countries (250,000–300,000 tonnes by 15–20 bulgur plants in the United States plus Canada, 60,000–80,000 tonnes by 4–6 bulgur plants in the EU and 100,000–120,000 tonnes

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by 10–15 bulgur plants in the Arabic countries) (Bayram & Öner, 2005, 2006).

The consumption of bulgur is also important to understand its economical and nutritional properties, which is approximately 2.5 and 2.0 times higher than that of pasta and rice in Turkey, respectively (Bayram & Öner, 2006). The average annual consumption of bulgur is about 12 kg/person. This consumption is extremely high in the East and South Parts of Turkey, Syria, Iraq, Iran, Israel, Lebanon, Arabia (~25–35 kg/person) (Bayram, 2000, 2005; Bayram & Öner, 2002; 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 undeveloped countries (Bayram & Öner, 2006, 2007).

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. One of the most important processing steps is the milling of bulgur.

Granules may be broken in many different ways, but only four of them are commonly used in size-reduction machines. These are compression, impacting, attrition or rubbing and cutting. In general, compression is used for coarse reduction of hard solids to give relatively few fines; impacting gives coarse, medium, or fine products; attrition yields very fine products from soft, nonabrasive materials. Cutting gives a definite particle size and sometimes a definite shape, with few or no fines. An ideal crusher or grinder would have a large capacity, require a small power input per unit of product and yield a product of single size or size distribution desired (McCabe, Smith, & Harriot, 1993).

In roller milling, particles of feed are nipped and pulled through rollers, experiencing a compressive force, which crushes them (Brennan, Butters, Cowell, & Lilly, 1976). Rollers can be corrugated or smooth, corrugated if for breaking or detaching, smooth if for reduction. Break rolls are always corrugated with flutes cut in a spiral pattern along the length of roller. Numerous configurations of roller corrugations are available. Different wheat requires different roller corrugations for the best milling results. The corrugations vary not only in the number per centimetre but also in the profile or shape of the tooth. A sharp angle is used primarily for hard wheat to produce granular products, whereas flatter angles are used for softer wheat. The corrugations may also be oriented to be either sharp or dull as determined by the direction of the sharp angles as the rollers rotate (Pomeranz, 1988).

Main principle during the size reduction of bulgur is the creation of new surface by dividing of whole dried wheat kernel into two or more particles. During this operation, the main problems are: (i) deformation, scratching and formation of burr on the surface of bulgur (abrasive type mills), (ii) formation of sharp edge on bulgur particles (causes adhesiveness, breaking, flour formation and quality loss during pilaf and köfte making), (iii) loss of translucency and brightness of bulgur, (iv) decreasing yield due to flour formation (under-screen product) during size reduction, (v) losing oval and smooth shape (formation of sharp edges), (vi) creation of different size bulgur particles i.e. not uniform sizes (Bayram & Öner, 2005).

The aim of this study was to use four rollers for ternary milling (triple passes) of bulgur in stead of six rollers. In addition, the effect of this system on the quality of bulgur was determined by measuring particle size, colour, ash content, yield, loss, hectolitre-weight (bulk density) and moisture content.

2. Materials and methods

2.1. Material

The cooked-dried and peeled durum wheat (*Triticum durum, Zenit* spp.) was obtained from Tiryaki Bulgur Factory (Gaziantep, Turkey). Its hectolitre-weight, moisture and ash contents were determined as 85.58 kg/hl, 11.92% (w.b.) and 1.36% (d.b.), respectively. The *L*, *a*, *b* and YI-values were 47.51, 5.65, 17.34 and 74.21, respectively.

2.2. Ternary roller milling

The mill with four rollers was used, which was constructed by Yükseliş Milling Machine Co. (Eskişehir, Tur-

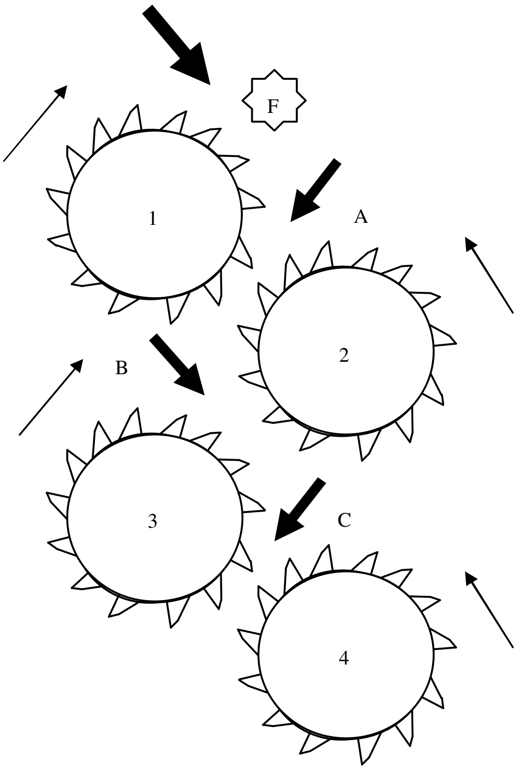

Fig. 1. Illustration of the disposition and passing of roller mill system (F: feeder, A: first break gap, B: second break gap, C: third break gap) (thin arrows show the revolution direction of rollers, bold ones show the direction of product).

key) (Fig. 1). In general, one break in a mill is made using two rollers. Therefore, three breaks need six rollers. However, ternary milling was achieved using vertical design with four rollers instead of six (Fig. 1). The diameter, length, revolution and twist (spiral) of rollers were 25 cm, 100 cm, 310 rpm and 5 cm, respectively (Fig. 2). The number of teeth per 1 cm for first and second rollers was 3.2 while it was 4 for third and fourth rollers. Total number of teeth for first and second rollers were 250 whereas 300 for third and fourth ones. The alpha, beta and depth of grooves for each roller were 30°, 65° and 2 mm, respectively (Fig. 3). The mirror of groove and width of groove of first and second rollers were 1 mm and 3.5 cm, respectively. Both values for third and fourth rollers were 0.7 mm and 2.5 cm, respectively. The dispositions of first–second, second–third and third–fourth to each other were sharp-to-dull, dull-to-sharp and sharp-to-dull, respectively (Fig. 1). The mill was run by one motor (18 kW, 970 rpm). The rollers were hard-steel.

The experimental set-up and arrangement of gaps (A, B and C) were given in Table 1. The gap adjustments were made using a micrometer hand-wheel. Screen analysis (%), moisture content (%, w.b.), ash content (%, d.b.), colour values (*L*, *a*, *b* and YI), loss (%) and yield (%) were determined at each treatment. Energy consumption and capacity of the roller mill were measured at the optimum condition. The experiments were two replicated and the measurements were duplicated. One kilogram of sample was collected at each treatment.

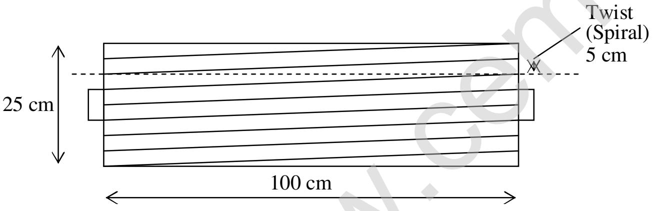

Fig. 2. Dimensions of roller.

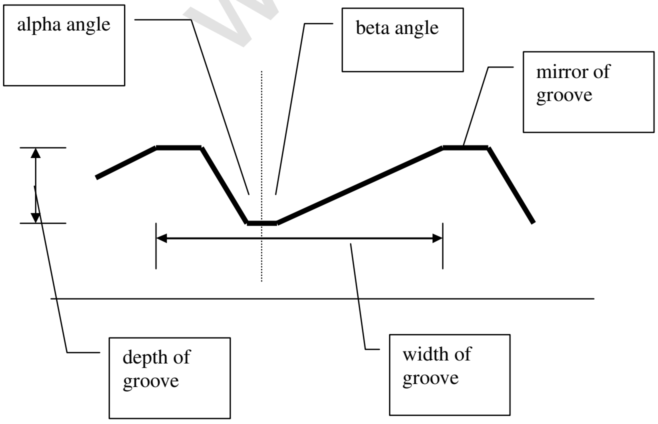

Fig. 3. Teeth of the roller mill.

Table 1
Experimental set-up and arrangement of gaps

Treatments	Gaps (mm)		
	A	B	C
1	1.9	1.2	0.4
2			0.5
3			0.6
4		1.0	0.4
5			0.5
6			0.6
7		0.8	0.4
8			0.5
9			0.6

2.3. Determination of energy consumption and capacity

The roller mill was run by a motor that had a speed of 970 rpm and power of 18 kW. Power index of motor was 0.574. The speed of motor (970 rpm) was decreased to 310 rpm on the rollers using the reductors and pulleys. The optimum feeding rate of roller mill was determined by measuring ampere value. During the experiments, when the ampere reached to 37.9 A (optimum ampere value was selected as 80% of maximum motor ampere), the feeding rate was fixed. Experiments were made at optimum working conditions i.e. 37.9 A, 380 V and 14.4 kW. Capacity and energy consumption were determined at the smallest gap adjustment (1.9 mm, 0.8 and 0.4 mm for first, second and third gaps, respectively).

2.4. Sample collection and analysis

When the optimum condition (14.4 kW and 37.9 A) was obtained, the roller mill was worked for further 15 min with continuous feeding, then the sample was collected. This operation was regularly repeated at each gap treatment. The screen analyses were carried out using the circular sieves with 3.5, 2.0, 1.0 and 0.5 mm of circular aperture made of steel. One hundred gram sample was used for the screen analysis. Moisture content (%, w.b.) was measured using the oven method at 105 °C (AOAC, 1990). Ash contents (%, d.b.) were measured using the method of AOAC (1990). Colour values (*L*, *a*, *b* and YI) were measured using Hunter Lab Colorimeter (Colorflex, USA). A white standard tile was used to calibrate the colorimeter ($L = 93.01$, $a = -1.11$, $b = 1.30$) before each measurement. *L*, *a*, *b* and YI-values represents lightness, redness, yellowness and yellowness index, respectively. Over of 2.0 mm sieve was used for the determination of ash content and colour values. Hectolitre-weight (bulk density, kg/hl) was measured using a graduated cylinder and an analytical balance (±0.01 g) (TSE, 2003). The results of the upper part of 0.5 mm sieve (+/0.5) were evaluated as the yield (%) and that of the lower part of 0.5 mm sieve (0.5/+) as the loss (%).

2.5. Statistical analysis

Data obtained was subjected to statistical analysis of variance (ANOVA) and Duncan multiple range test ($\alpha = 0.05$) to assess difference between means and homogeneous subsets using SPSS-2002 statistical software (SPSS Inc., Chicago, USA). Graphic representation was carried out using Sigma-Plot 2000 (SPSS Inc., Chicago, USA) graphic package. The experiments were replicated and the measurements were duplicated.

3. Results and discussion

In industry, bulgur is generally produced using a single breakage mill (stone, disc, roller, etc.). Therefore, broken kernels are sometimes being very long or having different shape due to the escape of intact kernels without breaking through gaps. Bayram and Öner (2005, 2007) used six different mills (stone, disc, hammer, single breakage roller, double disc and vertical disc) to determine the best milling system. However, the studies showed that each mill had either advantage or disadvantage. The yield was the highest in the single breakage roller. However, the uniform particle size was obtained using double breakage disc mill. These studies shows that the working principles of roller and double disc can be combined to obtained a modified milling system for bulgur. The result of double disc mill shows that to obtain uniform bulgur kernel, additional milling is required. Therefore, in the present study, a ternary milling with four rollers system was used.

3.1. Change in particle sizes

The particle size distribution of products milled at different roller gaps using triple breakages were evaluated with screen analysis with the sizes of 3.5, 2.0, 1.0 and 0.5 mm. The entire results of coarse (+/3.5), pilaf (3.5/2.0), medium (2.0/1.0), fine (1.0/0.5) size bulgurs and loss (0.5/+) at the different roller gap adjustments are given in Table 2.

When the first and second gaps were fixed, the amount of pilaf size bulgur significantly ($P < 0.05$) increased with increasing third gap. As expected, the major increase in the percent mass of pilaf size bulgur was obtained at third gap of 0.6 mm (Table 2). A regular change by increasing in second gap was not obtained. Therefore, the size of bulgur could be adjusted during third breakage.

The increase in third gap also significantly ($P < 0.05$) increased the percent mass of pilaf size bulgur (Table 2). The quantity of pilaf size bulgur obtained at 0.6 mm (third gap) was high extremely. According to the results, the gaps to obtain pilaf size bulgur could be arranged to be 1.9, 1.2 and 0.6 mm at first, second and third breakages, respectively. The biggest percent mass (59.78%) for medium size bulgur was significantly ($P < 0.05$) obtained at 1.9, 1.0 and 0.5 mm of first, second and third breakages, respectively (Table 2). It was obtained that there was no regular effect of second gap on medium size bulgur ($P < 0.05$) similar to coarse and pilaf size bulgur (Table 2).

As expected, the significant amount of fine size bulgur was obtained at the smallest third gap adjustment (0.4 mm, $P < 0.05$). The increase in third gap (0.6 mm), the percent mass of fine size bulgur decreased dramatically (Table 2). According to the results, different sizes bulgur i.e. coarse, pilaf, medium and fine could be produced using the roller mill by the arrangement of gaps. In addition, the ternary breakage with four rollers supplied uniform particle size and shape due to multiple breakage stages.

3.2. Change in colour values

The first quality judgement made by consumers on bulgur at the point of sale and acceptability is its visual appearance. Therefore, the colour of bulgur is the most important parameter for its acceptability (Bayram, Kaya, & Oner, 2004).

The colour values of the roller mill at different gap widths are illustrated in Table 3. The increase in third gap significantly ($P < 0.05$) decreased the lightness of bulgur when the first and second gaps were constant. The

Table 2
Percent mass values for coarse, pilaf, medium and fine size bulgur

Second gap (B, mm)	Third gap (C, mm)											
	Coarse			Pilaf			Medium			Fine		
	0.4	0.5	0.6	0.4	0.5	0.6	0.4	0.5	0.6	0.4	0.5	0.6
0.8	$0.55^{b,x}$ (±0.01)	$1.38^{c,y}$ (±0.02)	$1.40^{a,z}$ (±0.02)	$22.29^{b,x}$ (±0.01)	$68.56^{c,y}$ (±0.02)	$75.38^{a,z}$ (±0.01)	$48.48^{c,z}$ (±0.02)	$25.50^{a,y}$ (±0.02)	$21.38^{c,z}$ (±0.02)	$17.67^{b,z}$ (±0.02)	$2.11^{a,y}$ (±0.02)	$1.44^{c,x}$ (±0.01)
1.0	$0.42^{a,y}$ (±0.01)	$0.15^{a,x}$ (±0.02)	$7.74^{c,z}$ (±0.01)	$17.23^{a,x}$ (±0.02)	$21.99^{a,y}$ (±0.01)	$87.66^{b,z}$ (±0.02)	$51.79^{b,y}$ (±0.01)	$59.78^{c,z}$ (±0.01)	$3.50^{a,x}$ (±0.01)	$18.42^{c,z}$ (±0.02)	$6.41^{c,y}$ (±0.02)	$0.64^{b,x}$ (±0.02)
1.2	$0.76^{c,x}$ (±0.02)	$0.87^{b,y}$ (±0.01)	$6.73^{b,z}$ (±0.01)	$35.74^{c,x}$ (±0.01)	$37.44^{b,y}$ (±0.02)	$88.70^{c,z}$ (±0.02)	$46.98^{a,y}$ (±0.02)	$53.49^{b,z}$ (±0.01)	$3.95^{b,x}$ (±0.02)	$9.86^{a,z}$ (±0.02)	$4.10^{b,y}$ (±0.01)	0.37^{ax} (±0.02)

$^{a–c}$ Indicate statistically differences between each column for each size at $\alpha = 0.05$.
$^{x–z}$ Indicate statistically differences between each row for each product at $\alpha = 0.05$.
Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares, Duncan test was applied.

Table 3
Colour values (*L*, *a*, *b* and YI) of bulgur products, one-way ANOVA and multiple range test, when first gap hold constant at 1.90 mm, second and third gaps varied

Second gap (B, mm)	Third gap (C, mm)											
	L-value			*a*-value			*b*-value			YI-value		
	0.4	0.5	0.6	0.4	0.5	0.6	0.4	0.5	0.6	0.4	0.5	0.6
0.8	$60.81^{c,z}$ (±0.02)	$54.02^{a,x}$ (±0.02)	$55.59^{c,y}$ (±0.02)	$3.92^{a,x}$ (±0.01)	$4.90^{b,z}$ (±0.02)	$4.71^{a,y}$ (±0.01)	$20.59^{a,y}$ (±0.01)	$19.84^{a,x}$ (±0.02)	$20.89^{c,z}$ (±0.01)	$65.46^{a,x}$ (±0.02)	$72.43^{a,y}$ (±0.02)	$73.40^{a,z}$ (±0.01)
1.0	$59.85^{b,z}$ (±0.01)	$57.53^{c,y}$ (±0.02)	$51.04^{a,x}$ (±0.02)	$4.26^{b,x}$ (±0.01)	$4.58^{a,y}$ (±0.02)	$5.44^{b,z}$ (±0.02)	$20.93^{b,y}$ (±0.01)	$21.83^{b,z}$ (±0.01)	$19.65^{a,x}$ (±0.01)	$67.88^{b,x}$ (±0.01)	$73.62^{b,y}$ (±0.01)	$76.66^{b,z}$ (±0.01)
1.2	$56.01^{a,z}$ (±0.01)	$54.91^{b,y}$ (±0.01)	$52.39^{b,x}$ (±0.01)	$4.88^{c,x}$ (±0.01)	$5.27^{c,y}$ (±0.01)	$5.45^{c,z}$ (±0.01)	$21.55^{c,y}$ (±0.01)	$22.03^{c,z}$ (±0.02)	$20.84^{b,x}$ (±0.01)	$75.11^{c,x}$ (±0.02)	$78.57^{c,y}$ (±0.02)	$78.59^{c,z}$ (±0.01)

$^{a–c}$ Indicate statistically differences between each column for each size at $\alpha = 0.05$.
$^{x–z}$ Indicate statistically differences between each row for each property at $\alpha = 0.05$.
Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares, Duncan test was applied.

highest lightness value was obtained at A = 1.9, B = 0.8 and C = 0.4 mm. The decreasing the gap increased the lightness of bulgur. The effect of second gap on the lightness was not regular ($P < 0.05$).

The redness results of products milled with the roller mill were statistically analyzed. The highest result of redness (5.45) was found at the arrangement of gaps to be A = 1.9, B = 1.2 and C = 0.6 mm. The decrease in third gap significantly ($P < 0.05$) decreased redness values at constant first and second gaps which correlated with the increase in the lightness value. At fixed first (1.9 mm) and second (1.2, 1.0 and 0.8 mm) gaps, a regular increase in redness was obtained except at B = 0.8 mm (Table 3).

According to Table 3, the variation of third and second gaps at fixed first gap (1.9 mm) were significantly affected the yellowness of products ($P < 0.05$). Irregular change of yellowness values was observed at all gap arrangements. The highest YI-value (22.03) was obtained at the arrangements of gaps as 1.9, 1.2 and 0.5 mm for first, second and third gaps, respectively. Generally, the fine size bulgur had more pronounced yellow colour than the coarse one.

When third gap increased, the degree of yellowness index increased significantly ($P < 0.05$, Table 3). The highest yellowness index was obtained at A = 1.9, B = 1.2 and C = 0.6 mm.

3.3. *Change in ash content*

The maximum limits of ash content in bulgur according to Turkish, American and United Nation Standards are 1.8%, 3.0% and 3.0% (d.b.), respectively (TSE, 2003; USDA, 2002). In this study, the lowest (1.46%) and highest (2.28%) ash contents were obtained at third gaps of 0.4 and 0.6 mm, respectively, at A = 1.9 and B = 1.2 mm (Table 4, $P < 0.05$). There was also no regular effect of second gap on the ash content of samples milled. Additionally, third gap had significant ($P < 0.05$) effect on the ash contents. However, a consistent trend was not obtained at third gap. It might be due to the not removable stuck bran particles from the surface of bulgur kernels.

The milling of bulgur is different from flour and semolina. In flour and semolina millings, the separation should ideally occur at the level of the endosperm-aleurone layer

Table 4
The ash, yield, loss and hectolitre-weight values of bulgur products, one-way ANOVA and multiple range test, when first gap hold constant at 1.90 mm, second and third gaps varied

Second gap (B, mm)	Third gap (C, mm)											
	Ash (%, d.b.)			Yield (%)			Loss (%)			hl-wt (kg/hl)		
	0.4	0.5	0.6	0.4	0.5	0.6	0.4	0.5	0.6	0.4	0.5	0.6
0.8	$1.84^{b,z}$ (±0.02)	$1.79^{a,y}$ (±0.01)	$1.77^{b,x}$ (±0.01)	$88.99^{b,x}$ (±0.02)	$97.55^{c,y}$ (±0.02)	$99.60^{b,z}$ (±0.02)	$11.01^{b,z}$ (±0.02)	$2.45^{a,y}$ (±0.02)	$0.40^{b,x}$ (±0.02)	$70.08^{a,x}$ (±0.1)	$77.44^{c,y}$ (±0.2)	$77.56^{a,z}$ (±0.1)
1.0	$1.92^{c,y}$ (±0.01)	$2.25^{c,z}$ (±0.01)	$1.62^{a,x}$ (±0.02)	$87.86^{a,x}$ (±0.01)	$88.33^{a,y}$ (±0.02)	$99.54^{a,z}$ (±0.02)	$12.14^{c,z}$ (±0.01)	$11.67^{c,y}$ (±0.02)	$0.46^{c,x}$ (±0.02)	$70.84^{b,x}$ (±0.1)	$74.06^{a,y}$ (±0.15)	$79.44^{b,z}$ (±0.1)
1.2	$1.46^{a,x}$ (±0.02)	$1.94^{b,y}$ (±0.01)	$2.28^{c,z}$ (±0.01)	$93.34^{c,x}$ (±0.02)	$95.90^{b,y}$ (±0.01)	$99.75^{c,z}$ (±0.01)	$6.66^{a,z}$ (±0.02)	$4.10^{b,y}$ (±0.01)	$0.25^{a,x}$ (±0.01)	$73.20^{c,x}$ (±0.15)	$75.05^{b,y}$ (±0.15)	$81.08^{c,z}$ (±0.2)

$^{a–c}$ Indicate statistically differences between each column for each size at $\alpha = 0.05$.
$^{x–z}$ Indicate statistically differences between each row for each property at $\alpha = 0.05$.
Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares, Duncan test was applied.

(Peyron et al., 2002). First-break or the first roller mill operation in the milling process opens up the wheat kernel and releases the endosperm with minimum bran breakage (Pasikatan, Milliken, Steele, Spillman, & Haque, 2001). However, bran is removed before the milling operation using debranning or emery machines for bulgur.

3.4. Change in yield and loss

The yield and loss values were determined from the screen analyses that cumulative percent mass retained over (+/0.5) and lower (0.5/−) of 0.5 mm sieve, respectively (Table 4). The increase in third gap significantly ($P < 0.05$) increased the yield at fixed first and second gaps. The highest yield (99.75%) was obtained at $A = 1.9$, $B = 1.2$ and $C = 0.6$ mm. The effect of third gap on the yield was regular. However, second gap had no regular effects on the yield ($P < 0.05$).

The yield (87.86–99.75%) of the roller mill was high. The capacity of roller mill was determined to be 3500 kg/h. Energy consumption per one kg of products was found to be 0.00514 kW h/kg. Both values were measured at the optimum condition when the gaps were at the smallest value ($A = 1.9$, $B = 0.8$ and $C = 0.4$ mm). The yield and capacity of roller mill was higher than the other mills studied by Bayram and Öner (2005, 2007). The maximum loss was found at 1.9, 1.0 and 0.4 mm of gap adjustments for first, second and third, respectively.

3.5. Change in hectolitre-weight (bulk density)

Hectolitre-weights (kg/hl) are given in Table 4 at the different roller gap arrangements. The lowest value of hectolitre-weight (70.08 kg/hl) was obtained at $A = 1.9$, $B = 0.8$ and $C = 0.4$ mm. On the other hand the highest hectolitre-weight was 81.08 kg/hl that obtained at $A = 1.9$, $B = 1.2$ and $C = 0.6$ mm. It was due to big particle size (small surface area). The increase in third gap significantly ($P < 0.05$) increased the hectolitre-weight of products at constant first and second gaps (Table 4).

4. Conclusions

The milling characteristics of bulgur were determined using a new ternary breakage milling system with four rollers instead of six rollers. This system has a new principle for the milling of bulgur i.e. multiple stage milling in contrast to traditional method (one stage). This new design supplied an efficient milling. Its capacity and yield were pronounced. The energy consumption was acceptable. Due to multiple milling operations, the different sizes of bulgur could be obtained at the same time with one-running. The increase in third gap of the roller mill increased the percent mass of coarse, pilaf and medium size bulgur in contrast to decrease in the percent mass of fine size bulgur. Different types of bulgur such as coarse, pilaf, medium and fine size could be obtained at different rates, simultaneously.

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