EFFECT OF DIFFERENT MILLING SYSTEMS ON SELECTED QUALITY PARAMETERS OF BULGUR

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ABSTRACT

EFFECT OF DIFFERENT MILLING SYSTEMS ON SELECTED QUALITY PARAMETERS OF BULGUR

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Effect of different milling systems on selected quality parameters of bulgur was searched in this study. Studies were made with disc and roller mills, horizontal helical polisher and color sorting systems for bulgur production. Conventional disc mill and newly improved roller mill (with four rolls and three passing) used in bulgur production were compared based on; energy, capacity, yield, loss, milling characteristics, ash content, hectoliter weight, color and protein contents. The gaps of first-second rolls, second-third rolls and third-fourth rolls were adjusted to 1.90, 1.60 and 1.30 mm; 1.20, 1.00 and 0.80 mm, and 0.40, 0.50 and 0.60 mm, respectively, and twenty seven variations of those gaps were studied for roller mills. On the other hand, nine different gaps 1.90, 1.60, 1.30, 1.20, 1.00, 0.80, 0.60, 0.50 and 0.40 mm were studied for disc mill. The produced samples from both types of milling systems were screen analyzed using 3.50, 2.00, 1.00 and 0.50 mm size sieves. Screened fractions of (+/3.50), (3.50/2.00), (2.00/1.00), (1.00/0.50) and (0.50/-) mm named as coarse, pilaf, middle, fine sized bulgur and loss of bulgur, respectively. Also effect of the horizontal helical polishing system used in bulgur production line on quality factors such as color, protein content, loss, yield, moisture content and hectoliter weight of bulgur samples were researched. Color sorting system is applied on peeled intact, mixed and fine bulgur samples and effects of the system on percent purity (yield), loss and color values of the products were investigated. Yield values of samples from disc mill were found as 13.13, 72.33 and 84.84 % for gaps adjustments of 0.40, 0.50 and 0.60 mm, respectively. On the other hand, yield values of samples from roller mill were obtained between 84.77 and 99.75% for the same gaps. Especially for the fine bulgur, the yield values of the disc mill were found to be too low. The amount of loss in disc mill, especially for the 0.40 mm break was increased up to 86.87 % , was higher than that for improved roller mill. Even in the finest break of the improved roller mill system, the loss value was at most 15.23 %. The hectoliter weight values for the disc mill system were found to be higher than those of roller mill. In the roller system, coarse, pilaf, middle and fine bulgur products could have been produced simultaneously. The moisture and ash content were decreased from 13.08 to 11.15 % and 1.53 to 1.41% respectively, but hectoliter weight value measured on 2 mm sieve was increased from 67.16 to 85.35 kg/hl in horizontal helical polishing system. The measurements of color values from inlet and outlet of polisher were indicated decrease in L and increase in b values. Also, increase in YI (yellowness index) value which was parallel with this change reveals the fact that using polisher produces bulgur with desired amber color. Analysis of percent purity of intact, mixed and fine bulgur samples from color sorting system was showed that the highest value, 99.10 %, was obtained for intact bulgur.

Key words: bulgur, roller mill, disc mill, polisher, color sorting system.

ÖZ

FARKLI ÖĞÜTME SİSTEMLERİNİN BULGURUN SEÇİLMİŞ KALİTE PARAMETRELERİNE ETKİSİ

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Bu çalışmada diskli ve valsli değirmenlerin seçilmiş bulgur kalite parametrelerine olan etkisi araştırılmıştır. Çalışmalar diskli, valsli, yatık helezonik parlatıcı ve renk ayıklama sistemlerinde yapılmıştır. Bulgur üretiminde kullanılan mevcut diskli değirmen ile yeni geliştirilen dört toplu ve üç geçişli valslı değirmen; enerji, kapasite, verim, fire, parçacık boyut değişimi, kül, hektolitre, renk ve protein değerleri bakımından karşılaştırılmıştır. Valslı değirmen sisteminde ilk iki top aralığı 1.90, 1.60, 1.30 mm, ikinci ve üçüncü top aralığı 1.20, 1.00, 0.80 mm, üçüncü ve dördüncü top aralığı da 0.40, 0.50 ve 0.60 mm olarak ayarlanmış ve çalışmada bu aralıklar, yirmi yedi farklı varyasyonda kullanılmıştır. Diskli değirmende ise 1.90, 1.60, 1.30, 1.20, 1.00, 0.80, 0.60, 0.50 ve 0.40 mm olmak üzere dokuz farklı disk aralığı çalışılmıştır. Her iki sistemden elde edilen ürünlerin 3.50, 2.00, 1.00 ve 0.50 mm' lik elekler kullanılarak boyut analizleri yapılmıştır. 3.50 mm elek üstünde kalan kısım diri bulgur, 3.50 elek altı ve 2.00 mm elek üstü pilavlık bulgur, 2.00 mm elek altı ve 1.00 mm elek üstü orta boy pilavlık, 1.00 mm elek altı ve 0.50 mm elek üstü köftelik, 0.50 mm elek altı fire olarak değerlendirilmiştir. Ayrıca bulgur üretim hattında kullanılan yatık helezonik parlatma sisteminin renk, protein, fire, verim, hektolitre ve rutubet gibi kalite faktörleri açısından etkisi araştırılmıştır. Renk ayıklama sisteminin tüm, karışık ve köftelik bulgurlar üzerinde denenmiş, sistemin verimi, firesi, ürünün protein ve renk değerlerine olan etkisi incelenmiştir.

Diskli değirmende 0.4, 0.5 ve 0.6 mm disk aralıklarında verim sırası ile % 13.13, % 72.33 ve % 84.84 bulunmasına karşın, geliştirilen valslı değirmende % 84.77 ile % 99.75 arasında verim elde edilmiştir. Özellikle köftelik ince bulgurda diskli değirmen verim değerleri düşüktür. Diskli değirmende fire miktarı, özellikle 0.4 mm'lik kırımda fire 86.87% seviyesine kadar yükselmekte, geliştirilen valslı sistemden yüksektir. Geliştirilen valslı değirmende fire en ince kırımda bile %15.23 seviyesinde kalmaktadır. Diskli değirmende valslı değirmene göre daha yüksek hektolitre değerleri elde edilmiştir. Valslı sistemde aynı anda diri, pilavlık, orta ve köftelik bulgur üretimi yapılabilmektedir. Yatık silindirik helezon sisteminde rutubet değeri %13.08 den %11.15 e, kül miktarı da % 1.53 den %1.41 e düşmüş ancak 2 mm elek üstünde ölçülen hektolitre değeri 67.16 kg/hl den 85.35 kg/hl ye yükselmiştir. Parlatıcı cihazının giriş ve çıkışından alınan numunelerde yapılan renk ölçümleri ; L değerinde azalış ve b değerinde artış olduğunu göstermiştir. YI (sarılık indeksi) değerindeki artış ile de paralel olan bu değişim parlatıcının bulgura kabul gören amber renk kattığını göstermektedir. Renk ayıklama sistemiyle kabuğu soyulmuş tüm, karışık ve ince bulgur numuneleri için yapılan analizde, kabul veya ayıklanmış temiz oranını, %99.10 ile en yüksek değeri tüm bulgur vermiştir.

Anahtar kelimeler: bulgur, valslı değirmen, diskli değirmen, parlatıcı, renk ayıklama sistemi.

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CHAPTER I

INTRODUCTION

1.1. Definition of Bulgur

Refered to as "Arisah" in the Old Testament, this ancient food is variously known as bulgur, bulgor, boulgur, burgul, burghul, and burghoul (Haley and Pence, 1960). Bulgur is cleaned, cooked, dried and pulverized hard (durum) wheat product (Çömden, 1986). Bulgur has been consumed for centuries in Turkey, Syria, Jordan, Lebanon, Egypt and East European countries and its history goes back to 4000 years ago in these countries (Williams *et. al.*, 1984; Fisher, 1973; Özkaya *et. al.*, 1993).

Bulgur can be fixed in several different ways: falafel, for example, is a mixture of bulgur and faba bean flour, eaten as deep fried. In Syria, Jordan, and some other Arabic states, milk or yogurt is added to bulgur to prepare kishk. The mixture then fermented for a few days, until it forms little balls. Once dried, these can be stored for whole year. In Iraq, the same product is called kushuk. When prepared with oil, meat, or broth, bulgur is called pilaf in the Middle East and pilau in Pakistan (Fabriani and Lintas, 1988). A main food in Turkish cuisine is köfte in the Gaziantep style, a dish that is prepared with onions, garlic, salt, tomato paste, red pepper sauce, meat spice mix, chopped parsley, oil, well-minced meat, and fine bulgur (Bayram, 2000).

Bulgur is rapidly coming into commercial prominence in the United States to evaluate America's wheat and large amounts are being shipped overseas under government assistance programs, and as availability in domestic food channels is growing. Because, it is a relatively unrefined product, its nutritional values have been regarded as similar to those of whole wheat (Anon., 1996; Pence *et al.*, 1964). Migration from village to city, production of this type of food materials was carried to factories (Öktem, 1984).

In Turkey, bulgur was first produced at Karaman during the First World War by Rıza Küçükoglu at the industrial base (Seçkin, 1968). Significant amount of bulgur was produced respectively at Gaziantep, Karaman, İçel, and Çorum. The number of bulgur plants in Turkey is nearly 500 and about 1 million tones of bulgur are produced per year recently. This production is 2.5 times greater than macaroni (pasta) production, with an average consumption of 12 kg per person (Bayram *et. al.*, 2003).

1.2. Properties of Bulgur

Bulgur is an ideal food to meet the nutritional requirements of many people because of its low cost, long shelf-life, ease of preparation, and high nutritional value. Wheat is almost cooked, thus starch is gelatinized (Kıncal and Saygın, 1990). Also it is different usable food material and resists attack by insects and mites. Also, it is important for human diet and trade is spread over the world with this properties (Fisher, 1973; Öktem, 1984; Tahsin, 1964; Ercan,1986; Anon., 1995; Kent, 1975; Smith *et. al.*, 1964).

Bulgur is more stable than wheat at hot and humid environments due to inactivation of enzymes and microorganisms that present in wheat, during cooking and drying operations. (Neufeld *et. al.*, 1957). Additionally, bulgur is more important than wheat with respect to physiological properties and cooked easily to eat immediately (Ercan, 1986).

Other properties of bulgur can be explained as unabsorption of radiation, its low fat content and high protein content, and appealing taste. The differences in fat, fiber and ash are significant but moderate. The values for these factors in the bulgur are sufficiently larger than those normally found in flour or wheat endosperm to indicate that a fairly large part of the bran nutrients is retained in bulgur (Bayram and Öner, 2002).

In Turkey, two types of bulgur are standardized, coarse type for pilaf (kernel dimensions 3.55-1.66 mm) and fine type for köfte (kernel dimensions 2.00-0.50 mm). But, most of the bulgur are produced by the producers practically. According to the Turkish Standards, bulgur is explained with following properties (Anon., 1996; Bayram *et. al.*, 1996; Bayram and Öner, 1996; Baysal, 1996; Solak and Yılmaz, 1996; Tütüncü, 1993; Parlayıcı, 1993):

Types of bulgur:

Type I: Bulgur for pilaf (3.55 mm-1.60 mm),

Type II: Bulgur for köfte (2.00mm-0.50mm)

Properties of bulgur:

Color: should be natural

Taste: should be natural

Flavor: should be natural

Mold: should not be found

Waste of insects (insect's egg etc.): should not be found

Food additives: should not be found

Moisture content (w.b): should be less than 13 %

Ash content (d.b): should be less than 1.75 % (g/g)

Insoluble ash content in 10 % of HC1 (dry basis): should be less than 0.30 % (g/g)

Tolerances:

Stone, soil, sand, straw: should be less than 0.01 % (g/g)

Foreign herb seed: should be less than 0.1 % (g/g)

Cephalaria: should be less than 0.2 % (g/g)

Other cereal grains: should be less than 1 % (g/g)

Coarse wheat: should be less than 1 % (g/g)

White kernel: should be less than 1 % (g/g)

Lower screen: should be less than 0.5 % (g/g)

1.3. Raw Material

The type of wheat is a major factor that contributes to the production of high-quality bulgur. Common hard and even soft wheat can be used to produce bulgur. In general, *Triticum durum* is prepared to produce bulgur due to its good milling property, light yellow color, nitrogen and starch compounds that form a hard texture and chewing characteristics. Color (yellow color), water absorption, texture and chewing characteristics of final product depend on raw material (Öktem, 1984; Güven, 1986).

The grinding or milling value of durum wheat is defined as the yield of semolina or bulgur of defined purity under industrial conditions. The bulgur or semolina milling value is dependant on regulatory factors (ash value of bulgur percent masss), harvesting conditions, and intrinsic factors of grains. Among these, the structure of aleurone layer is presumed to play a significant role. The aleurone layer consists of living tissue, generally on cell thick, surrounding the endosperm. From a botanical standpoint, it is the outer layer of the endosperm. However, as it is removed during milling, it constitutes the inner most layer of bran (Peyron *et. al.*, 2003).

The world durum wheat production for the decade 1976-1985 was investigated by international wheat council in 1986. According to this investigation, Turkey was the largest producer, with an average 5.150.000 tones per year, followed by Italy at 3.330.000 tones and the USA at 3.200.000 tones (Pomeranz, 1988).

Until recently, durum wheat was thought to have come originally from Ethiopia and then, passing through Egyop, spread to the Mediterranean Basin. More recent studies, howover, indicate that the Gramineae, from which both common wheat (*T.vulgare*) and durum wheat developed later, originally came from the Zagros Mountains, which overlook the Mesopotamian Plain along the frontier between the Iran and Iraq (Bizzarri and Morelli, 1980).

In the *Triticum* genus, three distinct groups of species are distinguished by the number of their chromosomes: wheat with seven pairs of chromosomes, the principal representative of which is *T. monococcum*; wheat with 14 pairs of chromosomes, the principal wild variety of which is *T. dicoccum* and the principal domestic one, *T. durum,* and the most important wheat, with 21 pairs of chromosomes, *T. vulgare* or common wheat. The excavations of the Neolithic city of Catal-Hüyük in Turkey, which, dating back 8,000-8,500 years, older than Jerma, brought to light arich collection of seeds of numerous edible plants, among which those of interest to us are the seeds of *T. amyleum,* a type of emmer (*T. dicoccum*), and *T. monococcum*. Worthy of note is the fact that the caryopses of the *T. amyleum* seeds were large and uniform, which shows that the species had already been domesticated, having reached a standard, while the caryopses of the *T. monococcum* were small and irregular in form-an obvious sign that domestication had not yet begun or was only just beginning (Bizzarri and Morelli, 1980).

If there is insufficient durum wheat, bread type wheat is sometimes used at villages. In the Middle East, bulgur is traditionally made in homes from durum wheat, but commercial products used in the United States are made from both white and red wheat types in either whole grain or cracked forms (Çömden, 1986; Ercan, 1986; Aydın *et. al.*, 1994; Fabriani and Lintas, 1988; Elgün and Certel, 1987). In additional to physical properties, some characteristics such as, level of foreign materials, homogenity and seed of pelemir (cephalaria syriaca) (it is not separated from wheat easily) are important for processing of bulgur and quality of finished product (Öktem, 1984).

Aydın et al (1994) examined the bulgur quality obtained from some durum wheat varieties. In this study, durum wheat varieties in Turkey (Kunduru 1149, Cakmak 79 and Kızıltaş 91) grown at different locations (Haymana, Kozan, Polatlı and Çiçekdağı) were used. Physical and chemical characteristics and suitability of these varieties for bulgur production was investigated. The effects of variety and environment on bulgur process were also studied. According to their study, water absorption and pigment content of bulgur found to be affected by variety, stickiness and firmness. Total organic matters of bulgur and pilaf quality found to be affected by the environment. Additionally, another study on durum wheat varieties growth in Turkey was carried out by Ercan and Bildik (1993) to determine the their milling ability and physicochemical characteristics.

1. 4. Processing and Production of Bulgur

There are some different production processes of bulgur around the world. These differences come from technological level of countries, habits of humans, etc. Therefore, different types of processing are explained. In Turkish factories, bulgur is produced by the Antep and Mut style. In the Antep type production, after dry cleaning, the wheat is cooked, and the dried wheat is peeled, ground, polished, classified and packaged. In Mut type production, wheat is dry and wet cleaned, cooked, dried, tempered, stone peeled and ground, then redried, cleaned, sized, and packaged (Bayram and Öner, 2002).

Cleaning, soaking, cooking, drying, sieving, peeling, grinding, polishing, packaging and storage are used in new technology respectively. Cleaning is made using the aspirator installed sieving machine. This stage removes dust, soil and foreign materials. Cleaning step is finished with washing. Then cooking of wheat is made controlling white spot in endosperm. The cooked bulgur is dried in the tunnel dryer with the ventilation of hot air until the moisture content decreases to 10-12%. If the temperature of air increases, color of wheat would be darken. Sieve is used for sorting of wheat based on their sizes. Wheat bran can be peeled easily which is made using special dehullers. The peeled wheat is grinded with different mills. The processed bulgur is packaged into bag or sack and then stored. During cooking and grinding, testa, peripheral layers i.e. aleurone layer and pericarp are not separated. However, some parts of endocarp are peeled. As yield, 4 kg of bran and 4 kg of small bulgur are produced from 100 kg of wheat during bulgur production during these stages (Tahsin, 1964). Additionally, the production yield of cutting machine is more than grinding machines (Çömden, 1986). The product is sometimes used in whole kernel form, but it is usually coarsely cracked, screened to remove very fine particles, and bagged for distribution. (Smith *et. al.*, 1964)

1.4.1. Cleaning of raw material

Cleaning is the first step in production of bulgur. Generally, cleaning steps are nearly same for all types of processes of other food materials. The cleaning operations separate the impurities and foreign seeds by dimensions, weight, and form (Bizzarri and Morelli, 1980). At this step, stems, straws, stones, foreign matters, broken kernels and husk are separated using rotary or flat screen and aspirators. Stones, foreign materials and broken kernel are separated using separators. Then, vertical washer machine is used for cleaning using water and centrifugal force to remove excess water from kernel. In washing unit, dust and dirty materials are removed by centrifuge to prevent the damage of the outside of kernel. Additionally, in this unit light materials can be removed. Moisture content of wheat in this step is increased up to 15 %.

1.4.2. Cooking

The basic objective of the cooking cereals is to convert their starch content to a digestible form by gelatinization. However, commercial cooking processes give additional aims: to change the cereal's properties e.g. as in the case of parboiled rice or bulgur; to prepare the cereal for further processing e.g. corn flakes or rice crisps, and to shorten subsequent preparation stages e.g. for "instant groats" or "1 minute rice" in each case with only partial gelatinization of the starch and with minimum changes to product texture and consistency (Sherry and Amla, 1972).

The main requirement during cooking of wheat, moisture content should be more than 40%. If the moisture content of kernel is less than this limit, white spots occur in the kernel. This white spot shows the ungelatinized starch. The gelatinization of wheat starch starts at 67.5°C. During gelatinization, shape of the wheat starch does not change but it swells (Çömden, 1986; Öktem, 1984). During cooking, temperature should be below 95°C to prevent denaturation of the nutritional compounds (Çömden, 1986; Öktem, 1984; Tahsin, 1964). Addition of water is also important for nutritional content. If water content is high, solubilized vitamin B will be decanted at the end of cooking (Çömden, 1986).

In continuous cooking, hot wheat from the tempering operation is cooked in steam at 100°C on wire-cloth trays in a small belt-type cooker. Completion of cooking is judged by making "white center counts". Soaking and cooking conditions that minimize bursting of kernels and exudation of starch are required or grain becomes too sticky for the subsequent processing. Excessive darkening of grain, the development of undesirable flavors, and material loss of nutrients must also be avoided (Smith *et. al.*, 1964).

Cooking conditions must be selected to give complete gelatinization without darkening the product or making it so sticky as to interfere with subsequent drying. Conditions for the precook treatment and for drying should be selected carefully to balance the costs of these treatment with the quality characteristics of the product (Seçkin, 1968).

Cooking equipment varies from atmospheric batch kettles to continuous pressure cookers (Haley and Pence, 1960). In some plants, screw conveyer cooking system is applied. In batch system, 1.5-2 times water of wheat is added into kettle then 1-1.5 hours boiled. At the end of cooking, all water should be absorbed by kernel to prevent nutritional losses (Çömden, 1986).

1.4.3. Drying

Drying is another the most important step in bulgur production. Production of bulgur is the application of parboiling operation to wheat, preferably hard varieties. According to literature, industrially, drying can be made by fluidized bed, rotary dryer, sun drying, tower and tunnel. Cooked bulgur is dried in tunnel dryer with ventilation of hot air at 60 °C until 10-12% of moisture (Güven, 1986).

1.4.4. Milling

1.4.4.1. Tempering and dehulling

Tempering: is the controlled addition of moisture to wheat to achieve the following objectives: (Fang and Campbell, 2003)

i) to toughen the bran, reducing formation of bran powder during the size reduction process;

ii) to soften the endosperm, enhancing its millability and reducing the power consumed by the reduction rolls;

iii) to ensure that all materials leaving the grinding rolls are in optimum condition for classification by sieving;

iv) to ensure the endosperm moisture content is sufficient to a final product moisture content;

v) to facilitate separation of brain from the wheat kernel, reducing the power consumption of the break rolls and consequently reducing evaporative losses.

Separation of bran from endosperm depends on differences in mechanical properties between two tissues, which are amplified by grain conditioning (Peyron *et. al.*, 2002). After all the additional materials and foreign seeds as well as the dirt attached to the seed coat is eliminated in the first cleaning, the cleaned wheat is dampened at least once in automatic dampeners. An intensive dampener composed of a cylindrical steel body, a motor and equipped with high-speed slats, mixes the wheat with water, exposing all the grains of wheat to surface moisture in the same way. (Bizzarri and Morelli, 1980).

The time required for the grain of wheat to absorb the water depends on the structure and the natural moisture of grain. Wheat that is hard and dry must be tempered longer than soft wheat, since it takes more time for the water to penetrate into the hard kernel. Because hard, smooth grains absorb water more slowly, it is preferable to dampen a hard grain several times with a little water, rather than once with a lot of water. The conditioning of wheat, through repeated dampening and tempering in the tempering bins, brings wheat to the best condition for grinding. By adjusting the moisture content in general and the distribution of moisture in particular, conditioning ensures that the seed coat becomes sufficiently resistant not to be reduced in the breaking process and yet detaches itself easily from the farinaceous kernel. The kernel must not be too damp but uniformly friable enough to allow itself to be worked by the corrugated cylinders with a minimum of pressure. Therefore, the hard grains must be conditioned in such a way that, at the first breaking, they are optimally friable. Obviously, this does not mean that grains of different qualities must have the same degree of dampness, because, in general, a vitreous grain will be dampened much more than a less vitreous grain at the same degree of hardness (Bizzarri and Morelli, 1980).

Nowadays, the following tempering times and moisture contens are typical: for durum wheat, 16-24 hr of tempering to 17-17.5% moisture; for white durum wheat, 12-16 hr at 16-16.5% moisture. Obviously, the season of the year also plays a part, since dampness penetrates faster in summer than in winter (Bizzarri and Morelli, 1980).

Dehulling: The objective of de-hulling is to remove bran from wheat. During dehulling, aleurone and endocarp layers should not be damaged. Because, the aleurone layer is guardian for endosperm. During dehulling, cellulose compounds are removed; generally 7% of weight of dried wheat is decreased (Eğriçayır, 1979; Aydın, 1994). After dehulling process, ash content of the product is also decreased. Sprinkling the dried wheat with water and rubbing the moistened grain by mechanical dehuller often remove the bran. There are many dehullers used in bulgur production such as abrasive type mill, Konoz, stone mills (Bayram, 2000).

1.4.4.2. Grinding and size reduction

The objective of grinding is to produce small particles from larger ones. Smaller particles are desired either because of their large surface or because of their shape, size, and number. One measure of the efficiency of the operation is based on the energy required to create new surface, the surface area of a unit mass of particles increases greatly as the particle size is reduced (McCabe and Smith, 1993).

The term size reduction is applied to all the ways in which particles of solids are cut or broken into smaller pieces. Throughout the process industries solids are reduced in size by different methods for different purposes. Reducing the particle size also increases the reactivity of solids; it permits separation of unwanted ingredients by mechanical methods; it reduces the bulk of fibrous materials for easier handling (McCabe and Smith, 1993).

Solids may be broken in many different ways, but only four of them are commonly used it size-reduction machines. They are (1) compression, (2) impacting, (3) attrition, or rubbing, and (4) cutting. A nutcracker, a hammer, a file, and a pair of shears exemplify these four types of action. 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 (McCabe and Smith, 1993).

i. Criteria for comminution: Comminution is a generic term for size reduction; crushers and grinders are types of comminuting equipment. An ideal crusher or grinder would (1) have a large capacity, (2) require a small power input per unit of product, and (3) yield a product of the single size or the size distribution desired. The usual method of studying the performance of process equipment is to set up an ideal operation as a standard, compare the characteristics of the actual equipment with those of the ideal unit, and account for the difference between them. When this method is applied to crushing and grinding equipment, the differences between the ideal and the actual are very great, and despite extensive study the gaps have not been completely accounted for (McCabe and Smith, 1993). During comminution operations, both material properties and milling methods affect particle breakage (Scanlon and Lamb, 1995).

The capacities of comminuting machines are best discussed when the individual types of equipment are described. The fundamentals of product size and shape and of energy requirements are, however, common to most machines and can be discussed more generally (McCabe and Smith, 1993).

ii. *Characteristics of comminuted products*: Unlike an ideal grinder, an actual unit does not yield a uniform product, whether the feed is uniformly sized or not. The product always consists of a mixture of particles, ranging in size from a definite maximum to a submicroscopic minimum. Some machines, especially in the grinder class, are designed to control the magnitude of the largest particles in their products, but the fine sizes are not under control. In some types of grinders fines are minimized, but they are not eliminated. If the feed is homogeneous, both in the shapes of the particles and in chemical and physical structure, the shapes of the individual units in the product may be quite uniform; otherwise, the grains in the various sizes of a single product may vary considerably in proportions (McCabe and Smith, 1993).

In break roller milling of wheat, the factors affecting breakage of wheat grains can thus be broadly classified into those arising from the physicochemical properties of wheat (size distribution, moisture content, hardness) and those related to the design and operation of the milling equipment (Campbell *et. al.*, 2001).

iii. *Energy and power requirements in comminution*: The cost of power is a major expense in crushing and grinding, so the factors that control this cost are important During size reduction, the particles of feed material are first distorted and strained. The work necessary to strain them is stored temporarily in the solid as mechanical energy of stress, just as mechanical energy can be stored in a coiled spring. As additional force is applied to the stressed particles, they are distorted beyond their ultimate strength and suddenly rupture into fragments. New surface is generated.

Since a unit area of solid has a definite amount or surface energy, the creation of new surface requires work, which is supplied by the release of energy of stress when the particle breaks. By conservation of energy, all energy of stress in excess of the new surface energy created must appear as heat (McCabe and Smith, 1993).

The surface energy created by fracture is small in comparison with the total mechanical energy stored in the material at the time of rupture, and most of the latter converted to heat. Crushing efficiencies are therefore low. But the results do show that crushing efficiencies range between 0.06 and 1 percent. The energy absorbed by the solid is less than that fed to the machine. Part of the total energy input is used to overcome friction in the bearings and other moving parts, and the rest is available for crushing. The ratio of the energy absorbed to the energy input is the mechanical efficiency (McCabe and Smith, 1993).

For example, in semolina milling, size reduction is to dissociate the bran from the starchy endosperm. The separation should ideally occur at the level of the endosperm-aleurone layer interface if aleurone, with its high ash content, is to be excluded from semolina. However, the aleurone layer is ontogenetically part of endosperm, it is separated as part of the bran during the milling process. Differences in the mechanical properties of bran and starchy endosperm are major elements determining wheat milling quality (Peyron *et. al.*, 2002).

The hardness of starchy endosperm has been the subject of many studies and identified as a major factor influencing milling behavior. Bran thickness is considered to have a dual role in the size reduction process: (i) the endosperm/bran ratio is recognized as an intrinsic grain characteristic influencing the semolina or bulgur milling value, and (ii) the thickness of the peripheral bran layers may affect the mechanical resistance of bran and is a factor determining the ease of separation of the endosperm from bran (Peyron *et. al.*, 2002).

1.4.4.2.1. Roller mill

In this machine heavy steel cylinders revolve towards each other. Particles of feed are nipped and pulled through the rolls, experiencing a compressive force which crushes them. In some machines a differential speed is maintained between the rolls and shearing forces also arise. The throughput of these units is governed by roller length and diameter and by the speed of rotation. The diameter of the rolls, differential speed of the rolls and the 'nip', the spacing between the rolls, can be varied to suit the feed size and throughput rate required (Brennan *et. al.*, 1976).

The 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 the roll. Numerous configurations of roll corrugations are available to the miller, who may therefore choose the best arrangement. Different wheats require different roll corrugations for best milling results. For example, first break rolls in U.K. mills may have only three and three-quarters or four corrugations per centimeter of roll circumference, to facilate the grinding of the larger kernel characteristic of native wheat included in the grist. Most U.S. and Canadian millers prefer to have five corrugations on their first break rolls to accommodate the smaller-kernal domestic wheat. The corrugations vary not only in the number per centimeter but also in the "profile", or shape of the tooth. A sharp angle is used primarily for hard wheats to make semolina and bulgur, whereas flater angles are used for softer wheats. The corrugations may also be oriented to be either sharp or dull, as determined by the direction of the sharp angles as the rolls rotate (Pomeranz, 1988).

The working principle of grinding rolls is as follows; the product enters the cylinder, where a pulse transmitter controls the feed rate automatically according to the product. The pulse, amplified by servo-regulation, serves at the same time to engage and disengage both the milling and the feed rollers. The product conveyed by the feed system enters between the grinding cylinders where, through the effect of compression and difference of speed between the two rollers, it is ground (Bizzarri and Morelli, 1980).

The grinding area is always composed of one fixed roller (drive) and one movable roller for semolina milling. The roll gap is regulated by two hand-wheels. Transmission between the cylinders usually comes about by means of a gear wheel in gray cast iron and special cast iron. The ratios between the cylinders are usually 1:1.5-1:3.0 for corrugated and 1:1.05-1:1.5 for smooth. The number of revolutions of the fast cylinder varies from 250 to 650, according to the grinding requirements. The ground material flows into a collecting hopper and is then conveyed pneumatically to the dehuller or screening sections (Bizzarri and Morelli, 1980).

Studies on milling equipment, including roll design and operational settings, have long been reported for both fluted and smooth rolls. Niernberger and Farrell (1970) compared experimental results from fluted rolls with three different diameters of 152, 228, and 305 mm, and found that 228 mm rolls gave the lowest ash content. Creason (1975) believed larger diameter rolls, with their greater are of contact, would be better for coarser reduction (Pomeranz, 1988).

1.4.4.2.2. Disc mill

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, this type of mill finds extensive application. Two type of disc mill are the single and double disc mills (Brennan *et. al.*, 1976).

Single Disc Mill: In this device the feedstock passes into a narrow gap between a high speeds, 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.

Double Disc Mill: In this modification the casing contains two rotating discs. The discs rotate in opposite directions giving a greater degree of shear than that attainable in the single disc mill. This type of mill is widely used in cereal preparation, corn, rice, and wheat milling. The pin-disc mill, popular in the food industry, carries pins or pegs on the rotating elements. In this case impact forces also play a significant part in the breakdown of particulate matter (Brennan *et. al.*, 1976).

Disc mill grinds product between two discs upon which are mounted corrugated grinding elements. The profile and size of the corrugations, much like the fluting used on roller mills, is one of the factors that determine the characteristics of the ground product. Two other important factors influencing the grind characteristic are speed of rotation and the gap between the grinding elements. For each application the type of corrugation, relative disposition of the corrugations (sharp to sharp, dull to dull etc.), speed and motor size are selected by the machine is supplied as configured. The grinding gap can be adjusted on site, easily and accurately, by means of a micrometer hand-wheel. When the corrugated elements are worn, or a different corrugation profile is required, the elements can be changed quite easily. It takes about one hour for one man (Anon., 2003).

The disc mill has many applications and is the heart of several milling systems. It can be used with finesse to break open cereal grains such as wheat or it can be used with brute force to reduce granular products to fine flour. Disc mill bridges the gap between roller mills and hammer mills (Anon., 2003).

Installation of the disc mill is straightforward. It is supplied with vibration dampeners for each of the four feet of the freestanding support frame. The ground product discharge point is located at sufficient height to allow the installation of the ground product conveying line on the same floor as disc mill. This means the disc mill can be located on a solid ground floor if required. The compact design and small footprint compare favorably with those of a roller mill or hammer mill (Anon., 2003).

1.4.4.3. Screening and classification

Screening is the unit operation in which a mixture of various sizes of solid particles is separated into two or more percent masss by passing over a screen. Each percent mass is more uniform in size than the original mixture. A screen is a surface containing a number of equally sized apertures. The surface may be plane or it may be cylindrical. Small capacity plane screens are called sieves (Brennan *et. al.*, 1976).

Standard screens are used to measure the size (and size distribution) of particles in the size range between about 3 and 0.0015 in. (76mm and 38 μm). Testing sieves are made of woven wire screens, the mesh and dimensions of which are carefully standardized. The openings are square. Each screen is identified in meshes per inch. The actual openings are smaller than those corresponding to the mesh numbers, however, because of the thickness of the wires (McCabe and Smith, 1993).

In making an analysis a set of standard screens is arranged serially in a stack, with the smallest mesh at the bottom and the largest at the top. The sample is placed on the top screen and the stack shaken mechanically for a definite time, perhaps 20 min. The particles retained on each screen are removed and weighed, and the masses of the individual screen increments are converted to percent masss or mass percentages of the total sample. Any particles that pass the finest screen are caught in a pan at the bottom of the stack (McCabe and Smith, 1993).

1.4.4.4. Color sorting system

The main objective of a color sorting system is to remove foreign materials and obtain a homogeneously colored product in production lines (sometimes mixing occurs during production) and finished product. A color-sorting system is designed to differentiate colors in materials flowing at high velocity, using microprocessor control equipment (Figure 1.1). Automated separation and sorting of food products was first performed in 1880. When crude electrostatic methods were employed to remove chaff and other light materials from cereal grains. These early systems used photodiodes or photo-multiplier tubes to discriminate between the overall color of the desired product and foreign bodies, such as stones and glass. These detectors are still used today to identify large color variations, e.g. to identify nuts that have not been shelled. Today, almost all color sorters use high-speed, solid-state charge coupled device (CCD) cameras that can detect blemishes less than 1 mm in size. (Bayram *et. al.*, 2003).

Small-particulate foods can be automatically sorted at very high rates using microprocessor-controlled color-sorting equipment. Materials are fed from a vibrating hopper or conveyor belt onto a flat or channeled gravity chute. Ideally, feeding method should separate the product into a uniform sheet, or monolayer. The angle, shape, and lining material of the chute can be altered to control the velocity of the pieces. The product then passes into an optical inspection area (photo-detector). The color of the background and the type and intensity of the light used illuminate the materials are closely controlled for each product. A sensor detects colors and provides an alarm or control signal when a pre-selected color passes the detector beam. The detector is also able to distinguish between different colored products (Bayram *et. al.*, 2003).

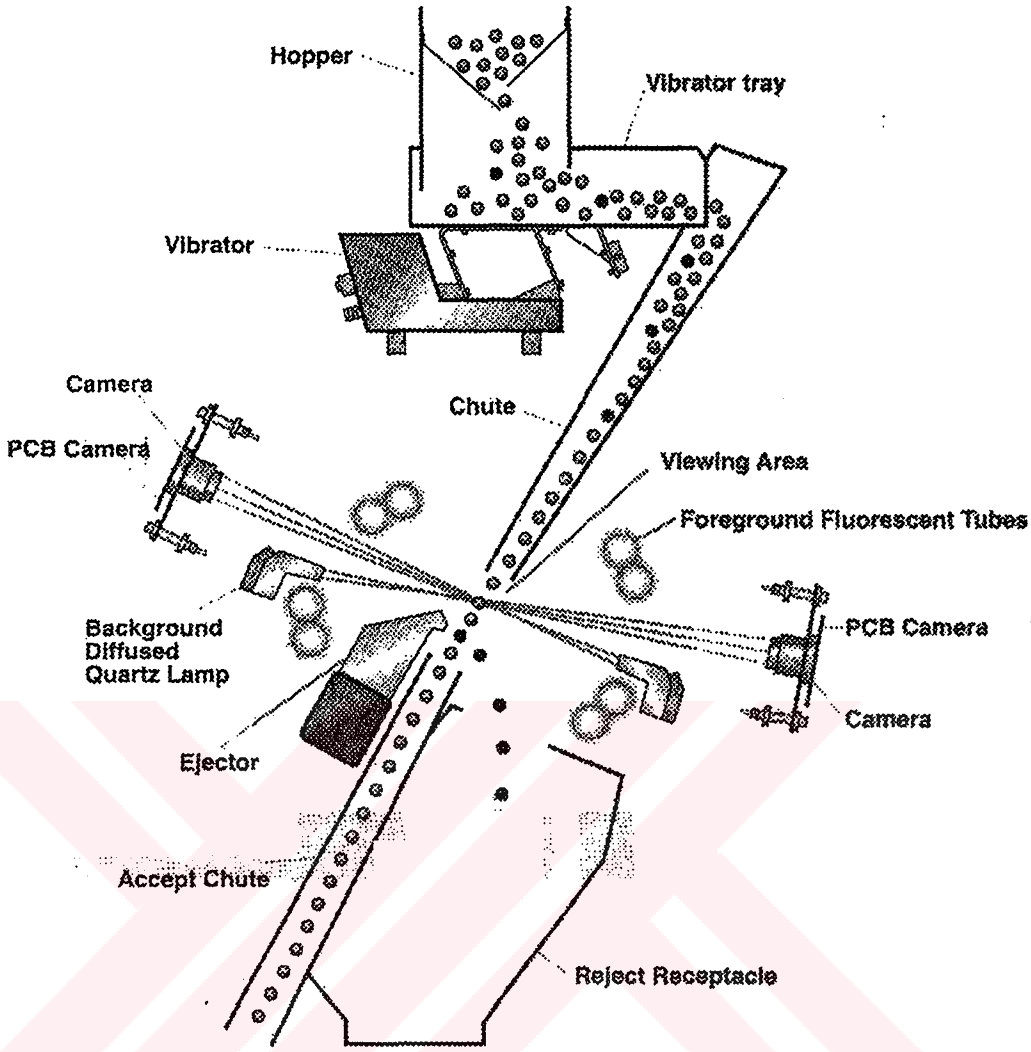

Figure 1.1. Illustration of the working principles of the color-sorting system

Photo-detectors measure the reflected color of each piece and compare it with preset standards. The relative intensities of reflected red, green, and yellow light are transmitted to the microcomputer, which constructs a composite image of each piece of food, showing both the spread of color and the mean color of the inspected product. The computer compares the constructed image with preset specifications. If the values are outside the range of acceptable values, a compressed air ejector, a mechanical deflector, or another mechanism is activated to remove the rejected food. The usual method for removing unwanted items from the main product stream is a controlled, short blast of compressed air from a high-speed solenoid or linear array of

pneumatic ejector valves connected to a nozzle strategically positioned along the product stream (Bayram *et. al.*, 2003).
The most important color problem for bulgur producers is the mixing of reddish wheat and durum wheat during harvesting and storage. Bulgur should have a light yellow, homogeneous color. The acceptability and economic value of bulgur can be decreased 5% (price level) due to foreign grain seeds (rye, barley, etc.), materials and reddish wheat seeds (dark brown or red). Foreign materials and reddish seeds in bulgur can cause economic losses of $25 million/year ($25/t) (Bayram *et. al.*, 2003).

Removing foreign materials and reddish wheat seeds from raw materials is impossible using standard pre-cleaning methods, particularly because some foreign seeds have the same specific gravity and shape as durum wheat. Color-sorting systems based on computer technologies have been widely adopted in other food sectors, especially in fruit and vegetable, legume (rice, beans, chickpeas, and lentils), and nut (hazelnuts, peanuts, pistachios, etc.) processing. Many of the typical foreign materials, discolored grains, and reddish wheat kernels found in durum wheat during bulgur production can be identified based on their color. By identifying and removing defective grains and foreign materials, producers could provide a consistent, premium quality product at increased profit margins, which would strengthen their competitive position (Bayram *et. al.*, 2003; Bee, 2002; Fellows, 1988).

Increasing consumer demands for better quality and improved safety measures, as well as tighter E.U. and U.S. Food and Drug Administration standards for food quality and adoption of hazard analysis critical control points (HACCP), have led food processors to implement new quality control measures. As part of these measures, food processors can benefit from using automated systems for food sorting. Machines can not only maintain greater levels of consistency in sorting than manual techniques, but also frequently offer reduced labor costs (Bayram *et. al.*, 2003; Bee, 2002; Fellows, 1988).

1.4.4.5. Polishing system

Polisher system is a new step that enhances good yellow color and improves the appearance of bulgur surface (Bayram and Öner, 2002). Cylindrical system is used to polish the product in order to have good yellow color. If the capacity of classification sieves is low, one horizontal cylindrical conveying system may be used instead of two.

Generally, when the broken products by mill are fed to polisher, some bran and flour that remained are firstly separated. For this reason, the product is prescreened. Then, in order to remove flour stuck, bran on surface and to smooth shells of edges of products, about 0.2-0.6 percent of water at 40-60^{0}C is added to the product and mixed. Bulgur could be fed by a pre-helical system.

1.4.4.6. Packaging

The classified product is packaged in different sized packages by using automatic packaging machines. Different packaging machines are used depending on the capacities of the factories and customers. The classified bulgur products are conveyed to the silo tanks by pneumatically, and to the packing unit.

1.5. The aim of this study

The aim of this study was to:

- determine the effects of different milling systems on bulgur quality;
- determine the effects of roll mills on particle size (% mass), color, yield , loss, hectoliter weight, protein, ash, and moisture contents;
- compare roller mill results with disc mill;
- determine the effects of polishing system on bulgur quality;
- determine the effects of the color sorting system on color, yield, and protein content of bulgur.

CHAPTER II

MATERIALS & METHODS

2.1. Materials

Triticum Durum wheat was used as raw material obtained from Tiryaki Bulgur Factory. Cleaned wheat was cooked at 100 °C and 1 atm for 40 minutes. 7 tons of water was added to 5 tons of wheat during cooking of wheat for bulgur production. Cooked wheat then was dried in a Tower Dryer with hot air (70-130 °C) in 9 hrs. Bulk density (hectoliter weight), moisture and ash content of intact bulgur (dried sample) were determined as 78.54 kg/hl, 11.32% (w.b.) and 1.65% (d.b.) for roller milling; 76.02 kg/hl, 11.86% (w.b.) and 1.60% (d.b.) for disc milling, respectively.

2.2. Methods

2.2.1. Roller milling

Roller mill was designed and constructed by Güney Machinary Co. (Gaziantep, Turkey) for the bulgur milling operation. Four rolls were used in roller milling equipment. Designed milling rolls were shown in Figures 2.1-2.5. Design parameters and properties of first and third rolls were same with second and fourth rolls, respectively. Their rpm's were identical as 310 rpm.

Roll disposition of four rolls was shown in Figure 2.1. First and second rolls were disposed as sharp-to-dull. Disposition of second and third rolls was dull-to-sharp. Third and fourth rolls were disposed as the same as first and second roll that sharp-to-dull.

In Figure 2.1, F is the feeder of roller mill. A, B and C are the gap or the passings between the 1st & 2nd rolls for first break, 2nd & 3rd rolls for the second break, and 3rd & 4th rolls for the third break, respectively. Due to these gaps between four rolls, intact dehulled bulgur was broken as three times. Each is driven by one motor with 18 kw of power and 970 rpm of speed.

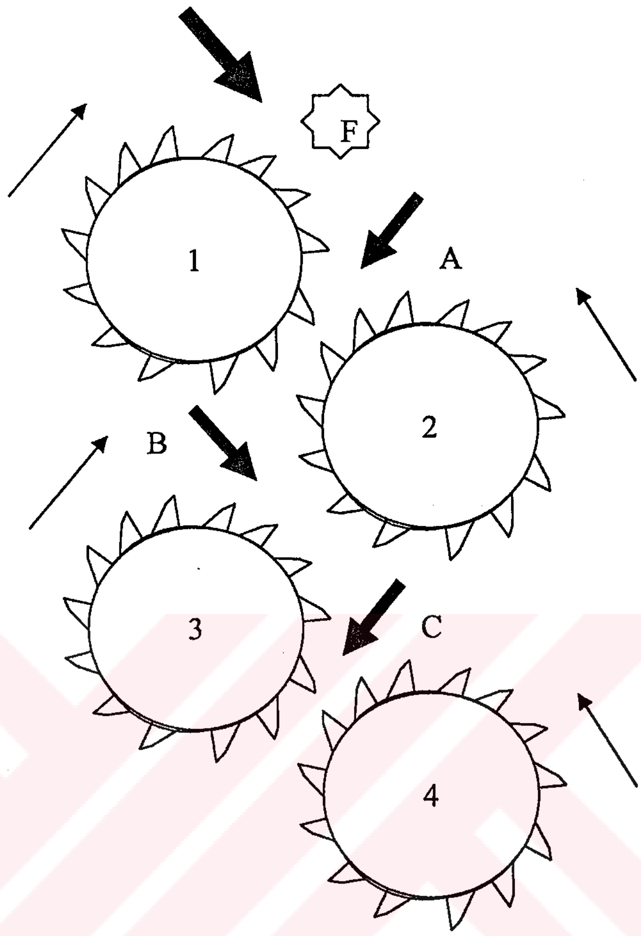

Figure 2.1. Illustration of the disposition and passing of roller mill system

2.2.1-1. Properties of 1st and 2nd rolls

Properties of the 1st and 2nd rolls are given as follows; (Figure 2.2)

Diameter: 25 cm (for each roll)

Length: 100 cm (for each roll)

Numbers of teeth per 1 cm: 3.2

Total numbers of teeth for each roll: 250

Drall value: 5 cm (Figure 2.3)

Roll speed: 310 rpm (for each roll)

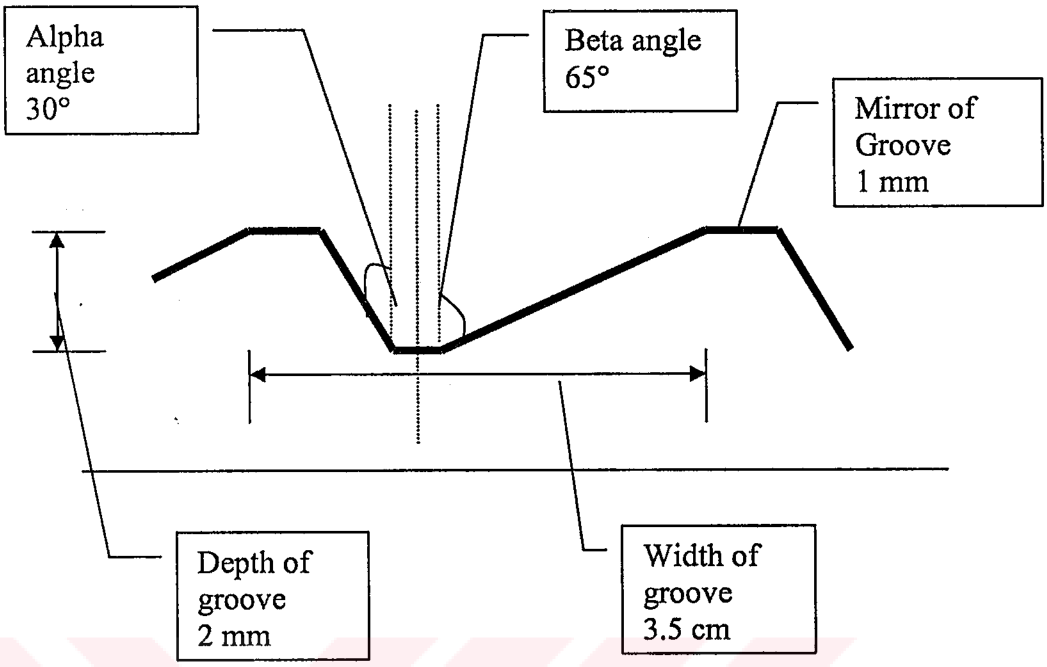

Figure 2.2. Teeth values of 1st and 2nd rolls of roller mill

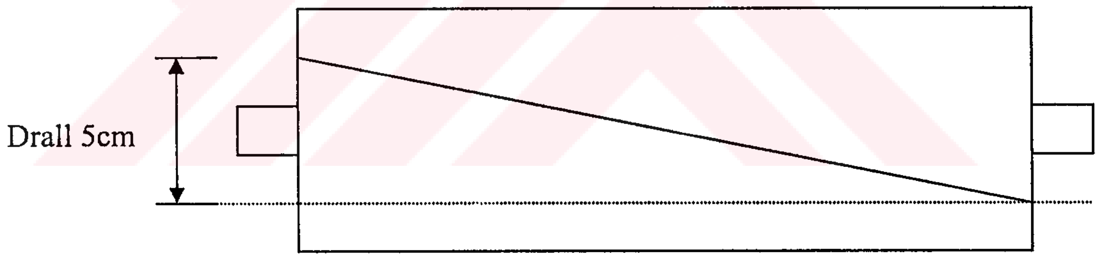

Figure 2.3. Drall value of 1st and 2nd rolls of roller mill

2.2.1-2. Properties of 3rd and 4th rolls

Properties of the 3rd and 4th rolls are given as follows;

Diameter: 25 cm

Length : 100 cm (for each roll)

Numbers of teeth per 1 cm: 4

Total numbers of teeth for each roll: 300

Drall distance: 5 cm (Figure 2.5)

Roll speed: 310 rpm

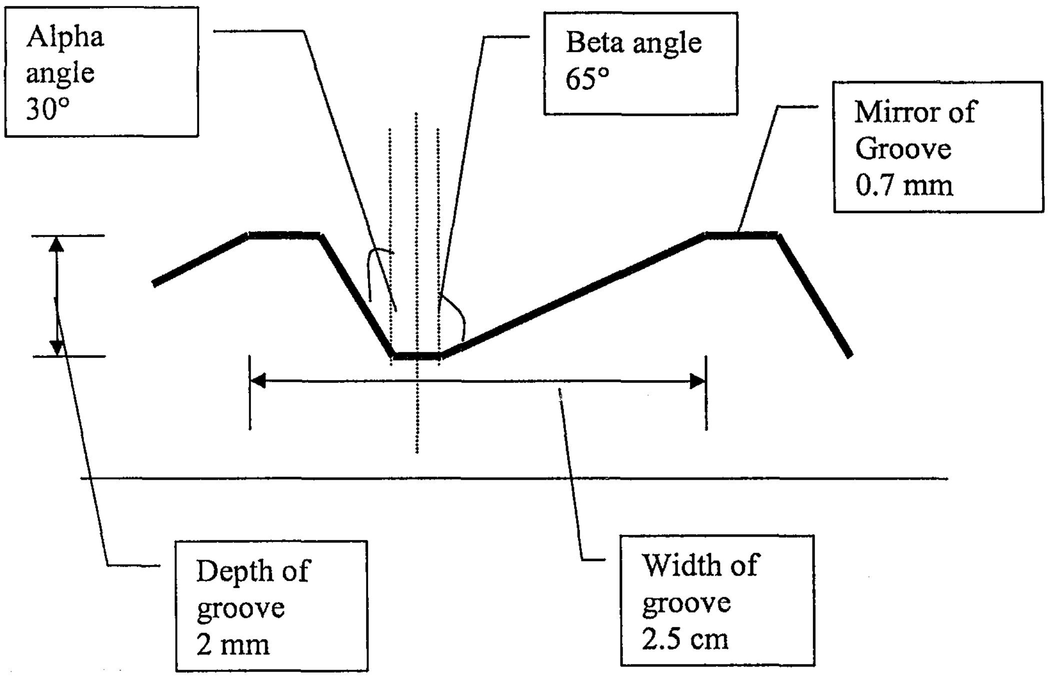

Figure 2.4. Teeth values of 3rd and 4th rolls of roller mill

The gaps of the roller mill were adjusted as 1.90 mm, 1.60 mm, 1.30 mm for first gap; 1.20 mm, 1.00 mm, 0.80 mm for second gap and 0.60mm, 0.50mm, 0.40mm for third gap, respectively using of a micrometer hand-wheel in this study (Table 2.1).

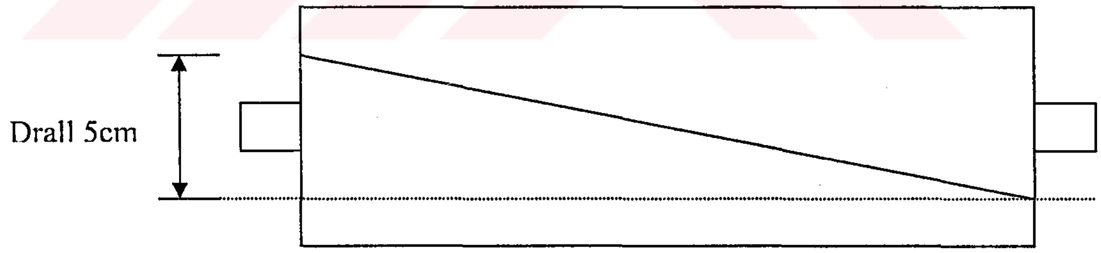

Figure 2.5. Drall values of 3rd and 4th rolls of roller mill

Experimental set-up and arrangement of gaps between rolls were given in Table 2.1. One kg of milled product was collected for experiments. Moisture content, particle size (screen analysis, % mass), ash content, color values (L, a, b and YI), loss, yield and protein contents were analyzed for each sample.

Table 2.1. Experimental set-up and arrangement of gaps between rolls

	Gaps (mm)		
Sample	1st	2nd	3rd
1	1.90	1.20	0.40
2	1.90	1.20	0.50
3	1.90	1.20	0.60
4	1.90	1.00	0.40
5	1.90	1.00	0.50
6	1.90	1.00	0.60
7	1.90	0.80	0.40
8	1.90	0.80	0.50
9	1.90	0.80	0.60
10	1.60	1.20	0.40
11	1.60	1.20	0.50
12	1.60	1.20	0.60
13	1.60	1.00	0.40
14	1.60	1.00	0.50
15	1.60	1.00	0.60
16	1.60	0.80	0.40
17	1.60	0.80	0.50
18	1.60	0.80	0.60
19	1.30	1.20	0.40
20	1.30	1.20	0.50
21	1.30	1.20	0.60
22	1.30	1.00	0.40
23	1.30	1.00	0.50
24	1.30	1.00	0.60
25	1.30	0.80	0.40
26	1.30	0.80	0.50
27	1.30	0.80	0.60

2.2.2. Disc milling

Disc mill used in this study was obtained from Tiryaki Bulgur Factory which was generally used in bulgur industry. It is designed and constructed for bulgur producer by Güney Machinary Co. (Gaziantep, Turkey).

The disc mill used in this study was a double disc type in which upper side one was stationary and the lower was rotated in 250 rpm (Figure 2.6). Intact bulgur enters from the center hole of the upper disc and distributes between stationary upper and revolved bottom disc (Figure 2.6). Bottom disc was revolved using 18 kW motor (970 rpm). Revolution per minute is decreased to 250 rpm at disc.

The intact bulgur was fed to center of the top disc of the disc mill, and was spread out between the two discs. It was shown in Figure 2.6.

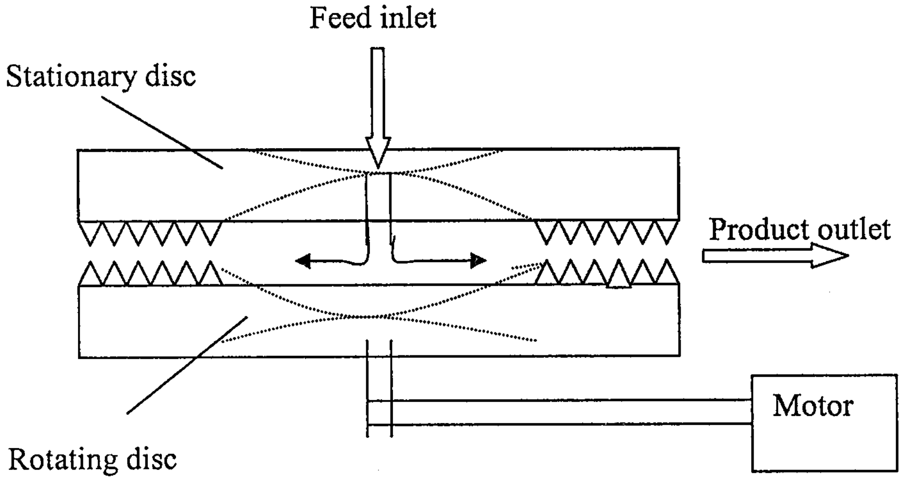

Figure 2.6. Profile of two discs for disc mill

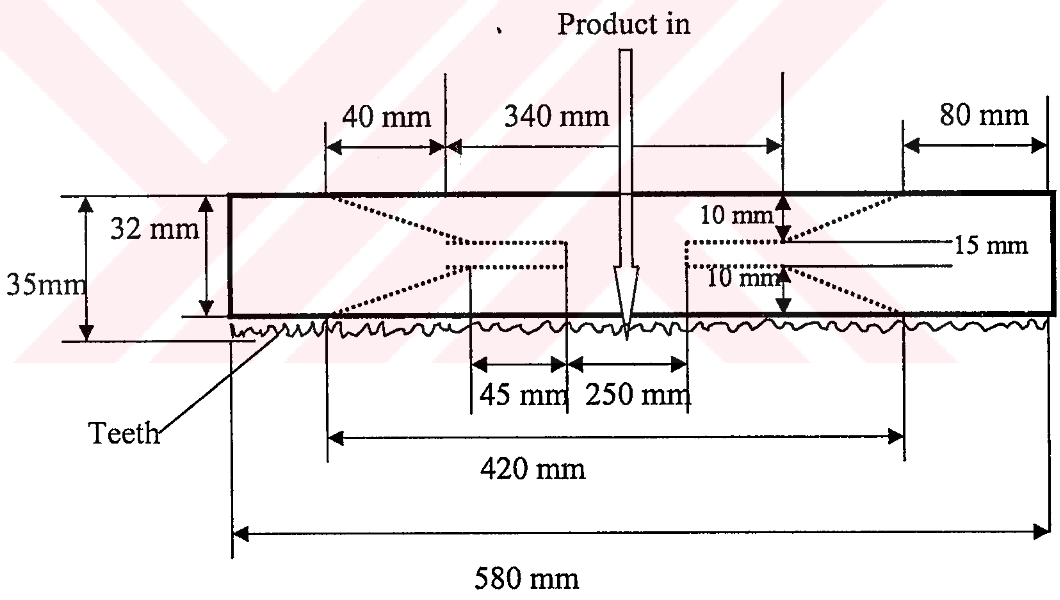

Figure 2.7. Illustration of dimensions of the top disc for disc mill

Details of top disc were shown in Figure 2.7. Diameter of the disc and uncorrugated part were 580 and 420 mm, respectively. The corrugation part of the disc was 80 mm in wide. The thicknesses of disc without and with tooth were 32 and 35 mm. The dimensions of the stationary disc were identical with the rotating one. The center hole of the disc was 250 mm in diameter.

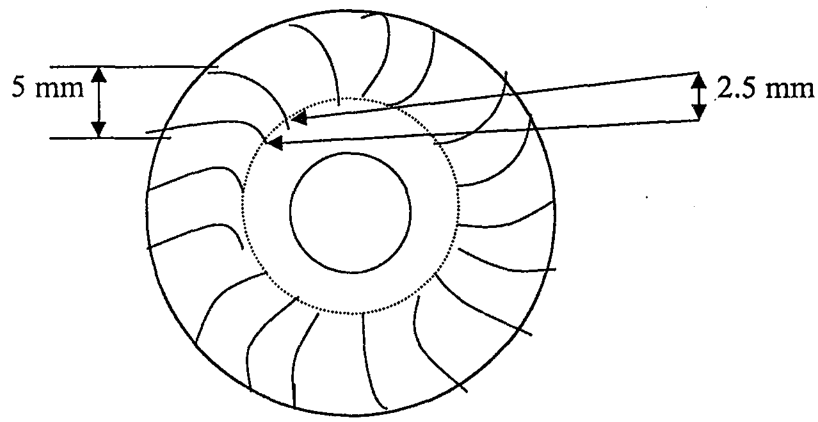

Figure 2.8. Drawing property of teeth of disc mill

Figures 2.8 and 2.9 were showed the drawing and teeth sizes of disc mill. The alpha and beta angles of teeth were 30° and 60°. The corrugation was designed that distances between two teeth line were 2.5 mm at the inside and 5 mm outside of disc. The thickness of teeth was 3 mm.

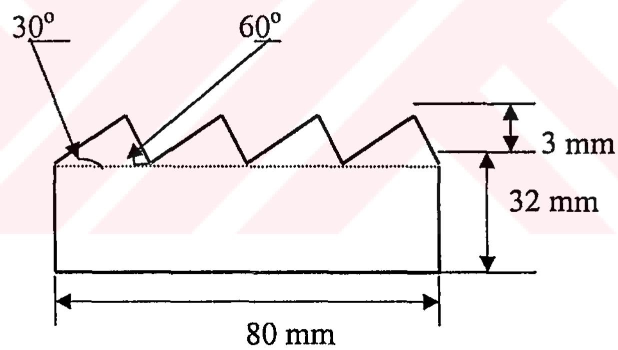

Figure 2.9. Teeth sizes of disc mill

The disc mill gap (space between two discs) was set to 1.90, 1.60, 1.30, 1.20, 1.00, 0.80, 0.60, 0.50 and 0.40 mm, similar to the roller mill, giving a total of nine different samples (Table 2.2). After, collection of samples, particle size (screen analysis, % mass), moisture content, ash content, color value (L, a, b and YI), loss, yield and protein content of each sample were analyzed.

Table 2.2. Distances between discs (gap) studied for disc mill

Sample	Gap of disc mill (mm)
1	1.90
2	1.60
3	1.30
4	1.20
5	1.00
6	0.80
7	0.60
8	0.50
9	0.40

2.2.3. Polishing

In this study, horizontal cylindrical helix system was designed for polishing system by Güney Machinary Co. (Gaziantep, Turkey). The broken and screened products were fed into horizontal cylindrical helix system. Before polishing system, remained bran and flour on surface of bulgur were removed by pre-screening system (Figure 2.10). Then, pre-screened product was dampened with 0.2-0.6 percent of water in to the premixing helix (Figure 2.10). In this section (helical conveyor), product was also mixed homogenously by high torque.

Two horizontal cylindrical polishing systems were used in parallel due to capacity and flexibility of system. Thus, the power of the motor was divided by half and warping of the pivot and palettes were prevented.

The feeding of material was performed by a pre-helical conveying system (Figure 2.10). When the system was worked the temperature of product had increased to 58°C due to friction. The properties of polishing section were explained in detailed below (Figures 2.10-13 and Table 2.4).

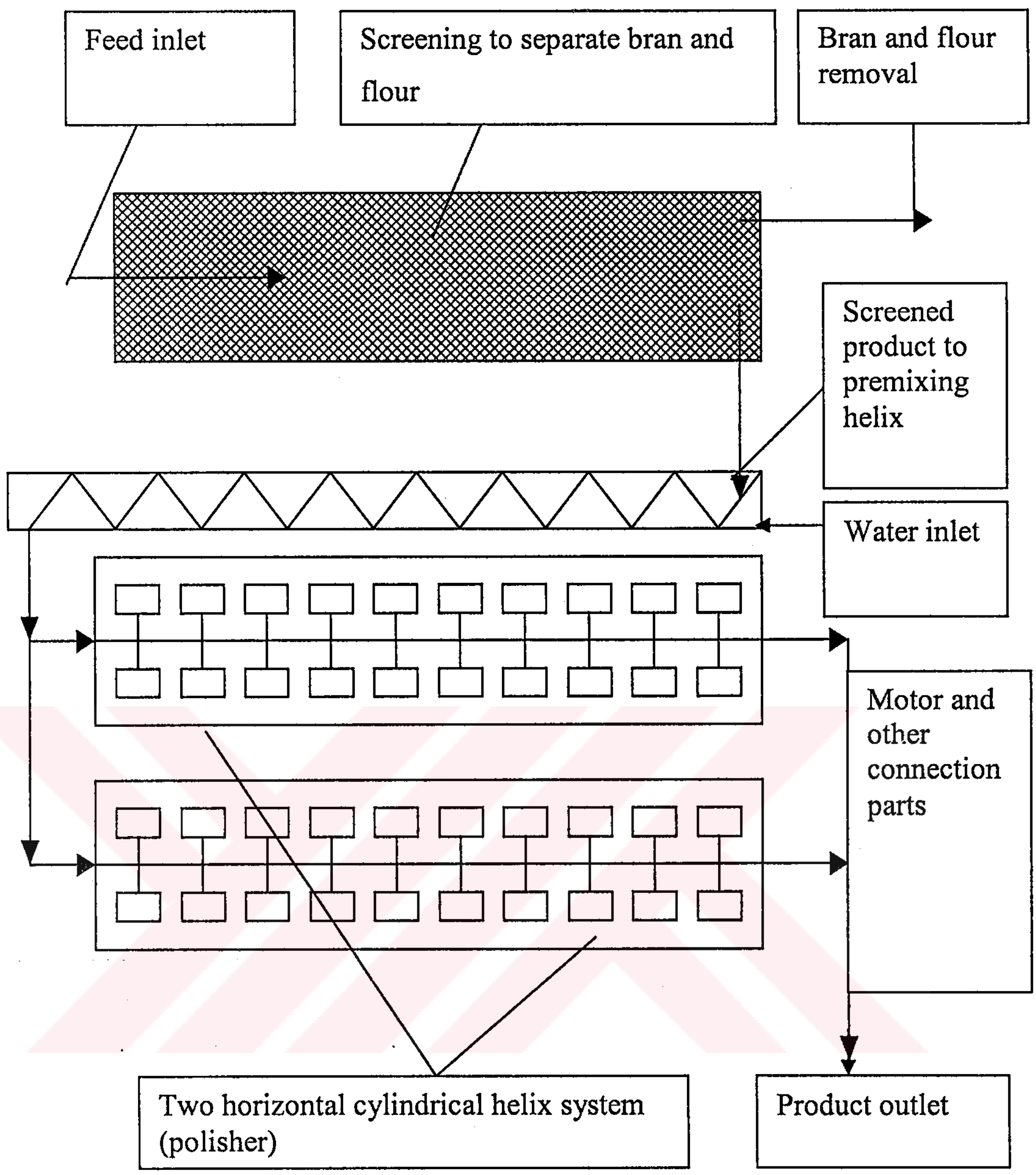

Figure 2.10. Illustration of horizontal cylindrical polishing system

Design and detailed properties of polishing system were given as follows;

Heights and diameters of iron lamas : 12 cm X 6 cm .

i. Datum of preliminary screening;

   Dimensions of sieve hoop: 96 cm X 300 cm

   Screen aperture: 0.80 mm

ii. Helix for premixing;

   Height: 3 m

Diameter: 12 cm

iii. Horizontal cylindrical helix;

Numbers of Palette raw: 26

Dimensions of Palette: 4 cm X 4 cm

Length and diameter of pivot: 3.80 cm X 2.50 m

Distance between palette and outer cylinder: 1.00 cm

Distance between two adjacent palettes: 7 cm

Number of Palette in one raw: 3

Properties of Motor: Two motors with 50HP, 970 rpm

Diameter of outer cylinder: 24.2 cm

Length of outer cylinder: 2.5 m

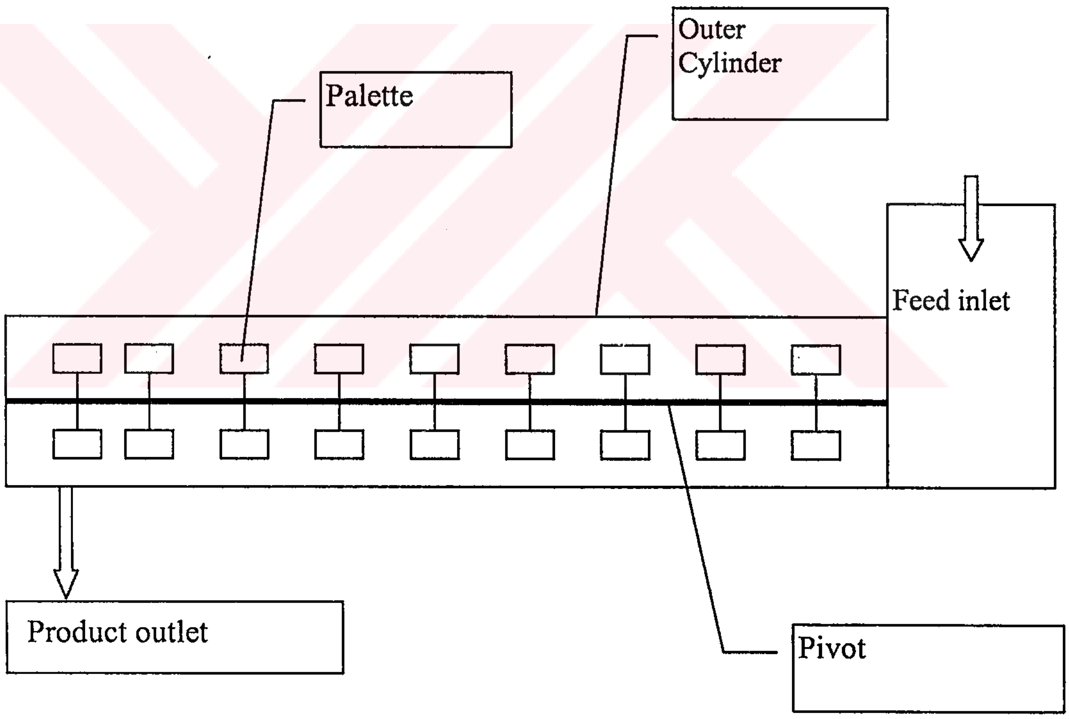

Figure 2.11. Parts of polishing system

The forehead position of the horizontal cylindrical helix system was drawn in Figure 2.12. Length of screw of palette was 5.2 cm. Each palette was 4 cm in length and 4 cm in height. Revolution of palettes was provided mixing of products as homogeneously.

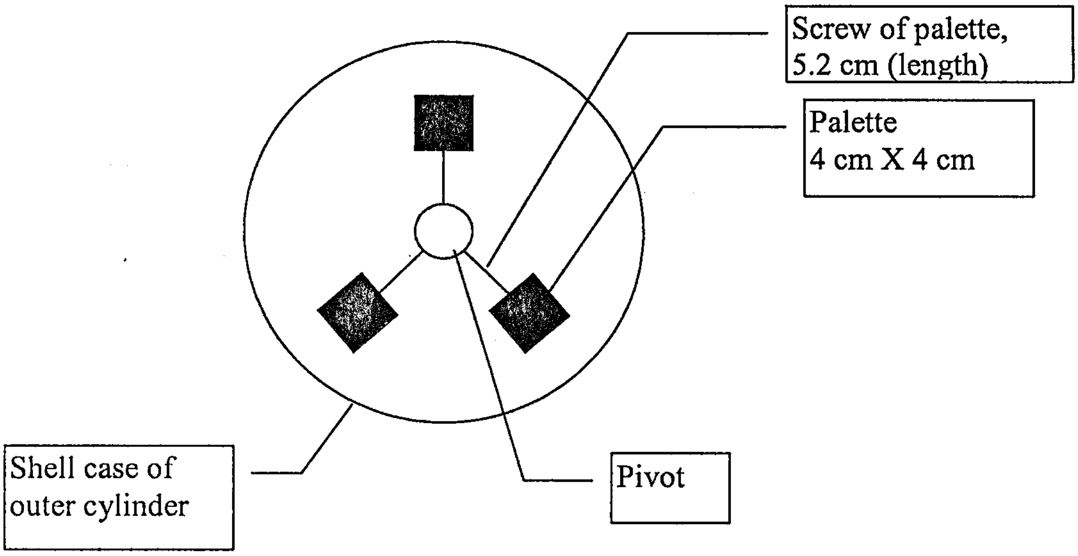

Figure 2.12. Forehead picture of horizontal cylindrical helix

Twenty-six palettes were fitting to pivot of the horizontal cylindrical helix system (Figure 2.13). The numbers, angles and properties of each palette were tabulated in Table 2.3.

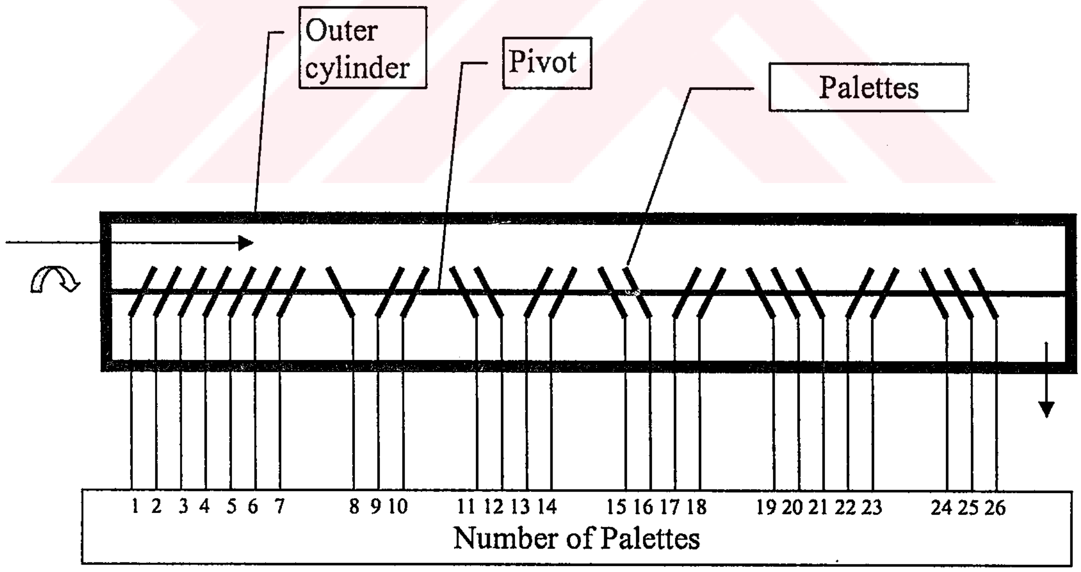

Figure 2.13. Directions and position of palettes of horizontal cylindrical system

Table 2.3. Angles of palettes according to their scales

Number of palette	Angle	Property
1	82	Carrier
2	82	Carrier
3	82	Carrier
4	82	Carrier
5	82	Carrier
6	82	Carrier
7	86.5	Carrier
8	100	Stopper
9	82	Carrier
10	86.5	Carrier
11	98	Stopper
12	100	Stopper
13	82	Carrier
14	86.5	Carrier
15	98	Stopper
16	100	Stopper
17	82	Carrier
18	86.5	Carrier
19	98	Stopper
20	98	Stopper
21	100	Stopper
22	82	Carrier
23	86.5	Carrier
24	82	Stopper
25	82	Stopper
26	82	Stopper

Samples were both collected from the inlet and outlet of the polishing system to analyse the particle size (% mass), moisture content (g/g, w.b.), color (L, a, b, YI), ash content (g/g, d.b.), hectoliter weight (kg/hl) and protein content (g/g, d.b.).

2.2.4. Color sorting system

In this section a new computerised color sorting system was used for sorting of the products. The properties of color sorting system were given in Figure 1.1 and 2.14. The parameters of this system were given as follows;

<u>Parameters of sorting system:</u>

Pressure: 3.60 Bar

Number of ejectors: 196

Capacity: 10 tons/hour

Number of feeders: 2 +1(for resort)

Type of fluorescent: 10 Blue light lamps

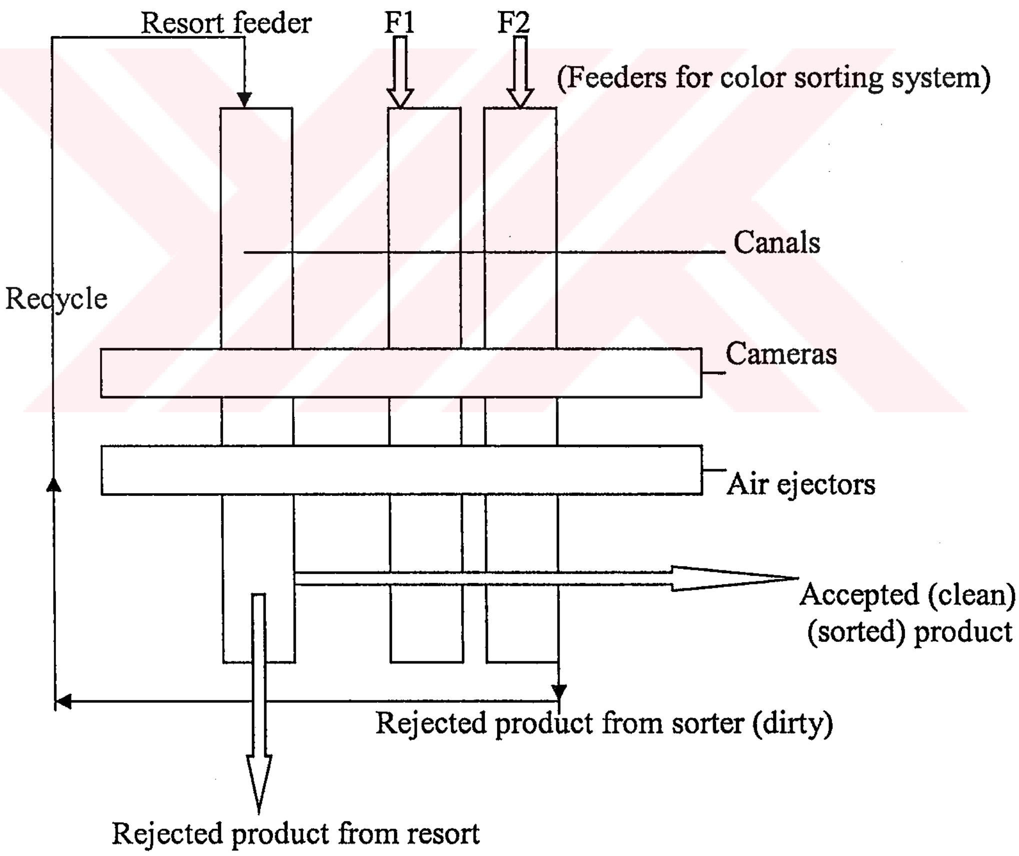

Figure 2.14. The working principle of color sorting system

The working principle of the color sorting system was shown in Figure 2.14 as schematically. The materials were fed from a vibrating hopper (feeder 1 and 2). The materials were passed into an optical inspection area (photo-detector). The sensor was detected colors and provided an alarm or control signal when a pre-selected color passed the detector beam. The computer of this system was compared the constructed image with preset specifications. If the values were outside the range of acceptable values, the compressed air ejectors were activated to remove the rejected products to the resort section. Then, rejected materials were recycled to resort section and final rejected particles were left the system.

Three samples (intact, milled and fine bulgur) were used to sort by color sorting system. After color sorting, percent purity (yield), color values and protein contents of each sample were measured.

2.2.5. Determination of milling characteristics (screen analysis)

Screen analysis were made in order to find the milling characteristics of both roller and disc mills by using circular sieves with circular aperture made of steel. Screen numbers that used in experiments were 3.50, 2.00, 1.00 and 0.50 mm, along with a bottom pan. 27 and 9 samples were collected after milling for both roll and disc mills, respectively (Figure 2.1 and 2.2). 6 tons of feed was used for each run of milling operations. 100 grams of each sample was used for screening, vibrating for 15 minutes. Samples for each gap were measured as percent mass retained on each sieve.

2.2.6. Determination of color

Color values (*L, a, b and YI*) of intact bulgur, samples obtained by size reduction with both roller and disc mills, polishing inlet and outlet, and color sorting section were measured by Hunter Lab Colorimeter (Colorflex, USA,type). Samples were first screened with 2.00 mm sieve, then retained parts were analysed for color. A white standard tile was used to calibrate the colorimeter (L=93.01, a = -1.11, b = 1.30) before measurements. *L , a, b, YI* represents respectively as lightness, redness, yellowness and yellowness index.

2.2.7. Determination of yield

From cumulative percent mass data obtained in screen analyses of roller mill, disc mill and polishing section, results for upper part of 0.50 mm sieve (+/0.50 mm) were evaluated as bulgur or yield (g/g). Yield of color sorting system and resort section was also evaluated from the data of percent purity for intact, milled and fine bulgur samples.

2.2.8. Determination of loss

Results obtained from data in screen analyses of roller mill, disc mill; and polisher inlet and outlet (0.50mm/-) was evaluated as flour and loss (g/g) for bulgur.

2.2.9. Determination of moisture content

Moisture content (g/g, wet basis) of dried, tempered and peeled intact bulgur samples for roller and disc mills, polishing inlet and outlet were measured by using oven method (130 ^{o}C) (AOAC, 1992).

2.2.10. Determination of ash content

Ash contents (g/g, dry basis) were measured using the method of AOAC (1992). Before the measurements, all samples were screened with 2.00 mm sieve. Then, retained part of samples on this sieve was used for ash content measurement.

2.2.11. Determination of bulk density (hectoliter-weight)

Bulk density values as kg/hl for all data from roller mill, disc mill, raw materials (dried, tempered, dehulled and milled), and polishing system were measured (TS 6531, 1989).

2.2.12. Determination of protein content

Protein contents (g/g, dry basis) were measured for products from roller and disc mills, polishing inlet and outlet, sorting inlet and outlet by using Kjeldahl method (AOAC, 1992).

2.2.13. Statistical analysis

Data obtained was subjected to statistical analysis of variance (ANOVA) and Duncan multiple range test to assess difference between means and homogeneous subsets using the SPSS statistical software (2002). Graphic representation was carried out using the Sigma plot 2000 (SPW6) graphic package.

CHAPTER III

RESULTS AND DISCUSSION

In this study, intact, milled (using roll and disc mills for different gaps arrangements) bulgur, samples from inlet and outlet of the polishing and color sorting systems were analyzed for sieve analysis (% mass), color values (L (lightness), a (redness), b (yellowness) and YI (yellowness index)), moisture, ash and protein contents, yield and loss. Then, the roller and disc mills were compared according to experimental results obtained.

3.1. Disc and Roll Millings for Bulgur Production

Main principle during size reduction for bulgur production is the creation of new surface by dividing of whole dried wheat kernel into two or more particles. During this operation main problems are; (i) deformation, scratching and formation of burr on the surface of bulgur particle (abrasive type mills), (ii) formation of sharp edge on granular bulgur (causes adhesiveness, breaking, flour formation and quality loss during pilaf and köfte making), (iii) loss of translucency and polish appearance of bulgur, (iv) decreasing of yield due to flour formation during size reduction of disc milling, (v) loss of oval and smooth shape (formation of sharp edges), (vi) creation of different sized bulgur particles i.e. not uniform sizes (Bayram and Öner, 2004).

During comminution operations, both material properties and milling methods affect particle breakage (Scanlon and Lamb, 1995). In first-break roller milling of wheat, the factors affecting breakage of wheat grains can thus be broadly classified into those arising from the physicochemical properties of the wheat (size distribution, moisture content, hardness) and those related to the design and operation of the milling equipments (Campbell *et. al.*, 2001).

The design and opration of milling equipments related to roller and disc type mills were compared in this investigation. Milling of wheat into bulgur can be viewed as "the evolution of the particle size distribution", as particles are progressively broken by roller or disc mills and separated by screening. The use of fluted rolls has the benefit that the bran particles tend to stay large, while the more friable endosperm breaks into small particles, allowing separation of bran from endosperm based on size using sieves. Studies on milling equipment, including roll design and operational settings, have long been reported for both fluted and smooth rolls (Campbell and Fang, 2003).

3.1.1. Screen analyses for roller mill

The entire milled stocks results of bulgur for different roll gap arrangements were given in Table 3.1-12. The particle size distribution of milled products for different roll gaps were evaluated using sieves with sizes of 3.50, 2.00, 1.00, 0.50 mm. Percent mass retained over 3.50 mm (+/3.50); lower than 3.50 mm and retained over 2.00 mm (3.50/2.00); lower than 2.00 mm and retained over 1.00 mm (2.00/1.00); lower than 1.00 mm and retained over 0.50 mm (1.00/0.50), finally lower than 0.50 mm (0.50/-) were classified as coarse, pilaf, middle (medium), fine sized bulgur and loss (by product), respectively.

3.1.1.1. Coarse sized (+/3.50) bulgur

The percent masses of coarse sized bulgur (+/3.50) were illustrated in Tables 3.1, 3.2 and 3.3 for first, second and third gaps at 1.90, 1,60 and 1.30 mm for the results of second (0.80, 1.00 and 1.20 mm) and third (0.40, 0.50 and 0.60 mm) gaps, respectively.

At fixed first and second gaps, the increase in third gap increased significantly ($P<0.05$) the percent mass of coarse sized bulgur (Table 3.1). The major increase in the percent mass was obtained at 0.60 mm for third gap. In order to determine the effect of the second gap for the percent mass of coarse sized bulgur, Table 3.2 was prepared and the results were statistically analyzed. According to ANOVA and Duncan's test, second gap significantly ($P<0.05$) affected the percent mass of coarse sized bulgur, but regular change by increasing second gap was not obtained. Similar irregularity was obtained for analysis of first gap at constant second and third gaps (Table 3.3). Therefore, it can be said that regulation of size for coarse sized bulgur can be arranged during pass through third gap. Also, first and second gaps work as randomized size reduction sections. Because, when the intact bulgur passed through both gaps, it cannot be always fed at some position and sometimes broken along crease or width. Also, the length and width of the wheat kernel are around 5-7 and 2-3 mm, respectively (Bayram *et. al.*, 2004). Therefore, during first and second gaps, size reduction may occur randomize.

Table 3.1. One-way ANOVA and multiple range test, when 1st and 2nd gaps (mm) hold as fixed and 3rd gap increased to 0.60 mm for percent mass (g/g) of coarse sized bulgur (+/3.50) from roller mill

3rd gap (mm)	1st gap 1.30 mm			1st gap 1.60 mm			1st gap 1.90 mm		
	2nd gap			2nd gap			2nd gap		
	0.80	1.00	1.20	0.80	1.00	1.20	0.80	1.00	1.20
0.40	0.27 a	0.05 a	0.16 a	0.15 a	0.12 a	0.08 a	0.55 a	0.42 b	0.76 a
0.50	0.95 c	0.50 b	1.41 c	0.89 b	0.37 b	0.78 b	1.38 b	0.15 a	0.87 b
0.60	0.87 b	0.87 c	0.98 b	1.42 c	1.22 c	1.07 c	1.40 c	7.74 c	6.73 c
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied.

Table 3.2. One-way ANOVA and multiple range test, when 1st and 3rd gaps (mm) hold as constant and 2nd gap increased to 1.20 mm for percent mass (g/g) of coarse sized bulgur (+/3.50) from roller mill

2nd gap (mm)	1st gap 1.30 mm			1st gap 1.60 mm			1st gap 1.90 mm		
	3rd gap			3rd gap			3rd gap		
	0.40	0.50	0.60	0.40	0.50	0.60	0.40	0.50	0.60
0.80	0.27 c	0.95 b	0.87 a	0.15 c	0.89 c	1.42 c	0.55 b	1.38 c	1.40 a
1.00	0.05 a	0.50 a	0.87 a	0.12 b	0.37 a	1.22 b	0.42 a	0.15 a	7.74 c
1.20	0.16 b	1.41 c	0.98 b	0.08 a	0.78 b	1.07 a	0.76 c	0.87 b	6.73 b
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied

Table 3.3. One-way ANOVA and multiple range test, when 2nd and 3rd gaps (mm) hold as constant and 1st gap increased to 1.90 mm for percent mass (g/g) of coarse sized bulgur (+/3.50) from roller mill

1st gap (mm)	2nd gap 0.80 mm			2nd gap 1.00 mm			2nd gap 1.20 mm		
	3rd gap			3rd gap			3rd gap		
	0.40	0.50	0.60	0.40	0.50	0.60	0.40	0.50	0.60
1.30	0.27 b	0.95 b	0.87 a	0.05 a	0.50 c	0.87 a	0.16 b	1.41 c	0.98 a
1.60	0.15 a	0.89 a	1.42 c	0.12 b	0.37 b	1.22 b	0.08 a	0.78 a	1.07 b
1.90	0.55 c	1.38 c	1.40 b	0.42 c	0.15 a	7.74 c	0.76 c	0.87 b	6.73 c
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied.

3.1.1.2. Pilaf sized (3.50/2.00) bulgur

For pilaf sized (3.50/2.00) bulgur, the percent masss were illustrated in Tables 3.4, 3.5 and 3.6 for first, second and third gaps at 1.90, 1.60 and 1.30 mm for the results of second (0.80, 1.00 and 1.20 mm) and third (0.40, 0.50 and 0.60 mm) gaps, respectively.

Table 3.4. One-way ANOVA and multiple range test, when 1st and 2nd gaps (mm) hold as constant and 3rd gap increased to 0.60 mm for percent mass (g/g) of pilaf sized bulgur (3.50/2.00) from roller mill

3rd gap (mm)	1st gap 1.30 mm			1st gap 1.60 mm			1st gap 1.90 mm		
	2nd gap			2nd gap			2nd gap		
	0.80	1.00	1.20	0.80	1.00	1.20	0.80	1.00	1.20
0.40	15.72 a	20.44 a	26.35 a	23.16 a	28.44 a	20.87 a	22.29 a	17.23a	35.74a
0.50	52.97 b	59.64 b	55.94 b	53.11 b	1.00 b	51.45b	68.56 b	21.99b	37.44b
0.60	59.90 c	69.80 c	66.22 c	63.61 c	51.07 c	58.54 c	75.38 c	87.66c	88.70c
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied.

The increase in third gap increased significantly (P<0.05) the percent mass of pilaf sized bulgur at fixed first and second gaps (Table 3.4). The significant pilaf sized bulgur was obtained at 0.60 mm for third gap. Similar to coarse sized bulgur, as explained in the previous section, first and second gaps had no regular effects on the size of pilaf sized bulgur due to different homogeneous groups and orders (Tables 3.5 and 3.6) ($P<0.05$). Regulation of size for pilaf-sized bulgur was also arranged during pass through third gap. The intact bulgur kernel entering the grinding zones i.e. first and second gaps were broken laterally. The mechanical properties of the kernel cross-section are not homogeneous because of the crease, which is more likely to be broken first (Fang and Campbell, 2002).

Table 3.5. One-way ANOVA and multiple range test, when 1st and 3rd gaps (mm) hold as constant and 2nd gap increased to 1.20 mm for percent mass (g/g) of pilaf sized bulgur (3.50/2.00) from roller mill

2nd gap (mm)	1st gap 1.30 mm			1st gap 1.60 mm			1st gap 1.90 mm		
	3rd gap			3rd gap			3rd gap		
	0.40	0.50	0.60	0.40	0.50	0.60	0.40	0.50	0.60
0.80	15.72 a	59.90 c	52.97 a	23.16 b	53.11 c	63.61 c	22.29b	68.56 c	75.38a
1.00	20.44b	59.64 b	69.80 c	28.44 c	51.00 a	51.07 a	17.23 a	21.99a	87.66b
1.20	26.35 c	55.94 a	66.22 b	20.87 a	51.45 b	58.54 b	35.74 c	37.44b	88.70c
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

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

Table 3.6. One-way ANOVA and multiple range test, when 2nd and 3rd gaps (mm) hold as constant and 1st gap increased to 1.90 mm for percent mass (g/g) of pilaf sized bulgur (3.50/2.00) from roller mill

1st gap (mm)	2nd gap 0.80 mm			2nd gap 1.00 mm			2nd gap 1.20 mm		
	3rd gap			3rd gap			3rd gap		
	0.40	0.50	0.60	0.40	0.50	0.60	0.40	0.50	0.60
1.30	15.72 a	59.90 b	52.97 a	20.44 b	59.64 c	69.80 b	26.35b	55.94c	66.22b
1.60	23.16 c	53.11 a	63.61b	28.44 c	51.00 b	51.07 a	20.87 a	51.45b	58.54a
1.90	22.29b	68.56 c	75.38 c	17.23 a	21.99 a	87.66 c	35.74 c	37.44a	88.70c
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

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

Therefore, during first and second gaps, size reduction may occur randomize. In order to obtain the significant amount of pilaf-sized bulgur, the gaps can be arranged as 1.90, 1.20 and 0.60 mm for first, second and third, respectively.

3.1.1.3. Middle (medium) sized (2.00/1.00) bulgur

For the middium sized bulgur type, the percent masss (2.00/1.00) were illustrated in Tables 3.7-9 for first (1.90, 1.60 and 1.30 mm), second (0.80, 1.00 and 1.20 mm) and third (0.40, 0.50 and 0.60 mm) gaps, respectively.

Table 3.7. One-way ANOVA and multiple range test, when 1st and 2nd gaps (mm) hold as constant and 3rd gap increased to 0.60 mm for percent mass (g/g) of middle sized bulgur (2.00/1.00) from roller mill

3rd gap mm)	1st gap 1.30 mm			1st gap 1.60 mm			1st gap 1.90 mm		
	2nd gap			2nd gap			2nd gap		
	0.80	1.00	1.20	0.80	1.00	1.20	0.80	1.00	1.20
0.40	55.04c	54.48 c	54.20 c	53.85 c	50.37 c	53.25 c	48.48 c	51.79b	46.98b
0.50	34.02a	34.20 b	37.22 b	39.07 b	41.14 a	38.57 b	25.50b	59.78c	53.49c
0.60	42.69b	25.05 a	27.98 a	29.07 a	42.33 b	36.19 a	21.38 c	3.50a	3.95a
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied

The biggest percent mass (59.78%) for middle-sized bulgur was significantly (P<0.05) obtained as arrangements of gaps at 1.90, 1.00 and 0.50 mm for first, second and third gaps, respectively (Table 3.7). When the first gap was decreased to 1.60 and 1.30 mm, the significant middle sized bulgur was obtained at 0.40 mm for third gap at both second gaps i.e. 1.20, 1.00 and 0.80 mm (P<0.05) (Table 3.7). In order to determine the effect of the first and second gaps on the middle sized bulgur, Tables 3.8 and 3.9 were used which were prepared based on ANOVA and Duncan's Test both tables illustrated that there were no regular effect of first and second gaps (P<0.05), similar to coarse and pilaf sized bulgur.

Table 3.8. One-way ANOVA and multiple range test, when 1st and 3rd gaps (mm) hold as constant and 2nd gap increased to 1.20 mm for percent mass (g/g) of middle sized bulgur (2.00/1.00) from roller mill

2nd gap (mm)	1st gap 1.30 mm			1st gap 1.60 mm			1st gap 1.90 mm		
	3rd gap			3rd gap			3rd gap		
	0.40	0.50	0.60	0.40	0.50	0.60	0.40	0.50	0.60
0.80	55.04 c	34.02 a	42.69 c	53.85 c	39.07 b	29.07 a	48.48 c	25.50 a	21.38c
1.00	54.48b	34.20b	25.05 a	50.37 a	41.14 c	42.33 c	51.79b	59.78 c	3.50 a
1.20	54.20 a	37.22 c	27.98 b	53.25 b	38.57 a	36.19 b	46.98 a	53.49 b	3.95 b
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied.

Table 3.9. One-way ANOVA and multiple range test, when 2nd and 3rd gaps hold as constant and 1st gap increased to 1.90 mm for percent mass (g/g) of medium sized bulgur (2.00/1.00) from roller mill

1st gap (mm)	2nd gap 0.80 mm			2nd gap 1.00 mm			2nd gap 1.20 mm		
	3rd gap			3rd gap			3rd gap		
	0.40	0.50	0.60	0.40	0.50	0.60	0.40	0.50	0.60
1.30	55.04 c	34.02 b	42.69 c	54.48 c	34.20 a	25.05 b	54.20 c	37.22a	27.98b
1.60	53.85 b	39.07 c	29.07 b	50.37 a	41.14 b	42.33 c	53.25b	38.57b	36.19c
1.90	48.48 a	25.50 a	21.38 a	51.79 b	59.78 c	3.50 a	46.98 a	53.49c	3.95 a
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied

3.1.1.4 Fine sized (1.00/0.50) bulgur

For the fine sized bulgur (1.00/0.50), which was in general used to make çiğ köfte and kısır in Turkey practically, the percent masss and roll gaps relations were given in Tables 3.10, 3.11 and 3.12.

As expected, the significant amount of fine sized bulgur was obtained at the smallest third gap regulation (0.40 mm) for each first and second gap (P<0.05, Table 3.10). The increase in third gap to 0.60 mm, percent masss of fine sized bulgur decreased dramatically (Tables 3.11 and 3.12).

Table 3.10. One-way ANOVA and multiple range test, when 1st and 2nd gaps (mm) hold as constant and 3rd gaps increased to 0.60 mm for percent mass (g/g) of fine sized bulgur (1.00/0.50) from roller mill

3rd gap (mm)	1st gap 1.30 mm			1st gap 1.60 mm			1st gap 1.90 mm		
	2nd gap			2nd gap			2nd gap		
	0.80	1.00	1.20	0.80	1.00	1.20	0.80	1.00	1.20
0.40	9.86 c	18.42 c	17.67 c	15.41 c	12.18 c	11.69 c	11.25 c	12.20c	13.74c
0.50	4.10 b	6.41 b	2.11 b	3.24 b	3.22 b	2.47 b	1.33 a	2.81b	1.50 a
0.60	0.37 a	0.64 a	1.44 a	0.97 a	1.67 a	1.88 a	1.85 b	2.01a	1.57 b
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied

According to the results, different sizes bulgur i.e. coarse, pilaf, middle and fine can be produced during one running operation using roll mill by arrangement of gaps in contrast to other types of mills i.e. disc mill used industrially in bulgur production.

Table 3.11. One-way ANOVA and multiple range test, when 1st and 3rd gaps (mm) hold as constant and 2nd gap increased to 1.20 mm for percent mass (g/g) of fine (1.00/0.50) sized bulgur from roller mill

2nd gap (mm)	1st gap 1.30 mm			1st gap 1.60 mm			1st gap 1.90 mm		
	3rd gap			3rd gap			3rd gap		
	0.40	0.50	0.60	0.40	0.50	0.60	0.40	0.50	0.60
0.80	13.74 c	1.50 b	1.57 a	11.69 a	2.47 a	1.88 c	17.67b	2.11 a	1.44 c
1.00	12.20 b	2.81 c	2.01 c	12.18 b	3.22 b	1.67 b	18.42 c	6.41 c	0.64 b
1.20	11.25 a	1.33 a	1.85 b	15.41 c	3.24 c	0.97 a	9.86 a	4.10 b	0.37 a
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied.

Table 3.12. One-way ANOVA and multiple range test, when 2nd and 3rd gaps (mm) hold as constant and 1st gap increased to 1.90 mm for percent mass (g/g) of fine (1.00/0.50) sized bulgur from roller mill

1st gap (mm)	2nd gap 0.80 mm			2nd gap 1.00 mm			2nd gap 1.20 mm		
	3rd gap			3rd gap			3rd gap		
	0.40	0.50	0.60	0.40	0.50	0.60	0.40	0.50	0.60
1.30	13.74b	1.50 a	1.57 b	12.20 b	2.81 a	2.01 c	11.25b	1.33 a	1.85 c
1.60	11.69 a	2.47 c	1.88 c	12.18 a	3.22 b	1.67 b	15.41 c	3.24 b	0.97 b
1.90	17.67 c	2.11 b	1.44 a	18.42 c	6.41 c	0.64 a	9.86 a	4.10 c	0.37 a
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied.

3.1.2. Screen analyses for disc mill

Similar to roller mill, screen analysis for disc mill was made using sieves with 3.50, 2.00, 1.00 and 0.50 mm sizes. The identical gaps (0.40, 0.50, 0.60, 0.80, 1.00, 1.20, 1.30, 1.60 and 1.90 mm) and bulgur sizes (coarse, pilaf, middle and fine) were used to compare with roller mill. The experimental results for disc mill were illustrated in Table 3.13.

In order to determine the effect of the gaps on coarse, pilaf, middle and fine sized bulgur, Table 3.13 was prepared using ANOVA and Duncan's test. The coarse sized bulgur (+/3.50) was not obtained for the gaps at 0.40, 0.50, 0.60 and 0.80 mm due to more reduction effect of the teeth of disc mill at these gaps. But, the increase in the disc gap from 1.00 to 1.90 mm significantly (P<0.05) increased the percent mass of coarse sized bulgur (Table 3.13). For the pilaf size bulgur (3.50/2.00), the largest percent mass was obtained for the gap at 1.60 mm. Similar to coarse sized bulgur, when the gap was increased to 1.90 mm; the percent mass was also increased significantly (P<0.05, Table 3.13). Table 3.13 also illustrated that there was a regular effect of the gap on the percent mass of both coarse and pilaf sized bulgur. On the other hand, the increasing the gap also significantly (P<0.05) affected the percent mass of middle and fine sized bulgur types. But, a regular change was not obtained. The percent masss for the middle and fine sized bulgur was changed as randomly. It should be note that the percent mass of pilaf sized (3.50/2.00) bulgur was higher than that of coarse (+/3.50), middle (2.00/1.00) and fine (1.00/0.50) sized ones.

Table 3.13. One-way ANOVA and multiple range test, when disc gap increased to 1.90 mm for percent mass (g/g) of coarse (+/3.50), pilaf (3.50/2.00), middle (2.00/1.00) and fine (1.00/0.50) sized bulgur from disc mil

gap (mm)	% mass for (+/3.50) mm	% mass for (3.50/2.00) mm	% mass for (2.00/1.00)mm	% mass for (1.00/0.50) mm
0.40	0.00 a	0.05 a	11.48 c	1.60 g
0.50	0.00 a	12.11 b	59.26 i	0.96 e
0.60	0.00 a	18.95 c	56.06 h	5.57 i
0.80	0.00 a	31.61 d	52.25 g	0.54 a
1.00	0.05 b	57.48 e	28.93 f	2.13 h
1.20	0.14 c	66.24 f	23.43 e	1.20 f
1.30	0.20 d	75.74 g	15.47 d	0.86 d
1.60	0.98 e	87.55 h	6.95 a	0.69 b
1.90	1.29 f	86.58 i	7.38 b	0.71 c
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied

In order to obtain different types of bulgur during the disc milling operation such as coarse, pilaf, middle and fine sized, the gap must be changed for each time. So, the arrangement of gaps for different type of bulgur would be taken long time and this was more time consuming than roller mill.

3.1.3. Energy consumption and capacities of roller and disc mills

Both roller and disc mills were runned by a motor that had a speed of 970 rpm. The speed of motor (970 rpm) was decreased on disc and rolls using reductors. Each motor was consumed 18 kW of energy per hour. So, in order to compare the characteristics of roller and disc mills, energies of motors were held constant.

Capacities of roller and disc mills were found as 3500 and 700 kg product per hour, respectively. The capacity of roll mill was higher than disc mill as 5 times. When the energy consumptions were calculated from energy and capacity values, it was found that lower energy consumption per one kg of products (0.00514 kW per hour per kg of the product) was found for roller mill. On the other hand, this value was 0.0257 kW per hour per kg of product for disc mill. The decrease in energy was determined as 79.99 %. The less energy consumption is an important factor for bulgur producers.

3.1.4. Color values

The first quality judgement made by consumers on bulgur at the point of sale and acceptability is its visual appearance (Bayram *et. al.*, 2003). Therefore, the color of bulgur is the most important parameter for acceptability of final product. A common problem with the processing of the wheat-bulgur is the color loss of the finished product, which in turn affects the consumer acceptability and addition of color additives are forbidden by law to give good yellowness; in another word, bulgur should have its natural color. Processing steps (milling, soaking in water and heating) also affect the color of bulgur (Bayram *et. al.*, 2004).

In order to examine the effect of tempering, peeling, milling (roller and disc mills), polishing and color sorting systems, the colors of all products were measured in present study. The color values (L, a, b and YI) of samples were measured for sieved (+/2.00) products. The experimental results for the color values of intact bulgur samples, milled products (roller and disc mills), polishing and color sorting systems were given in Tables 3.14-27, 3.47-51.

3.1.4.1. Color values during preceding operations for both roller and disc mills

During bulgur production before the milling operations, wheat is cooked, dried, tempered and peeled. The color values (L, a, b and YI) of preceding operations (dried, tempered and peeled) for both roller and disc mills were given in Tables 3.14. The L-value (lightness) of intact dried bulgur was 40.82, and then it increased to 41.20 and 47.51 during tempering and peeling operations for roller mill, respectively. Similar increase in lightness value was also obtained for disc mill. It could be explained that water adsorption on the surface of the wheat kernel during tempering operation increased the lightness value, and also, when the bran of wheat was removed during peeling operation, light color endosperm increased the lightness of sample. In addition, Tables 3.14 illustrated that the effect of the peeling operation on lightness was greater than that of tempering operations due to dark color of bran.

Table 3.14. Color (L, a, b and YI) values of dried, tempered, peeled intact and milled (gaps at 1.90, 1.20 and 0.60 mm) bulgur samples for both roller and disc mills

Type of sample	Roller mill				Disc mill			
	L	a	b	YI	L	a	b	YI
Dried bulgur	40.82	5.88	15.69	79.58	41.78	5.04	14.40	73.88
Tempered bulgur	41.20	5.78	15.43	77.59	42.53	4.83	14.21	70.54
Peeled bulgur	47.51	5.65	17.34	74.21	44.76	4.82	16.96	68.58

The a-(redness) value for roller mill decreased during preceding operations that was also correlated with increase in the lightness (a-value) (Table 3.14). The similar relation for redness of disc mill was shown in Table 3.14. The yellowness values for both mills related with preceding operations decreased during tempering operation then increased after peeling operation due to remove of some bran part (Table 3.14).

3.1.4.2. Color values of products milled by roller mill

The L (lightness), a (redness), b (yellowness) and YI (yellowness index) were illustrated in Tables 3.15-3.26 for first, second and third roll gaps at 1.90, 1.60 and 1.30 mm for the results of second (0.80, 1.00 and 1.20 mm) and third (0.40, 0.50 and 0.60 mm) roll gaps.

In order to determine the effects of the third, second and first roll gaps on L (lightness) of the product, Tables 3.15-17 were prepared using ANOVA and Duncan Test's. The increase in third gap significantly ($P<0.05$) decreased the lightness of bulgur at constant first and second gaps (Table 3.15). But, for first and second gaps at 1.60, 1.30 and 0.80, 1.00 mm, an irregular change was obtained (Table 3.15). The highest lightness value was obtained for first, second and third gaps at 1.90, 0.80 and 0.40 mm. Also, second gap at fixed first and third gaps significantly ($P<0.05$) affected the lightness of products (Table 3.16). Similarly, the first gap was significantly ($P<0.05$) changed at fixed second and third rolls gaps (Table 3.17). However, the effect of first and second gaps on lightness was not regular.

Table 3.15. One-way ANOVA and multiple range test, when 1st and 2nd gaps (mm) hold as constant and 3rd gap increased to 0.60 mm for lightness from roller mill

3rd gap (mm)	1st gap 1.30 mm			1st gap 1.60 mm			1st gap 1.90 mm		
	2nd gap			2nd gap			2nd gap		
	0.80	1.00	1.20	0.80	1.00	1.20	0.80	1.00	1.20
0.40	56.53c	59.67 c	59.59 c	59.63 c	58.40 c	59.75 c	60.81 c	59.85c	56.01c
0.50	54.12a	54.88 a	56.00 b	54.74 a	55.42 b	55.20 b	54.02 a	57.53b	54.91b
0.60	55.20b	55.02 b	53.70 a	55.23 b	52.93 a	53.29 a	55.59b	51.04a	52.39a
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied.

Table 3.16. One-way ANOVA and multiple range test, when 1st and 3rd gaps (mm) hold as constant and 2nd gap increased to 1.20 mm for lightness from roller mill

2nd gap (mm)	1st gap 1.30 mm			1st gap 1.60 mm			1st gap 1.90 mm		
	3rd gap			3rd gap			3rd gap		
	0.40	0.50	0.60	0.40	0.50	0.60	0.40	0.50	0.60
0.80	56.53 a	54.12 a	55.20 c	59.63 b	54.74 a	55.23 c	60.81 c	54.02a	55.59c
1.00	59.67 c	54.88 b	55.02 b	58.40 a	55.42 c	52.93 a	59.85b	57.53c	51.04a
1.20	59.59 b	56.00 c	53.70 a	59.75 c	55.20 b	53.29 b	56.01 a	54.91b	52.39b
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied.

The effect of a (redness) values of second (0.80, 1.00 and 1.20 mm) and third (0.40, 0.50 and 0.60 mm) roll gaps for first roll gap at 1.90, 1,60 and 1.30 mm were illustrated in Figures 3.18-3.20.

The redness results of products milled by roller mill were stastically analyzed using ANOVA and Duncan's test. The highest result of redness (5.45) was found at the arrangement of gaps as 1.90, 1.20 and 0.60 mm for first, second and third, respectively. The increase in third gap significantly (P<0.05) increased redness values at constant first and second gaps (1.20,1,00 and 0.80 mm). At fixed first (1.90 and 1.30 mm) and second (1.20, 1.00 and 0.80 mm) gaps, a regular increase in redness was also obtained (Table 3.18). But, a regular change was not obtained for second and first gaps due to different homogeneous groups and orders (Tables 3.19 and 3.20). Comparing with the large particle size, redness values of milled samples were higher than that of dried, tempered and milled intact materials, as explained in Section 3.2.1.

Table 3.17. One-way ANOVA and multiple range test, when 2nd and 3rd gaps (mm) hold as constant and 1st gap increased to 1.90 mm for lightness from roller mill

1st gap (mm)	2nd gap 0.80 mm			2nd gap 1.00 mm			2nd gap 1.20 mm		
	3rd gap			3rd gap			3rd gap		
	0.40	0.50	0.60	0.40	0.50	0.60	0.40	0.50	0.60
1.30	56.53 a	54.12b	55.20 a	59.67 b	54.88 a	55.02 c	59.59b	56.00c	53.70c
1.60	59.63b	54.74 c	55.23 b	58.40 a	55.42 b	52.93 b	59.75 c	55.20b	53.29b
1.90	60.81 c	54.02 a	55.59 c	59.85 c	57.53 c	51.04 a	56.01 a	54.91a	52.39a
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied.

According to ANOVA and Duncan's tests, the variation of third, second and first gaps were significantly affected the yellowness (b) of the products (P<0.05, Tables 3.21-23). Irregular change of yellowness values was observed for all gap arrangements. The biggest yellowness value (22.17) was obtained as arrangements of gaps at 1.30, 1.20 and 0.40 mm for first, second and third gaps, respectively. On the other hand, the yellowness values of dried, tempered and peeled bulgur samples for roller mill were found as 15.69, 15.43 and 17.34 (Table 3.14) respectively which were smaller than 22.17. This result confirmed that the decrease in size increased the yellowness. Generally, fine sized bulgur has also good yellow color than coarse one at indentically scale, practically.

Table 3.18. One-way ANOVA and multiple range test, when first and second gaps (mm) hold as constant and third gap increased to 0.60 mm for redness from roller mill

3rd gap (mm)	1st gap 1.30 mm			1st gap 1.60 mm			1st gap 1.90 mm		
	2nd gap			2nd gap			2nd gap		
	0.80	1.00	1.20	0.80	1.00	1.20	0.80	1.00	1.20
0.40	4.39 a	4.50 a	4.53 a	4.18 a	4.51 a	4.29 a	3.92 a	4.26 a	4.88 a
0.50	5.40 b	5.35 c	4.96 b	5.29 c	4.97 b	5.13 c	4.90 c	4.58 b	5.27 b
0.60	5.10 c	4.95 b	5.10 c	4.85 b	5.16 c	5.08 b	4.71 b	5.44 c	5.45 c
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied

Table 3.19. One-way ANOVA and multiple range test, when first and third gaps (mm) hold as constant and second gap increased to 1.20 mm for redness from roller mill

2nd gaps (mm)	1st gap 1.30 mm			1st gap 1.60 mm			1st gap 1.90 mm		
	3rd gap			3rd gap			3rd gap		
	0.40	0.50	0.60	0.40	0.50	0.60	0.40	0.50	0.60
0.80	4.39 a	5.40 c	5.10 b	4.18 a	5.29 c	4.85 a	3.92 a	4.90 b	4.71 a
1.00	4.50 b	5.35 b	4.95 a	4.51 c	4.97 a	5.16 c	4.26 b	4.58 a	5.44 b
1.20	4.53 c	4.96 a	5.10 b	4.29 b	5.13 b	5.08 b	4.88 c	5.27 c	5.45 c
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied.

When third roll gap was increased to 0.60 mm, the degree of yellowness index was increased significantly (P<0.05) for constant first gap at 1.90 mm (Table 3.24). Similarly, the increase in second gap increased the yellowness index value regularly for first gap at 1.90 mm (P<0.05, Table 3.25). Similar regularity was not obtained for first gap (P<0.05, Tables 3.26). The highest value of yellowness index was obtained at 1.90, 1.20 and 0.60 mm for first, second and third gaps.

Table 3.20. One-way ANOVA and multiple range test, when 2nd and 3rd gaps (mm) hold as fixed and 1st gap increased to 1.90 mm for redness from roller mill

1st gap (mm)	2nd gap 0.80 mm			2nd gap 1.00 mm			2nd gap 1.20 mm		
	3rd gap			3rd gap			3rd gap		
	0.40	0.50	0.60	0.40	0.50	0.60	0.40	0.50	0.60
1.30	4.39 c	5.40 c	5.10 c	4.50 b	5.35 c	4.95 a	4.53 b	4.96 a	5.10 b
1.60	4.18 b	5.29 b	4.85 b	4.51 c	4.97 b	5.16 b	4.29 a	5.13 b	5.08 a
1.90	3.92 a	4.90 a	4.71 a	4.26 a	4.58 a	5.44 c	4.88 c	5.27 c	5.45 c
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied.

Table 3.21. One-way ANOVA and multiple range test, when first and second gaps (mm) hold as constant and third gap increased to 0.60 mm for yellowness from roller mill

3rd gap (mm)	1st gap 1.30 mm			1st gap 1.60 mm			1st gap 1.90 mm		
	2nd gap			2nd gap			2nd gap		
	0.80	1.00	1.20	0.80	1.00	1.20	0.80	1.00	1.20
0.40	20.12a	21.58 c	22.17 c	21.46 c	21.30 c	21.76 c	20.59b	20.93b	21.5 b
0.50	20.88b	21.48 b	21.52 b	21.40 b	21.27 b	21.58 b	19.84 a	21.83c	22.03c
0.60	21.34c	21.07 a	20.66 a	21.09 a	20.06 a	19.97 a	20.89 c	19.65a	20.84a
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied

Table 3.22. One-way ANOVA and multiple range test, when first and third gaps (mm) hold as constant and second gap increased to 1.20 mm for yellowness from roller mill

2nd gap (mm)	1st gap 1.30 mm			1st gap 1.60 mm			1st gap 1.90 mm		
	3rd gap			3rd gap			3rd gap		
	0.40	0.50	0.60	0.40	0.50	0.60	0.40	0.50	0.60
0.80	20.12 a	20.88 a	21.34 c	21.46 b	21.40 b	21.09 c	20.59 a	19.84a	20.89c
1.00	21.58 b	21.48 b	21.07 b	21.30 a	21.27 a	20.06 b	20.93b	21.83b	19.65a
1.20	22.17 c	21.52 c	20.66 a	21.76 c	21.58 c	19.97 a	21.55 c	22.03c	20.84b
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied.

Table 3.23. One-way ANOVA and multiple range test, when second and third gaps hold as constant and first gap increased to 1.90 mm for yellowness from roller mill

1st gap (mm)	2nd gap 0.80 mm			2nd gap 1.00 mm			2nd gap 1.20 mm		
	3rd gap			3rd gap			3rd gap		
	0.40	0.50	0.60	0.40	0.50	0.60	0.40	0.50	0.60
1.30	20.12 a	20.88 b	21.34 c	21.58 c	21.48 b	21.07 c	22.17 c	21.52a	20.66b
1.60	21.46 c	21.40 c	21.09 b	21.30 b	21.27 a	20.06 b	21.76b	21.58b	19.97a
1.90	20.59b	19.84 a	20.89 a	20.93 a	21.83 c	19.65 a	21.55 a	22.03c	20.84c
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied

Table 3.24. One-way ANOVA and multiple range test, when first and second gaps (mm) hold as constant and third gap increased to 0.60 mm for yellowness index from roller mill

3rd gap (mm)	1st gap 1.30 mm			1st gap 1.60 mm			1st gap 1.90 mm		
	2nd gap			2nd gap			2nd gap		
	0.80	1.00	1.20	0.80	1.00	1.20	0.80	1.00	1.20
0.40	69.48a	70.27 a	72.09 a	69.54 a	70.93 a	70.42 a	65.46 a	67.88a	75.11a
0.50	76.27c	77.02 c	75.15 b	76.88 c	75.14 c	76.59 c	72.43b	73.62b	78.57b
0.60	75.81b	75.02 b	75.70 c	74.67 b	74.94 b	74.06 b	73.40 c	76.66c	78.59c
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied

Table 3.25. One-way ANOVA and multiple range test, when first and third gaps (mm) hold as constant and second gap increased to 1.20 mm for yellowness index from roller mill

2nd gap (mm)	1st gap 1.30 mm			1st gap 1.60 mm			1st gap 1.90 mm		
	3rd gap			3rd gap			3rd gap		
	0.40	0.50	0.60	0.40	0.50	0.60	0.40	0.50	0.60
0.80	69.48 a	76.27b	75.81 c	69.54 a	76.88 c	74.67 b	65.46 a	72.43a	73.40a
1.00	70.27b	77.02 c	75.02 a	70.93 c	75.14 a	74.94 c	67.88b	73.62b	76.66b
1.20	72.09 c	75.15 a	75.70 b	70.42 b	76.59 b	74.06 a	75.11 c	78.57c	78.59c
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied.

Table 3.26. One-way ANOVA and multiple range test, when second and third gaps (mm) hold as constant and first gap increased to 1.90 mm for yellowness index from roller mill

1st gap (mm)	2nd gap 0.80 mm			2nd gap 1.00 mm			2nd gap 1.20 mm		
	3rd gap			3rd gap			3rd gap		
	0.40	0.50	0.60	0.40	0.50	0.60	0.40	0.50	0.60
1.30	69.48b	76.27 b	75.81 c	70.27 b	77.02 c	75.02 b	72.09b	75.15a	75.70b
1.60	69.54 c	76.88 c	74.67 b	70.93 c	75.14 b	74.94 a	70.42 a	76.59b	74.06a
1.90	65.46 a	72.43 a	73.40 a	67.88 a	73.62 a	76.66 c	75.11 c	78.57c	78.59c
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied

YI (yellowness index) value is a numerical representation of how yellow a material is in comparision with a clear water white standart. Thus, low yellowness indexes indicate greater clarity (cleaness) (indicates the degree of departure of an object color from colorless or from a preferred white). The increase in yellowness index was opposite to decreasing the lightness (L-value) and in parallel with the yellowness (b-value). Namely, a change of YI value was correlated with L- and b-values (Bayram *et al.*, 2004).

3.1.4.3. Color values of products milled by disc mill

The L (lightness), a (redness), b (yellowness) and YI (yellowness index) values with repect to gaps for products milled by disc mill were illustrated in Figures 3.1-3.4, respectively. Statistical analysis results were given in Table 3.27.

The change of disc gaps were significantly (P<0.05) affected the color values (L, a, b, and YI). But, regular effects were not obtained for color values of products. When experimental results of milled products compared with the peeled intact bulgur, the color values would significantly affected milled samples. L (lightness) value for intact peeled bulgur was found as 44.76 that were lower than that for disc milled products i.e. 53.30 for gap at 1.90 mm. This means that milled bulgur has high lightness value than intact bulgur for disc milling. Similarly, an increase in yellowness and redness values were obtained when the intact bulgur was milled for gap at 1.90 mm. On the other hand, the milling decreased in yellowness index value (from 68.58 to 65.63) for the same gap.

Table 3.27. One-way ANOVA and multiple range test, when disc gap increased to 1.90 mm for (L (lightness), a (redness), b (yellowness), YI (yellowness index), ash (g/g, d.b.), yield (g/g), loss (g/g) and hectoliter weight (kg/hl)) of products from disc mill

Gap (mm)	L	a	b	YI
0.40	57.58g	4.82 c	20.55h	69.85 i
0.50	59.27 i	4.70 b	20.99 i	69.27 g
0.60	57.33 f	4.85 e	20.22 f	69.43 h
0.80	58.00h	4.62 a	20.44g	68.99 f
1.00	56.39e	4.83 d	19.65e	68.63 d
1.20	56.04d	5.03 h	19.40d	68.69 e
1.30	53.81c	5.00 g	17.94c	66.77 c
1.60	52.97a	4.87 f	17.10a	64.91 a
1.90	53.30b	5.03 h	17.38b	65.63 b
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied

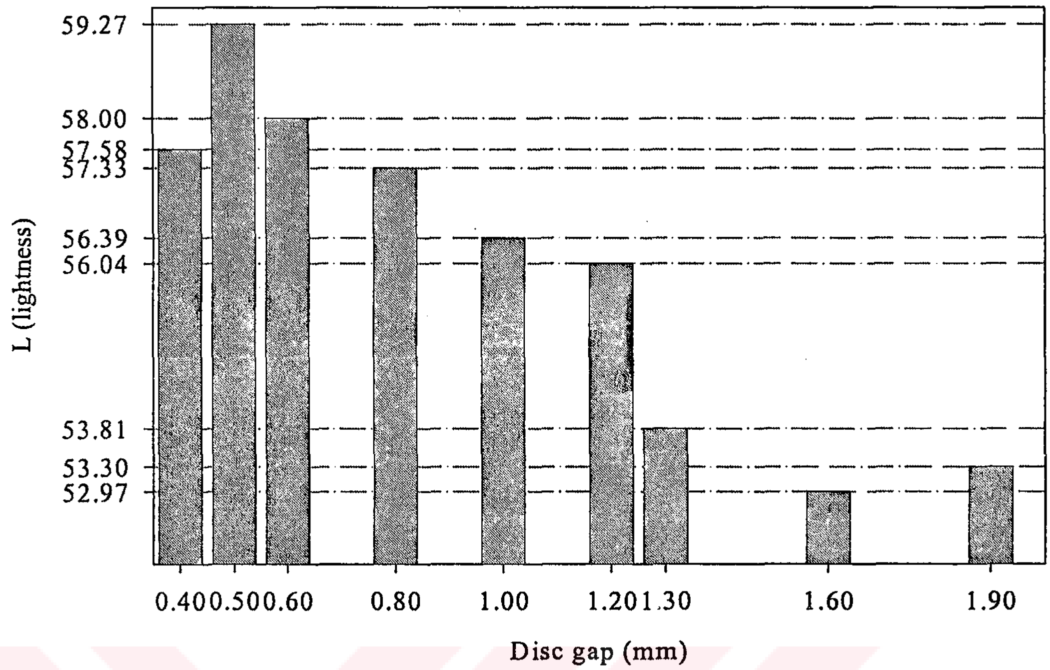

Figure 3.1. L (lightness) values of the samples milled by disc mill for different gaps arrangements

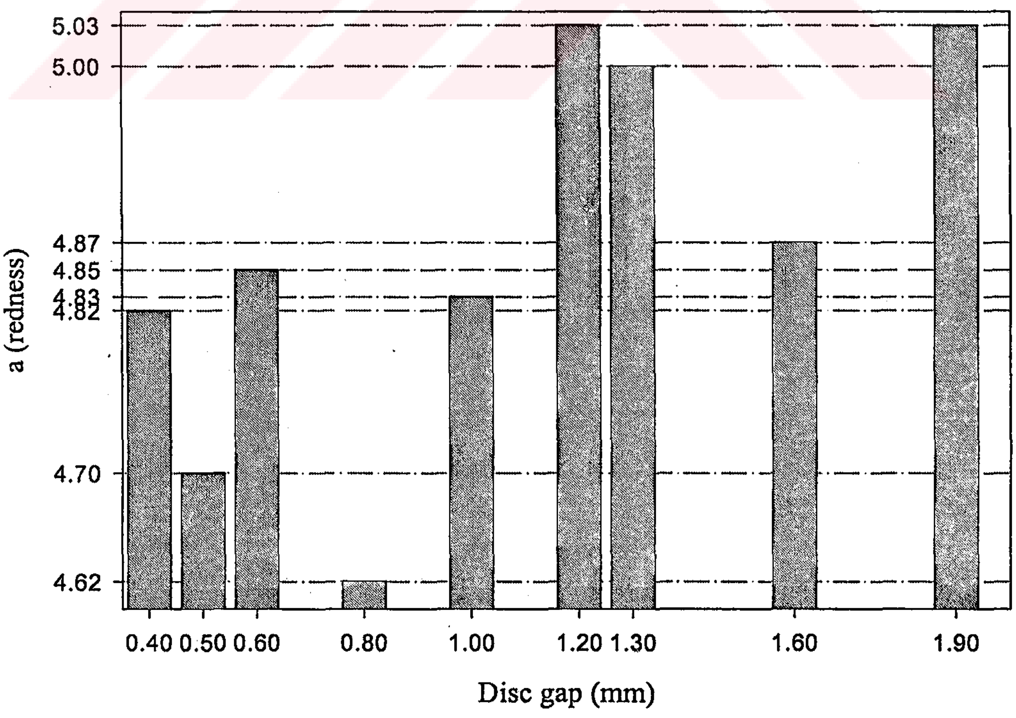

Figure 3.2. a (redness)-values of the samples milled by disc mill for different gaps arrangements

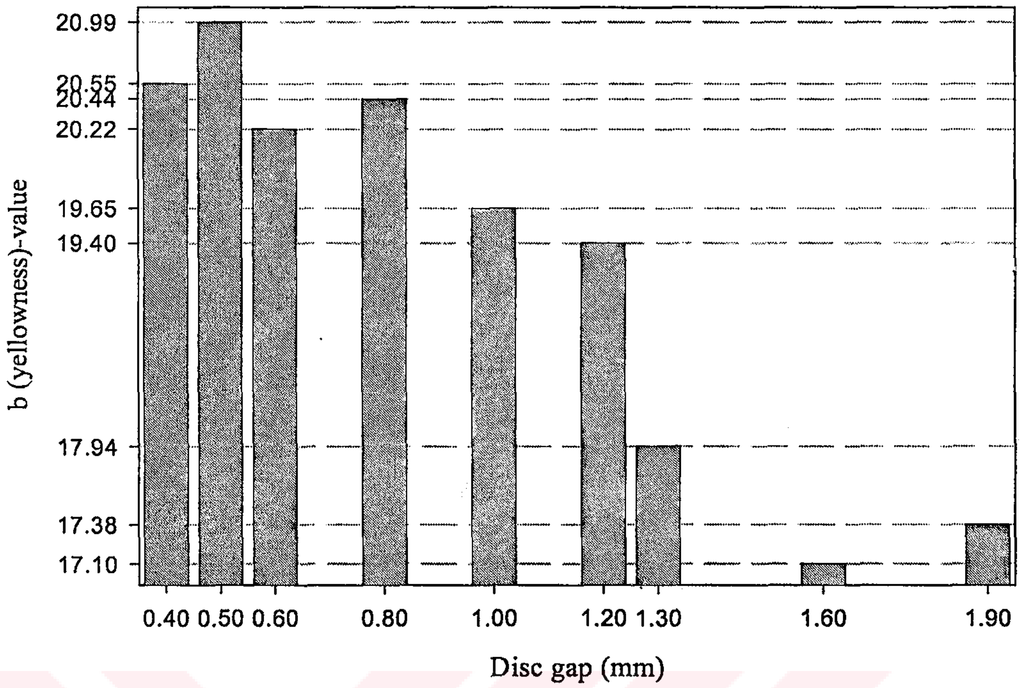

Figure 3.3. b (yellowness) values of the samples milled by disc mill for different gaps arrangements

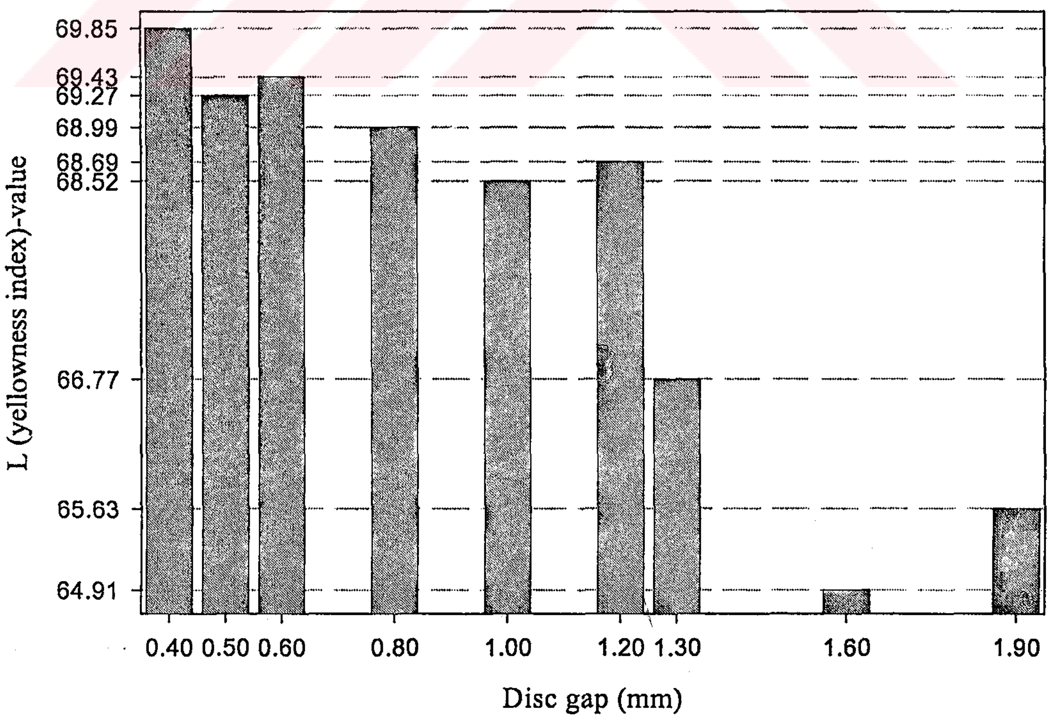

Figure 3.4. YI (yellowness index) values of the samples milled by disc mill for different gaps arrangements

3.1.5. Ash contents related to milling operations

Niernberger and Farrell (1970) compared experimental results from fluted rolls with different diameters, and found that medium sized diameter rolls gave the lowest ash content. Gehle (1965), and Cleve and Will (1966) reported that the type of corrugation affects the ash content in the flour released first-break roller milling. According to Chaurand *et al.* (1999), the semolina milling value is dependent on regulatory factors such as ash content, harvesting conditions, and intrinsic factors (i.e. factors related to the morphological and physical characteristics of the grain). Among these, the structure of the aleurone layer is presumed to play a significant role. From a botanical standpoint, it is the outer layer of the endosperm. However, as it is removed during milling, it constitutes the innermost layer of bran (Peyron *et. al.*, 2002). However, during bulgur production less amount of bran is removed. The ash content related to bran layer of grain wheat is also an important characteristic for bulgur milling. According to Turkish Standart (Anon., 1996), the ash content of finished bulgur should be less than 1.75 % (g/g, d.b.).

3.1.5.1. Ash contents during preceding operations for both roller and disc mills

As explained in Section 3.1.4.1, before the milling operation, wheat is cooked, dried, tempered and peeled. The experimental results of ash contents (%, g/g, d.b.) of dried, tempered and peeled samples for both roller and disc mills were given in Table 3.28. The decrease in ash content values i.e. 1.65, 1.60 and 1.36%, were obtained for dried, tempered and peeled samples, respectively. Similar relation was also obtained for disc mill. The large amount of ash content exists in the bran part of wheat kernel. When this layer is removed during peeling operation, ash content decreased. Also, during tempering operation, a decrease in ash content observed. Because, during tempering, some inorganic materials that is caused the ash content increase are desolved .in water and during centrifugal washing unit. Some amount of this bran layer may adhesive on surface of screen of washer unit. The experimental results correlated this decrease of ash content.

Table 3.28 Ash contents (%, g/g, d.b.) of dried, tempered and peeled intact bulgur samples for both roller and disc mills

Type of sample	% Ash (g/g)	
	Roller mill	Disc mill
Dried bulgur	1.65	1.60
Tempered bulgur	1.60	1.57
Peeled bulgur	1.36	1.36

3.1.5.2. Ash contents of products from roller mill

The ash contents (%, g/g, d.b.) of products milled using roller mill were evaluated as screen analysed with 2.00 mm sieve (+/2.00). The ash contents relation to fixed first roll gaps (1.90, 1.60 and 1.30 mm), second roll gaps (1.20, 1.00 and 0.80 mm) and third gaps (0.40, 0.50 and 0.60 mm) were illustrated in Table 3.29. The statistical results for ash contents were given in Tables 3.29-31.

Table 3.29. One-way ANOVA and multiple range test, when first and second gaps (mm) hold as constant and third gap increased to 0.60 mm for percent ash (d.b, g/g) from roller mill

3rd gap (mm)	1st gap 1.30 mm			1st gap 1.60 mm			1st gap 1.90 mm		
	2nd gap			2nd gap			2nd gap		
	0.80	1.00	1.20	0.80	1.00	1.20	0.80	1.00	1.20
0.40	1.58 c	1.30 b	1.22 a	1.41 c	1.32 a	1.30 b	1.84 c	1.92 b	1.46 a
0.50	1.34 b	1.29 a	1.31 b	1.32 b	1.37 c	1.26 a	1.79 b	2.25 c	1.94 b
0.60	1.32 a	1.35 c	1.36 c	1.31 a	1.34 b	2.08 c	1.77 a	1.62 a	2.28 c
ANOVA	$P<0.05$	$P<0.05$	$P<0.05$	$P<0.05$	$P<0.05$	$P<0.05$	$P<0.05$	$P<0.05$	$P<0.05$

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

The lowest ash content (1.22%, d.b.) was obtained as arrangements of roll gaps at 1.30, 1.20 and 0.40 mm for first, second and third gaps, respectively (Table 3.29). But, highest ash content (2.28%, d.b.) was significantly ($P<0.05$) obtained with the gaps arrangements at 1.90, 1.20 and 0.60 mm for first, second and third gaps. Change in ash content was not regular due to change in third gap. Tables 3.30 and 3.31

illustrated that there were also no regular effect of first and second gaps on ash content for roller-milled samples.

Table 3.30. One-way ANOVA and multiple range test, when first and third gaps (mm) hold as constant and second gap increased to 1.20 mm for percent ash (g/g, d.b.) from roller mill

2nd gap (mm)	1st gap 1.30 mm			1st gap 1.60 mm			1st gap 1.90 mm		
	3rd gap			3rd gap			3rd gap		
	0.40	0.50	0.60	0.40	0.50	0.60	0.40	0.50	0.60
0.80	1.58 c	1.34 c	1.32 a	1.41 c	1.32 b	1.31 a	1.84 b	1.79 a	1.77 b
1.00	1.30 a	1.29 b	1.35 b	1.32 b	1.37 c	1.34 b	1.92 c	2.25 c	1.62 a
1.20	1.31 b	1.22 a	1.36 c	1.30 a	1.26 a	2.08 c	1.46 a	1.94 b	2.28 c
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied.

Table 3.31. One-way ANOVA and multiple range test, when second and third gaps (mm) hold as constant and first gap increased to 1.90 mm for percent ash (g/g, d.b.) from roller mill

1st gap (mm)	2nd gap 0.80 mm			2nd gap 1.00 mm			2nd gap 1.20 mm		
	3rd gap			3rd gap			3rd gap		
	0.40	0.50	0.60	0.40	0.50	0.60	0.40	0.50	0.60
1.30	1.58 b	1.34 b	1.32 b	1.30 a	1.29 a	1.35 b	1.31 b	1.22 a	1.36 a
1.60	1.41 a	1.32 a	1.31 a	1.32 b	1.37 b	1.34 a	1.30 a	1.26 b	2.08 b
1.90	1.84 c	1.79 c	1.77 c	1.92 c	2.25 c	1.62 c	1.46 c	1.94 c	2.28 c
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied.

Milling operation during bulgur production is different from other granular food milling, e.g., flour, semolina etc. The seperation should be ideally occured at the level of the endosperm-aleurone layer interface of aleurone layer is onto genetically part of endosperm; it is separated as part of the bran during milling process (Peyron *et. al.*, 2002). First-break or the first roll mill operation in the milling process opens up the wheat kernel, and release the endosperm with minimum bran breakage (Pasikatan *et. al.*, 2001).

So, milling operation of bulgur production is similar to first- break of flour milling operation, which removes less amount of bran part from the intact bulgur and less decrease in ash content. According to results, as the particle size decreased, the percent ash was also decreased.

3.1.5.3. Ash contents of products from disc mill

The ash content results (% ash, g/g, d.b.) of samples obtained using disc mill were given in Table 3.32 for different gaps (0.40, 0.50, 0.60, 0.80, 1.00, 1.20, 1.30, 1.60 and 1.90 mm). The illustration of ash content relation with different disc gaps arrangements was shown in Figure 3.5.

Table 3.32. One-way ANOVA and multiple range test, when disc gap increased to 1.90 mm for percent ash (g/g, d.b.) from disc mill

Gap (mm)	0.40	0.50	0.60	0.80	1.00	1.20	1.30	1.60	1.90
% ash	1.24 b	1.26 d	1.20 a	1.26 d	1.27 e	1.25 c	1.27 e	1.34 f	1.36 g
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied

Table 3.32 and Figure 3.5 indicated that, similar to roller mill, the decrease in particle size was significantly (P<0.05) affected the ash contents of milled samples at different disc gaps arrangements. However, an irregular effect of ash content was obtained for gaps at 0.40, 0.50, 0.60, 0.80, 1.00 and 1.20 mm. On the other hand, a regular change (1.27, 1.34 and 1.36 %) was obtained for gaps at 1.30, 1.60 and 1.90 mm.

Generally, as expected, increase in gap size increased the ash content due to remaining of the unhulled bran part on surface of bulgur particles. Also, frictional effect of discs removed efficiently bran at lower gap sizes.

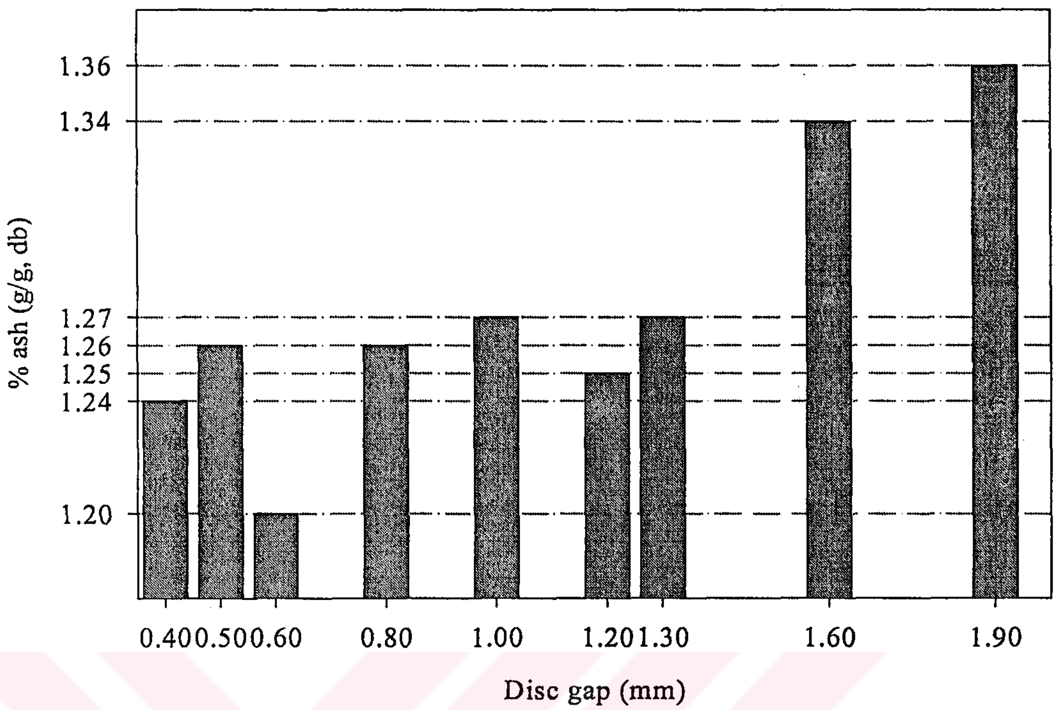

Figure 3.5. Percent ash (g/g, d.b.) of milled products by disc mill for different disc gaps arrangements

3.1.6. Percent yield and loss

The percent yield for bulgur production is the amount of bulgur produced from one hundred kilograms of wheat sample. On the other hand, loss value for bulgur, opposite of yield value, is the amount of non-bulgur or by products. The yield and loss values were found from the screen analyses results that cumulative percent masss retained over 0.50 mm sieve (+/0.50) and lower than 0.50 mm sieve (0.50/-), respectively.

3.1.6.1. Percent yield and loss of products from roller mill

Experimental results of yield (%, g/g) and loss (%, g/g) values of products from roller mill for different gap arrangements were given in Tables 3.33-38.

Table 3.33 illustrated the yield and loss values of second (0.80, 1.00 and 1.20 mm) and third (0.40, 0.50 and 0.60 mm) roll gaps for first gap at 1.90 mm, respectively. The yield and loss results were also statistically analyzed using ANOVA and

Duncan's test (Tables 3.33-38). The increase in third gap significantly (P<0.05) increased the yield and decreased (P<0.05) the loss value at fixed first and second roll gaps (Tables 3.33 and 3.34). The largest yield (99.75%) value was obtained at 1.90, 1.20 and 0.60 mm for first, second and third gaps arrangements. However, at the same arrangements of roll gaps, the lowest loss value (by product, 0.25%) was obtained. The effect of third gap on yield and loss values was regular. But, first and second roll gaps had no regular effects on the yield and loss values (P<0.05, Tables 3.35-38).

Table 3.33. One-way ANOVA and multiple range test, when first and second gaps (mm) hold as constant and third gap increased to 0.60 mm for yield (%, g/g) from roller mill

3rd gap (mm)	1st gap 1.30 mm			1st gap 1.60 mm			1st gap 1.90 mm		
	2nd gap			2nd gap			2nd gap		
	0.80	1.00	1.20	0.80	1.00	1.20	0.80	1.00	1.20
0.40	84.77a	87.17 a	91.96 a	88.85 a	91.11 a	89.61 a	88.99 a	87.86a	93.34a
0.50	96.37b	97.15 b	95.90 b	95.54 b	95.73 b	94.04 b	97.55b	88.33b	95.90b
0.60	98.10c	97.73 c	97.03 c	95.98 c	96.29 c	96.77 c	99.60 c	99.54c	99.75c
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied

Table 3.34. One-way ANOVA and multiple range test, when first and second gaps (mm) hold as constant and third gap increased to 0.60 mm for loss (%, g/g) from roller mill

3rd gap (mm)	1st gap 1.30 mm			1st gap 1.60 mm			1st gap 1.90 mm		
	2nd gap			2nd gap			2nd gap		
	0.80	1.00	1.20	0.80	1.00	1.20	0.80	1.00	1.20
0.40	15.23c	12.83 c	8.04 c	11.15 c	8.89 c	10.39 c	11.01 c	12.14c	6.66 c
0.50	3.63 b	2.85 b	4.10 b	4.46 b	4.27 b	5.96 b	2.45 b	11.67b	4.10 b
0.60	1.90 a	2.27 a	2.97 a	4.02 a	3.71 a	3.23 a	0.40 a	0.46 a	0.25 a
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied

Table 3.35. One-way ANOVA and multiple range test, when first and third gaps (mm) hold as constant and second gap increased to 1.20 mm for yield (%, g/g) from roller mill

2nd gap (mm)	1st gap 1.30 mm			1st gap 1.60 mm			1st gap 1.90 mm		
	3rd gap			3rd gap			3rd gap		
	0.40	0.50	0.60	0.40	0.50	0.60	0.40	0.50	0.60
0.80	84.77 a	96.37b	98.10 c	88.85 a	95.54 b	95.98 a	88.99b	97.55c	99.60b
1.00	87.17 b	97.15 c	97.73 b	91.11 c	95.73 c	96.29 b	87.86 a	88.33a	99.54a
1.20	91.96 c	95.90 a	97.03 a	89.61 b	94.04 a	96.77 c	93.34 c	95.90b	99.75c
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied

Table 3.36. One-way ANOVA and multiple range test, when first and third gaps hold as constant and second gap increased to 1.20 mm for loss (%, g/g) from roller mill

2nd gap (mm)	1st gap 1.30 mm			1st gap 1.60 mm			1st gap 1.90 mm		
	3rd gap			3rd gap			3rd gap		
	0.40	0.50	0.60	0.40	0.50	0.60	0.40	0.50	0.60
0.80	15.23c	3.63 b	1.90 a	11.15 c	4.46 b	4.02 c	11.01b	2.45	0.40 b
1.00	12.83b	2.85 a	2.27 b	8.89 a	4.27 a	3.71 b	12.14 c	11.67	0.46 c
1.20	8.04 a	4.10 c	2.97 c	10.39 b	5.96 c	3.23 a	6.66 a	4.10	0.25 a
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied.

Table 3.37. One-way ANOVA and multiple range test, when second and third gaps hold as constant and first gap increased to 1.90 mm for yield (%, g/g) from roller mill

1st gap (mm)	2nd gap 0.80 mm			2nd gap 1.00 mm			2nd gap 1.20 mm		
	3rd gap			3rd gap			3rd gap		
	0.40	0.50	0.60	0.40	0.50	0.60	0.40	0.50	0.60
1.30	84.77 a	96.37 b	98.10 b	87.17 a	97.15c	97.73 b	91.96b	95.90b	97.03b
1.60	88.85 b	95.54 a	95.98 a	91.11 c	95.73b	96.29 a	89.61 a	94.04a	96.77a
1.90	88.89 c	97.55 c	99.60 c	87.86 b	88.33a	99.54 c	93.34 c	95.90b	99.75c
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed.Based on Type III sum of squares. Duncan test was applied.

Table 3.38. One-way ANOVA and multiple range test, when second and third gaps (mm) hold as constant and first gap increased to 1.90 mm for loss (%, g/g) roller mill

1st gap (mm)	2nd gap 0.80 mm			2nd gap 1.00 mm			2nd gap 1.20 mm		
	3rd gap			3rd gap			3rd gap		
	0.40	0.50	0.60	0.40	0.50	0.60	0.40	0.50	0.60
1.30	15.23 c	3.63 b	1.90 b	12.83 c	2.85 a	2.27 b	8.04b	4.10 a	2.97 b
1.60	11.15b	4.46 c	4.02 c	8.89 a	4.27 b	3.71 c	10.39 c	5.96 b	3.23 c
1.90	11.01 a	2.45 a	0.40 a	12.14 b	11.67 c	0.46 a	6.66 a	4.10 a	0.25 a
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed.Based on Type III sum of squares. Duncan test was applied.

3.1.6.2. Percent yield and loss of products from disc mill

Similar to roll gaps as explained in previous section, same gaps (0.40, 0.50, 0.60, 0.80, 1.00, 1.20, 1.30, 1.60 and 1.90 mm) were used in this section for both percent yield and loss results. The results of both values were given in Table 3.39. Figures 3.6 and 3.7 illustrated the relation of yield and loss values at different gaps arrangements.

Table 3.39. One-way ANOVA and multiple range test, when disc gap increased to 1.90 mm for yield (%, g/g) and loss (%, g/g) from disc mill

Gap(mm)	0.40	0.50	0.60	0.80	1.00	1.20	1.30	1.60	1.90
% yield	13.13 a	72.33 b	80.58 c	84.40 d	88.59 e	91.01 f	92.27g	95.96 h	96.17 i
% loss	86.87 i	27.67 h	19.42 g	15.60 f	11.41 e	8.99 d	7.73 c	4.04 b	3.83 a
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

When the disc gap was increased from 0.40 to 1.90 mm, also yield values were increased from 13.13 to 96.17 % (Table 3.39, Figure 3.6). The highest loss value (86.87 %) was obtained at 0.40 mm gap (Table 3.39, Figure 3.7). However, at this gap arrangement, the percent of yield for bulgur was the lowest one. According to ANOVA and Duncan's test, disc gap significantly (P<0.05) affected the yield and loss values, and a regular effect was obtained (Table 3.39).

Statistical analysis and results shows that by-products (loss %) from disc mill were higher than that of roller mill. In order to obtain high amount of bulgur, the use of roller mill was efficient than disc mill.

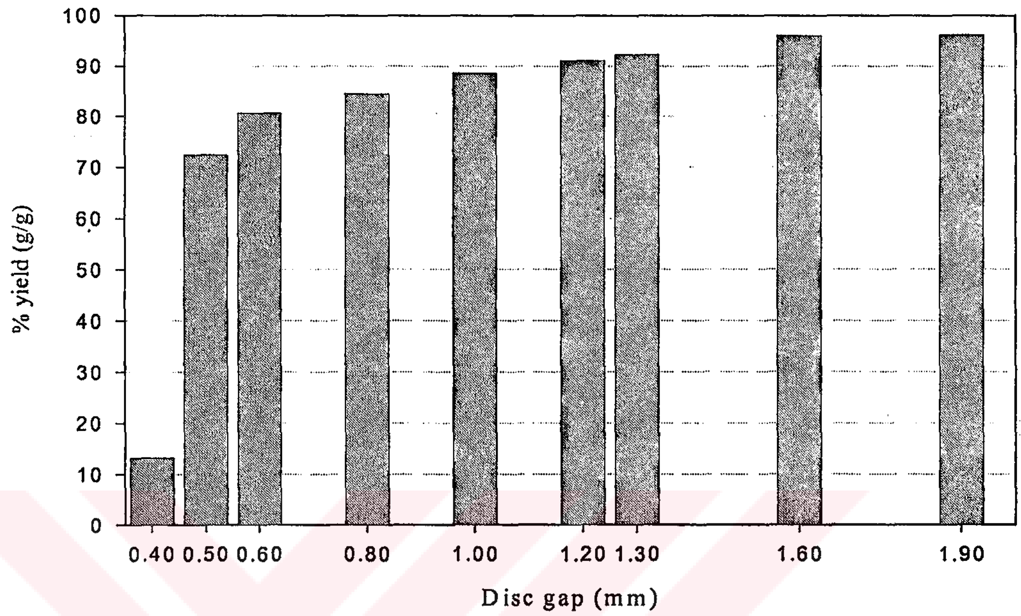

Figure 3.6. Yield (%, g/g)) values of milled products by disc mill for different gaps arrangements

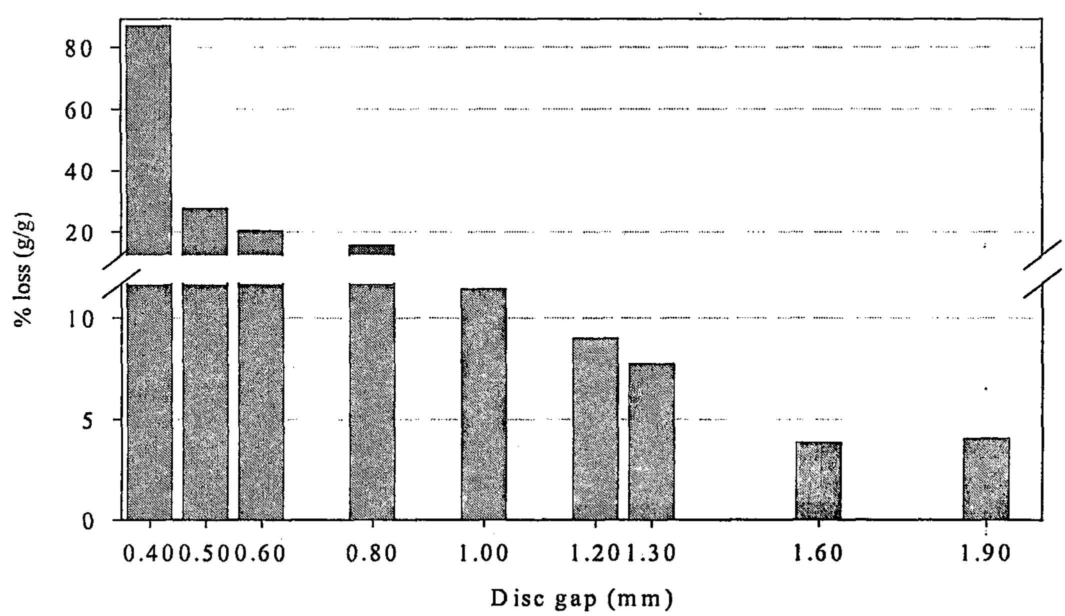

Figure 3.7. Loss (%, g/g)) values of milled products by disc mill for different gaps arrangements

3.1.7. Hectoliter weight or bulk density

Hectoliter weight is the weight of sample at constant volume (kg/hl). It is used as a quality factor for millers. Producers of grain like materials prefer the high values of hectoliter weight. Because, hight value in hectoliter weight means less voids in grains. Hectoliter weights of raw materials (hectoliter weight during preceding operations for both roller and disc mill), milled products by both roller and disc mills were measured.

3.1.7.1. Hectoliter weight (bulk density) values during proceeding operations for both roller and disc mill

The hectoliter weight values of dried, tempered and peeled intact bulgur samples before milling for both roller and disc mills were given in Table 3.40. As expected due to water absorption, the hectoliter weight of tempered intact bulgur (75.65, kg/hl) was found as lower than the intact dried bulgur (78.54, kg/hl), and also peeled one for roller mill. Hectoliter weight of peeled sample was the highest one because of removing of cellulosic bran layer. Similarly, the same relation of hectoliter weight and type of intact samples were observed for disc mill (Table 3.40).

Table 3.40. Hectoliter weights (kg/hl) of dried, tempered and peeled intact bulgur samples for both roller and disc mills

Type of sample	Hectoliter weight (kg/hl)	
	Roller mill	Disc mill
Dried bulgur	78.54	76.02
Tempered bulgur	75.65	73.94
Peeled bulgur	85.58	84.32
Milled bulgur	81.08	81.68

3.1.7.2. Hectoliter weights of products milled by roller mill

The measurements of hectoliter weights were done for the roll milled samples without screening (mixed stocks). The experimental results of hectoliter weight (kg/hl) were given in Table 41-43 for different roll gaps arrangements. The lowest value of hectoliter weight (64.96 (kg/hl)) was obtained at 1.30, 0,80 and 0.40 mm for first, second and third gaps arrangements. On the other hand the highest hectoliter weight was 81.08 (kg/hl) that obtained at 1.90, 1.20 and 0.60 mm for first, second and third gaps arrangements due to lowest surface area (big particle size). The increase in third gap significantly (P<0.05) increased hectoliter weight of product from roller mill at constant first and second gaps (Table 3.41). The second and first gaps also significantly (P<0.05) affected the hectoliter weight (Tables 3.42 and 3.43).

Table 3.41. One-way ANOVA and multiple range test, when first and second gaps hold as constant and third gap increased to 0.60 mm for hectoliter weights (kg/hl) of products from roller mill

3rd gap (mm)	1st gap 1.30 mm			1st gap 1.60 mm			1st gap 1.90 mm		
	2nd gap			2nd gap			2nd gap		
	0.80	1.00	1.20	0.80	1.00	1.20	0.80	1.00	1.20
0.40	64.96a	69.74 a	70.16 a	70.34 a	70.76 a	71.03 a	70.08 a	70.84a	73.20a
0.50	76.36b	73.79 b	74.60 b	76.89 b	75.75 b	76.18 b	77.44b	74.06b	75.05b
0.60	79.00c	76.49 c	77.00 c	77.28 c	77.84 c	79.16 c	77.56 c	79.44c	81.08c
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied

Table 3.42. One-way ANOVA and multiple range test, when first and third gaps hold as constant and second gap increased to1.20 mm for hectoliter weights (kg/hl) of products from roller mill

2nd gap (mm)	1st gap 1.30 mm			1st gap 1.60 mm			1st gap 1.90 mm		
	3rd gap			3rd gap			3rd gap		
	0.40	0.50	0.60	0.40	0.50	0.60	0.40	0.50	0.60
0.80	64.96 a	76.36 c	79.00 c	70.34 a	76.89 c	77.28 a	70.08 a	77.44c	77.56a
1.00	69.74 b	73.79 a	76.49 a	70.76 b	75.75 a	77.84 b	70.84b	74.06a	79.44b
1.20	70.16 c	74.60 b	77.00 b	71.03 c	76.18 b	79.16 c	73.20 c	75.05b	81.08c
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied.

Table 3.43. One-way ANOVA and multiple range test, when second and third gaps hold as constant and first gap increased to1.90 mm for hectoliter weights (kg/hl) of products from roller mill

1st gap (mm)	2nd gap 0.80 mm			2nd gap 1.00 mm			2nd gap 1.20 mm		
	3rd gap			3rd gap			3rd gap		
	0.40	0.50	0.60	0.40	0.50	0.60	0.40	0.50	0.60
1.30	64.96 a	76.36 a	79.00 c	69.74 a	73.79 a	76.49 a	70.16 a	74.60a	77.00a
1.60	70.34 c	76.89 b	77.28 a	70.76 b	75.75 c	77.84 b	71.03b	76.1 c	79.16b
1.90	70.08b	77.44 c	77.56 b	70.84 c	74.06 b	79.44 c	73.20 c	75.05b	81.08c
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied

3.1.7.3. Hectoliter weights of products milled by disc mill

Hectoliter weight values of products milled by disc mill were measured at the same condition with the roller mill. The hectoliter weight of milled products with related to different gaps arrangements were illustrated in Figure 3.8. According to ANOVA and Duncan's test, the increase in the gap significantly (P<0.05) increased the hectoliter weight (Table 3.44). A regular increase was obtained in hectoliter weights of samples. The highest hectoliter weight was obtained at 1.90 mm gap, as expected.

Table 3.44. One-way ANOVA and multiple range test, hectoliter weight (kg/hl)) of products from disc mill, when disc gap increased to 1.90 mm

Gap (mm)	0.40	0.50	0.60	0.80	1.00	1.20	1.30	1.60	1.90
Hectoliter weight	81.68 a	83.04b	83.50 c	84.56 d	84.76 e	84.87 f	85.20g	85.49 h	87.37 i
ANOVA	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Different letters indicate statistically differences exist at α=0.05. Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares. Duncan test was applied

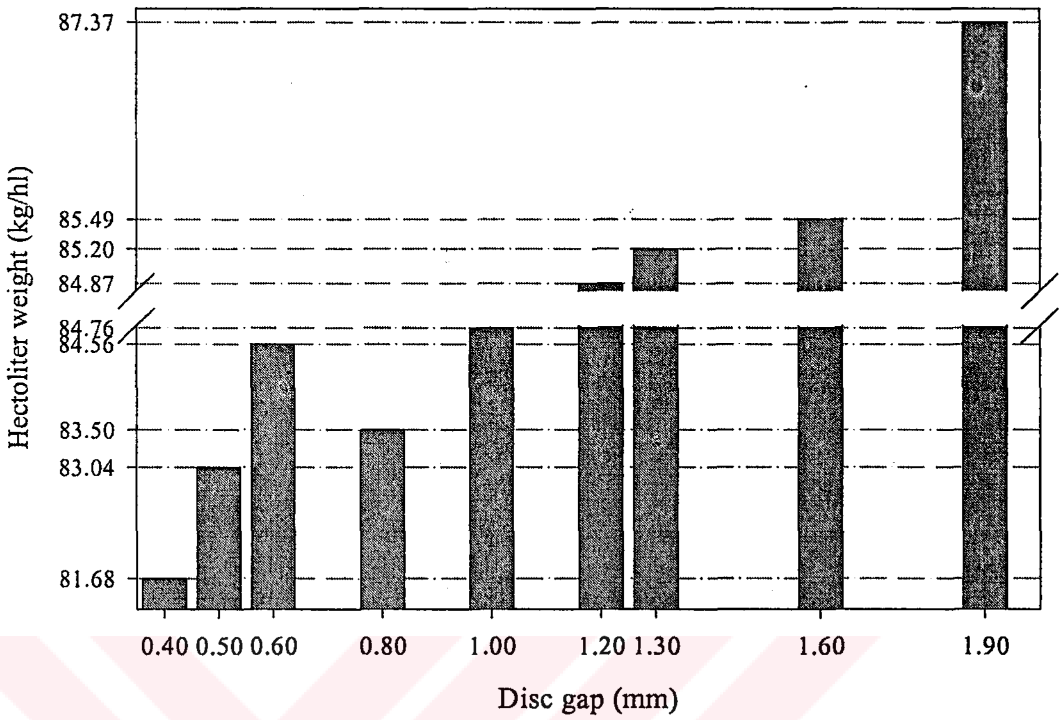

Figure 3.8. Hectoliter weight (kg/hl) values of milled products by disc mill for different gaps arrangements (0.40, 0.50, 0.60, 0.80, 1.00, 1.20, 1.30, 1.60 and 1.90 mm)

3.1.8. Moisture contents during preceding operations for both roller and disc mills and milled products

Moisture contents of products are very important criteria for the acceptable and feasible bulgur production. When the moisture content of the sample was too low, some problems may be carried out during milling and peeling operations such as difficult bran removal and heating of milling machine.

Moisture contents of dried, tempered, peeled and milled bulgur samples were determined as 11.32, 15.90, 11.92 and 10.25 % (g/g, w.b.) for roller mill, respectively (Table 3.45). During drying operation, the moisture of product should be low i.e<12.00 %. Addition of water (tempering) to the sample increased the moisture content of the product. When the product was peeled, moisture content decreased due to removing bran and generation of heat during occurance of friction between bulgur and peeler discs. Obtained moisture content values are suitable for bulgur milling operation, industrially.

Moisture contents for intact bulgur samples were also varied during drying, tempering, peeling operations for disc mill. The same effect of moisture content for roller mill was obtained (Table 3.45). After peeling operation the moisture content was regulated 13.92 % (g/g, w.b.) to prevent adhesiveness of bran on surface of teeths of discs. On the other hand, the moisture content of milled bulgur sample for disc gap at 1.90 mm was found as 12.06 % (g/g, w.b.) that was greater than sample milled by roller mill (Table 3.5).

Table 3.45. Moisture content (%, g/g, w.b.) of dried, tempered and peeled intact bulgur and milled (gaps at 1.90 mm) samples for both roller and disc mills

Type of Sample	% Moisture	
	Roller mill	Disc mill
Dried bulgur	11.32	11.86
Tempered bulgur	15.90	17.70
Peeled bulgur	11.92	13.92
Milled wheat	10.25	12.06

3.2. Polishing System

A double helical horizontal system was used in this section in order to polish the bulgur products removing of adhesive bran, and flour, and smoothing of surface of bulgur particles. About 0.2-0.6 % of water was added from inlet of polisher in order to remove dusts and flours easily and obtain a light color of product. In this section, screen analysis (% mass), color values (L, a, b and YI), moisture content, hectoliter weight, yield, loss (by product), ash and protein contents of both inlet and outlet were measured, and results were given in Tables 3.46 and 3.47.

3.2.1. Screen analysis of products from polishing section

For polishing section, percent masss of coarse (+/3.50), pilaf (3.50/2.00), medium (2.00/1.00) and fine (1.00/0.50) sized bulgur were measured using screen analysis at inlet and outlets. Table 3.46 illustrated the relation between percent mass of coarse, pilaf, middle and fine sized bulgur at inlet and outlet positions of polishing section.

Table 3.46. Percent masss (g/g) of coarse ((+/3.50), pilaf (3.50/2.00), middle (2.00/1.00) and fine (1.00/0.50) sized bulgur from inlet and outlet of polishing system

	Bulgur size			
Condition	+/3.50 mm	3.50/2.00 mm	2.00/1.00 mm	1.00/0.50 mm
Polisher inlet	0.60	59.46	35.53	0.31
Polisher outlet	0.00	2.76	65.80	2.10

Percent mass of pilaf-sized bulgur was changed from 59.46 to 2.76 % at inlet and outlet, respectively (Table 3.46). A significant percent mass (65.80 %) was obtained at outlet of polishing system for middle sized (2.00/1.00) bulgur. For fine (1.00/0.50) sized bulgur, percent mass was also significantly changed at inlet and outlets. It can be explained as the polisher system broken the particle size for pilaf, middle and fine sized bulgur whereas not for coarse sized type. The most change in particle size was observed for middle-sized bulgur. The reason of decrease in particle size could be due to abrasion of particle with double helical system used in polisher section.

3.2.2. Color values of products from polishing section

Temperature of polishing system was measured as 58 $^{\circ}$ C from outlet product. For polishing system, results of color (L, a, b and YI) at inlet and outlet of system were given in Table 3.47.

The purpose of polishing section is to give a good yellow color to bulgur. Thus, degree of L, a, b and YI are the most important parameters for the measuring quality of bulgur. From the results, lightness (L) decreased from 55.51 to 52.94 (Table 3.47). The decrease in lightness indicated the loss in lightness due to removing of adhesive flour particles from surface of bulgur. Increase in yellowness (b) from 19.97 to 21.42 confirmed the expected bulgur color. Also, the increase in yellowness index (from 70.19 to 79.36) correlated the results of b-values. On the other hand, the increase in redness (a) (4.28 to 5.17) gave an ambergris color to bulgur. From experts and evaluation of consumers and results of instrumental analysis it had reported that the polishing system gives to the bulgur an attractive color. As a result, the polishing system used in this study give a good color that was an important quality characteristic for consumers.

Table 3.47. Color values (L, a, b, YI) of samples from inlet and outlet of polishing system

Condition	L	a	b	YI
Inlet	55.51	4.28	19.97	70.14
Outlet	52.94	5.17	21.42	79.36

3.2.3. Ash content of products from polishing system

The experimental results of ash content for the samples from inlet and outlet of polishing system were found as 1.53 and 1.41, respectively. The percent ash (g/g, d.b.) decreased from 1.53 to 1.41 % for polishing section. It was less than 1.75 % that is limit for Turkish Standard. The decrease in ash content was expected due to removal of adhesived bran particle over bulgur granules. Additionally, the decrease in particle size that was explained in Section 3.2.1 was correlated this decrease in ash content and the bran layer of bulgur particle contains most of ash. On the other hand, the decrease in ash content by polisher also increased the quality of bulgur.

3.2.4. Percent yield and loss for polishing system

From screen analysis (Section 3.2.1), the yield (g/g, %) values were found as 95.90 % at inlet and 70.66 % at outlet of polisher. As expected due to size reduction, the amount of loss (by-product, 29.34%) increased during polishing system. The increase in by-product was not feasible on the productivity aspect for bulgur producers, on the other hand, was preferable on the point of color quality.

3.2.5. Moisture content for polishing section

The moisture contents of samples from inlet and outlet of polishing system were found as 13.08 and 11.15 % (g/g, w.b.), respectively. The moisture content decreased during polishing of the product due to generation of heat via friction and evapotation, as expected (58 ^{o} C).

3.2.6. Hectoliter weight for polishing system

Hectoliter weight values (kg/hl) of samples from inlet and outlet of polishing system were measured with unscreened samples (mixed). The experimental results were found as 67.16 (kg/hl) at inlet and 85.35 (kg/hl) at outlet of polishing system. Polishing system increased the hectoliter weight of bulgur sample due to producing flour participating between bulgur and filling voids. In addition, as expected, the moisture content decreased during polishing (Section 3.2.5). Generally, this decrease in moisture content decreased the hectoliter weight value. However, filling flour particles to voids to increase the hectoliter weight value is higher than decrease in hectoliter weight value by moisture content.

3.2.7. Protein content for polishing system

The protein content of inlet of the polishing system was found as 12.46 % (g/g, d.b.). When the product was polished, the protein content increased to 12.55 % (g/g, d.b.). This increase in proten content was expected because of collapsing of small amount of bran inside polisher or removing some bran part, i.e. increase in protein as percent mass. This collapsed bran was discharged simultaneously by system as part time.

3.3. Color Sorting System

The color sorting system rejects dark objects reflecting less than the signal threshold automatically. The product is illuminated with visible light from fluorescent tubes that provide the required intensity and uniformity of light needed for accurate color sorting. In this system, ten blue light lamps were used to eject the black, red and foreign spacts via detector. Peeled sample (intact bulgur) was analyzed for color (L, a, b and YI), purity percentage (# of acceptable particles/total # of particles) and protein contents. In addition, milled (mixed) and fine bulgur samples were analyzed in order to compare with peeled intact bulgur sample. The experimental results were given in Tables 3.48-52.

3.3.1. Color values for color sorting system

The most important color problem for bulgur producers is the mixing of reddish wheat with durum wheat during harvesting and storage. Bulgur should have a light yellow, and homogeneous color. The acceptability and economic value of bulgur can be decreased by %5 (price level) due to foreign grain seeds (rye, barley, etc.) and materials, and reddish wheat seeds (dark brown or red). Foreign materials and reddish seeds in bulgur can cause loss of quality and economical value (Bayram *et al.*, 2003).

The color sorting system was used in order to remove reddish particles and foreign materials from bulgur. Three types of samples (intact, milled (mixed) and fine bulgur) were used for color sorting system in the present investigation. Results of color values (L, a, b and YI) for each sample were illustrated in Tables 3.48-51. The relation of L (lightness) values and type of samples for sorter inlet, outlet, and resort inlet, outlet were illustrated in Table 3.48. The L (lightness) of intact bulgur sample was increased from 43.63 to 44.48 during color sorting. Similar relations were observed for milled (mixed) and fine bulgur, i.e. the numbers of reddish and black foreign particles decreased and clean material was obtained. On the other hand, for resort section in color sorting system, as excepted, the lightness values of dirty (rejected) portion decreased due to more reddish and foreign particles.

Table 3.48. L (lightness) values of intact, milled (mixed) and fine bulgur samples from sorter inlet, sorter outlet (acceptable), resort inlet (recycle) and resort outlet (rejected) of color sorting system

	L (lightness)			
Type of product	Sorter inlet	Sorter outlet	Resort inlet	Resort outlet
Intact bulgur	43.63	44.48	40.74	41.50
Mixed bulgur	48.59	48.85	44.67	39.73
Fine Bulgur	56.01	56.22	52.86	49.01

From Table 3.49, when the samples (intact, mixed and fine bulgur) were sorted, a-values (redness) decreased due to decreasing the numbers of reddish and black particles. In another word, a good color was obtained for bulgur. Similarlly, a-values of resort part also decreased.

Yellowness values of peeled intact, mixed and fine bulgur increased as the samples sorted (finished product) using the color sorting system due to removing of brown or reddish bulgur and dark colored foreign materials (Table 3.50). As the particle size was decreased the difference between b-values of inlet and outlet products increased due to high surface area.

Table 3.49. a (redness) values of intact, milled (mixed) and fine bulgur samples from sorter inlet, sorter outlet (acceptable), resort inlet and resort outlet (rejected) of color sorting system

	a (redness)			
Type of product	Sorter inlet	Sorter outlet	Resort inlet	Resort outlet
Intact bulgur	5.79	5.34	5.67	5.29
Mixed bulgur	6.84	6.64	6.88	7.40
Fine Bulgur	5.56	5.70	5.77	5.85

Table 3.50. b (yellowness) values of intact, milled (unclassified) and fine bulgur samples from sorter inlet, sorter outlet (acceptable), resort inlet and resort outlet (rejected) of color sorting system

	b (yellowness)			
Type of product	Sorter inlet	Sorter outlet	Resort inlet	Resort outlet
Intact bulgur	17.03	17.05	15.05	14.01
Mixed bulgur	21.79	21.81	19.12	15.71
Fine Bulgur	23.50	23.83	21.79	19.17

Table 3.51 was illustrated for YI-values (yellowness index) of three types of samples (intact, mixed and fine bulgur) for inlet and outlet of the color sorting system. In contrast to L-value, yellownes index values decreased, as the samples were sorted by the color sorting system. In another word, the clearness of particles increased when particles were sorted. A light yellow colored product was obtained.

Table 3.51. YI (yellowness index) values of intact, milled (mixed) and fine bulgur from sorter inlet, sorter outlet (acceptable), resort inlet and resort outlet (rejected) of color sorting system

Type of product	YI (yellowness index)			
	Sorter inlet	Sorter outlet	Resort inlet	Resort outlet
Intact bulgur	79.61	77.46	76.57	70.23
Mixed bulgur	89.95	89.22	87.59	84.74
Fine Bulgur	81.65	83.14	81.51	78.78

3.3.2. Purity percentages for color sorting system

The purity percentages (# of acceptable particles / total # of particles) were analyzed to find the efficiency of the color sorting system and resort section. Percent purity and type of samples (intact, milled (mixed) and fine bulgur) for color sorting system was illustrated in Table 3.52 and Figure 3.9. The percent purity increased as the samples (peeled intact, milled (mixed) and fine bulgur) were sorted due to rejecting reddish or dark particles and foreign materials. On the other hand, for resort section, the percent purity of all samples decreased because of removing dark color particles (resort outlet) (Table 3.52). The highest percent purity (99.10%) was obtained for intact bulgur sample during color sorting due to its big size.

Table 3.52. Percent purity (# of acceptabe particles / total # of particles) of intact, milled (unclassified) and fine bulgur from sorter inlet, sorter outlet (acceptable), resort inlet and resort outlet (rejected) of color sorting system

Type of product	% purity			
	Sorter inlet	Sorter outlet	Resort inlet	Resort outlet
Intact bulgur	91.40	99.10	62.83	35.76
Mixed bulgur	87.31	98.75	62.62	28.57
Fine Bulgur	83.42	95.65	88.50	66.98

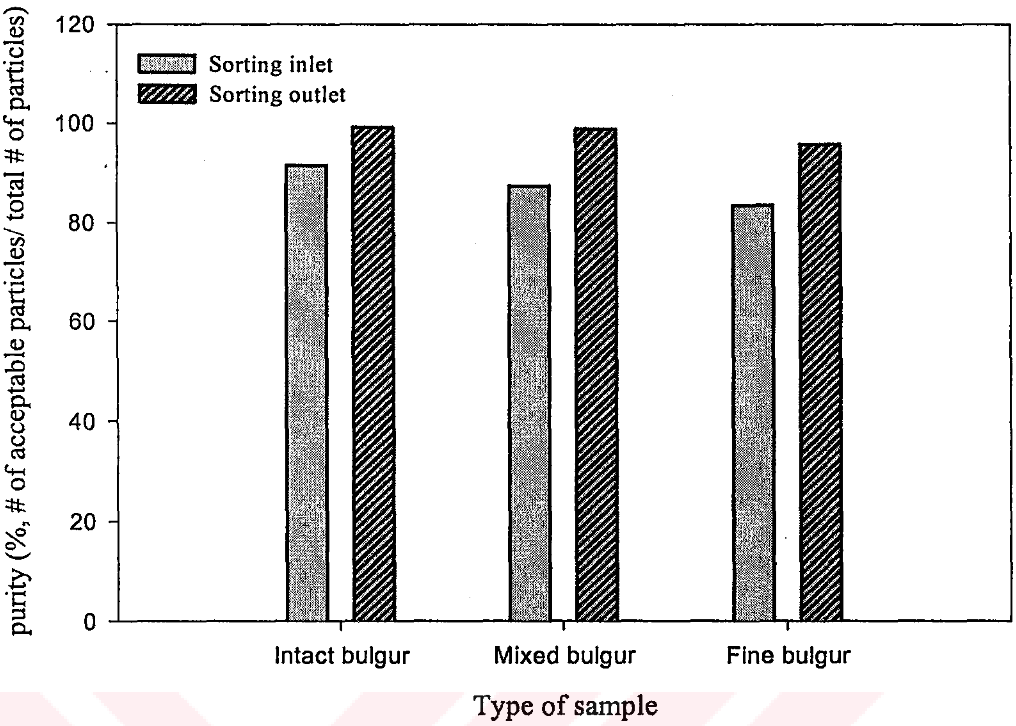

Figure 3.9. Percent purity (# of acceptable particles/total # of particles) of intact, milled (mixed) and fine bulgur from inlet and outlet of color sorting system

3.3.3. Protein content for color sorting system

Protein contents (%, g/g, d.b.) of samples from inlet and outlet of color sorting system were found that it increased from 12.55 to 12.69 due to removing foreign materials, red bulgur particles and soft wheat grains during color sorting system. Because, protein contents of foreign materials, brown bulgur particles and soft wheat grains are lower than pure durum wheat. Therefore, removing of those materials from bulgur sample increased the protein content of finished product using color-sorting system.

CHAPTER IV

CONCLUSIONS

- Quality of the bulgur produced was found to be affected from utilization of disc or roller mills, horizontal helical polisher and color sorting systems.
- The increase in third gap of the roller mill increased the percent mass of coarse, pilaf and medium sized bulgur in contrast to decrease in the percent mass of fine sized bulgur.
- The increase in disc gap for the disc mill increased the percent mass of coarser products. The coarse sized bulgur was not produced with the disc gaps of 0.40, 0.50, 0.60 and 0.80 mm.
- Different types of bulgur such as coarse, pilaf, medium and fine sized could be obtained simultaneously using roller mill. But, it was limited for disc mill. Also, the arrangements of gaps for the roller mill were easier than the disc mill.
- The roller mill had higher capacity, lower energy consumption and labor cost than disc mill.
- The yield (84.77 to 99.75 %) of the roller mill was higher; in turn loss was lower, than that (13.13 to 84.84 %) of the disc mill.
- The ash content of bulgur from the roller mill could be adjusted by changing the gaps of the rolls.
- The hectoliter weight of product from the disc mill was higher than that of the roller mill due to particle size and shape.
- The ash content of bulgur parallel to moisture content was decreased during polishing due to removal of bran part of the kernels.
- The polishing system also increased the hectoliter weight of product due to decrease in moisture content of product and increase in the smoothness of surface.

- The polishing system decreased the lightness due to removal of flour particles from surface and increased the yellowness, redness and yellowness index of bulgur, which was expected an attractive, and amber color to bulgur which is an important quality characteristic for consumers.
- The color sorting system increased the purity of samples (intact, milled (mixed) and fine bulgur) due to rejecting reddish or dark particles and foreign materials; significantly, clean and color improved product was obtained.

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