FEBRUARY 2019 M.Sc. in Food Engineering İSLİM DAYIOĞLU

GAZİANTEP UNIVERSITY

GRADUATE SCHOOL OF

NATURAL & APPLIED SCIENCES

SOLID HANDLING PROPERTIES OF BULGUR PRODUCED BY ANTEP AND KARAMAN/MUT TECHNIQUES

M.Sc. THESIS

IN

FOOD ENGINEERING

BY

İSLİM DAYIOĞLU

FEBRUARY 2019

Solid Handling Properties of Bulgur Produced by Antep and Karaman/Mut Techniques

M. Sc. Thesis

in

Food Engineering

Gaziantep University

Supervisor

Prof. Dr. Mustafa BAYRAM

by

İslim DAYIOĞLU

FEBRUARY 2019

REPUBLIC OF TURKEY

GAZİANTEP UNIVERSITY

GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES

FOOD ENGINEERING

Name of the thesis: Solid Handling Properties of Bulgur Produced by Antep and Karaman/Mut Techniques

Name of the student: İslim DAYIOĞLU

Exam date: 06.02.2019

Approval of the Graduate School of Natural and Applied Sciences

Prof. Dr. A. Necmeddin YAZICI
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Prof. Dr. Medeni MASKAN
Head of Department

This is to certify that we have read this thesis and that in our consensus opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Prof. Dr. Mustafa BAYRAM
Supervisor

Examining Committee Members:	Signature
Prof. Dr. Mustafa BAYRAM	---
Assoc. Prof. Dr. Çiğdem AYKAÇ SOYSAL	---
Assoc. Prof. Dr. Ali YILDIRIM	---

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

İslim DAYIOĞLU

ABSTRACT

SOLID HANDLING PROPERTIES OF BULGUR PRODUCED BY ANTEP AND KARAMAN/MUT TECHNIQUES

DAYIOĞLU, İslim
M. Sc. in Food Engineering
Supervisor: Prof. Dr. Mustafa Bayram
February 2019
136 pages

The interest on bulgur is increasing overall the World due to its nutritional and functional properties. It was one of the traditional product. However, its production has been started to made in modern plants for about 30 years. Due to the lack of the solid handling properties of bulgur in the literature, there are some plant and equipment design problems. The designers and manufacturers need some important solid handling properties.

In this study, the solid handling properties of Durum and bread types bulgur were determined at each processing step of Antep and Karaman/Mut bulgur production methods. The sphericity, particle size (mm), packed and loose bulk densities (kg/m^3), voidage, angle of repose, sliding angle, particle density, minimum fluidization velocity (m/s), silo discharge capacity, flow regime and size distribution (screen analysis) were measured. Additionally, the moisture (%, w.b.), protein (%, d.b.), ash (%, d.b.) contents and color values (L*, a*, b* and YI) were determined as quality parameters. It was found that the solid handling properties of bulgur during Antep and Karaman/Mut processing significantly ($p \leq 0.05$) changed. The changes in raw material, moisture, particle size and shape were very important for the solid handling properties of bulgur.

Key Words: bulgur, solid handling property, sphericity, Antep bulgur, Karaman/Mut bulgur, Durum wheat, bread wheat

ÖZET

ANTEP VE KARAMAN/MUT TEKNİKLERİ İLE ÜRETİLEN BULGURUN KATI İŞLEME ÖZELLİKLERİ

DAYIOĞLU, İslim
Yüksek Lisans Tezi, Gıda Mühendisliği
Danışman: Prof. Dr. Mustafa Bayram
Şubat 2019
136 sayfa

Dünya genelinde, bulgura olan ilgi bulgurun besinsel ve fonksiyonel özellikleri sebebi ile artmaktadır. Bulgur geleneksel ürünlerden biriydi. Ancak, yaklaşık 30 yıldır, bulgur üretimi modern fabrikalarda yapılmaktadır. Literatürde, bulgurun katı özelliklerindeki bilgi eksikliklerinden dolayı, bazı fabrika ve ekipman tasarım problemleri yaşanmaktadır. Tasarımcılar ve üreticiler bazı önemli katı özelliklerine ihtiyaç duymaktadır.

Bu çalışmada, Antep ve Karaman/Mut bulgur üretim yöntemleri esnasında, Durum ve ekmeklik bulgur çeşitlerinin katı işleme özellikleri her iki üretim aşamasında belirlenmiştir. Küresellik, parçacık büyüklüğü (mm), sıkıştırılmış ve serbest yığın yoğunluğu (kg/m^3), boşluk oranı, yığın açısı, kayma açısı, parçacık yoğunluğu, minimum akışkanlaşma hızı (m/s), silo boşaltma kapasitesi, akış rejimi ve boyut dağılımı (elek analizi) ölçülmüştür. Ek olarak, nem (%, w.b.), protein (%, d.b.), kül (%, d.b.) içeriği ve renk değerleri (L*, a*, b* ve YI) kalite parametreleri olarak belirlenmiştir. Antep ve Karaman/Mut bulgur üretimi esnasında, bulgurun katı işleme özelliklerinin önemli ölçüde değiştiği tespit edilmiştir ($p \leq 0.05$). Hammadde, nem, parçacık büyüklüğü ve şekildeki değişikliklerin bulgurun katı işleme özellikleri için çok önemli olduğu tespit edilmiştir.

Anahtar Kelimeler: bulgur, katı işleme özelliği, küresellik, Antep bulgur, Karaman/Mut bulgur, Durum buğday, ekmeklik buğday

To My Beloved Father

ACKNOWLEDGEMENTS

I wish to express my deepest gratitude to my supervisor Prof. Dr. Mustafa BAYRAM for their guidance, invaluable advice, criticism, encouragements and insight throughout the research. I would like to express that I consider myself lucky to work under his guidance. I thank you again.

Thanks to all bulgur producers, especially my father, who continued to produce bulgur despite all the difficulties. I want to also express that I am grateful to my grandfather, who left to us this job as a legacy. Rest in peace.

I wish also thank to Günmak Machine Co., Dayıoğlu Flour Co., Dayıoğlu Bulgur Co., Sıddık Kayabaş, Mahmut Dayıoğlu, İbrahim Dayıoğlu and Mustafa Dayıoğlu for their supports in the experiments. I am so lucky that you are always there when I need your perspective.

I would like to acknowledge to the staff of Food Engineering Department, University of Gaziantep for the technical and administrative support and special thanks to Res. Assist. Dr. Ayşe Nur Yüksel and Res. Assist. Dr. Derya Dursun Sayar for their help and discussions about studies and life.

I am greatly indebted to my family: my parents, my brothers, my sister and my cousin Fethiye Nur Sert for their endless love, encouragement, patience and trust during my whole life. You are always there for me.

My dear, Mümine Guruk, I thank you for being with me during all this time by helping and supporting me. I wish you to live all good things in your life.

I want to thank to my friends; Özge Şahin, Şeyma Zülkadiroğlu Bayazıt, Ayşegül Oduncu, Buket Bilgin, Öznur Barak, Kevser Çoban, Elif Kasırga, Ghaith Al-Qudsi, Mümine Bostan Kaya, Ökkeş Burak Bülbül, Yeşim Öztürk, Şükriye Çılgın, Saad Ibrahim Yousıf, Mustafa Çağrı Demir. Have a good life!

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Given their central role in the human diet, a wide range of cereal-based products are universally produced and consumed with the increasing consumer awareness of the health benefits. The major cereal-based foods include bread, pasta, bulgur, couscous, noodle, tarhana, biscuits, cookies and cakes, etc.

1.1 Wheat

Wheat is a major component of most diets of the world because of its agronomic adaptability, ease of storage and nutritional goodness, low cost, and to produce a variety of palatable, interesting, and satisfying foods (Orth and Shellenberger, 1988). Like maize and rice, wheat is the most cultivated cereal in the world. It supplies about 19% of the calories and 21% of the protein to the world's population (Ali, 2017).

Wheat is considered of the oldest food that human beings started to produce. According to the archeological studies it was found in various countries of the Middle East, it is presumed that wheat was already being cultivated thousands of years before Christ, first in the “fertile crescent” as Karacadağ in Mesopotamia, later spreading to Western Europe.

Wheat and its products are considered as main food for humans and have a crucial role in human diets due to their essential nutrients. When consumed as a major component of the diet, it provides energy, fiber, carbohydrates (starch), proteins, B vitamins, iron, calcium, phosphorus, zinc, potassium and magnesium (Orth and Shellenberger, 1988).

By industrialization and westernization demand of wheat increases because it provides diversity of food product such as breakfast cereals, breads, other baked goods, pasta, semolina, bulgur, noodles, couscous, tarhana and boza (Shewry and Hey, 2015).

Wheat kernel or berry is one seeded fruit, called caryopsis. Shape of wheat grains can be spherical to long, narrow and flattened shapes. However, it is generally recognized by oval shapes. The wheat kernel is usually between 5–9 mm in length, weighs between 35–50 mg and has a longitudinal crease that extends almost to the center of the kernel so the wheat grains handling is sometimes difficult because of presence of the crease. The size and shape of the kernels varies depending upon the cultivar and their location in the wheat head or spike. The wheat grain includes 2-3% embryo (germ), 13-17% outer layers (bran) and 80-85% mealy endosperm (Figure 1.1).

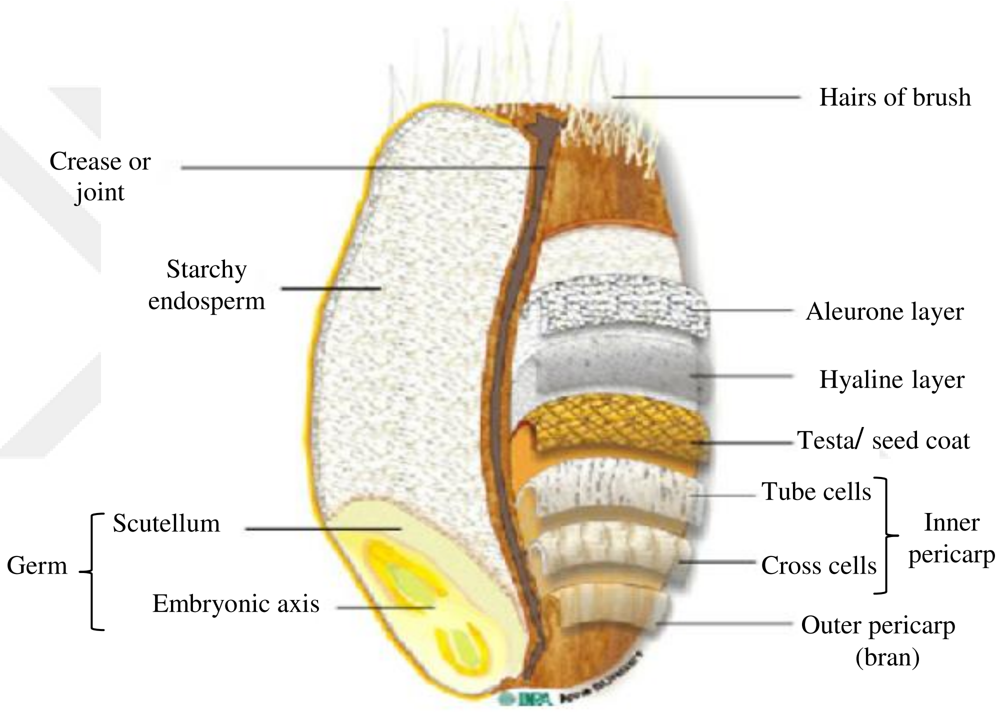


Figure 1.1 Longitudinal section of a wheat kernel (Saulnier et al., 2007)

The outer layers of wheat grain as called bran is consist of several layers, which protect the main part of the grain against bacteria, molds, insects and unsuitable wheather conditions. Bran is wealthy in B vitamins and minerals; it is separated easily from the starchy endosperm during the dehulling operation. The fused pericarp and seed coat surround the endosperm. The aleurone layer (the outer endosperm) is source of proteins and enzymes and it plays an essential role during germination process.

The inner endosperm (without the aleurone layer) is attributed to as mealy or starchy endosperm. The endosperm mainly contains food reserves, which are essential for growth of the seedling due to its energy-yielding starch. The mealy endosperm involves fats (1.5%) and proteins (13%) apart from carbohydrates. The germ lies at one end of the grain which is the most nutritious part of the wheat kernel and it is available as a separate entity because wheat germ is a rich source of vitamin E and B group, DNA, RNA, unsaturated fatty acids, proteins, cellulosic and inorganic materials (Šramková et al., 2009). The quality of wheat products is heavily affected by the grain quality characteristics (size/homogeneity, color, hardness and vitreousness), which depend on the wheat variety cultivated, the environmental effects (Magallanes-López et al., 2017).

Wheat belongs to the genus *Triticum*, a member of the grass (*Poaceae*) family. Three species of wheat are grown in the world. It is commonly classified as hard (*Triticum aestivum vulgare*), soft (*Triticum compactum*) and durum (*Triticum turgidum durum*). The species of wheat are convinced considerably differ in terms of quality characteristics and the differences are reflected to production of diversity product. *Triticum aestivum* is used to making bread and fermented products, which has high protein and hard in texture. Soft wheat contains low protein and typically soft texture and so it is excellent for cakes, biscuits and pastries production. Kernels of durum wheat are generally extra hard, translucent and rather high in protein content. It is preferred for pasta, bulgur and like couscous products principally because of the following reasons: durum wheat provides more bright (translucence and glassy appearance) and yellow color product as compared to bread wheat due to including double concentration of yellow pigment as called xanthophyll, durum wheat kernels resist disintegration when cooked, gives firm texture, good mechanical strength, mineral composition particularly for calcium, phosphorous and magnesium of durum wheat is approximate two times greater than the bread wheat. These minerals have a significant role in improving the cooking quality of products (Sharma, 2003).

1.2 Bulgur

Bulgur is a wheat product, which is obtained mostly as a result of the stages of cleaning, cooking, drying, debranning, grinding, optionally polished and finally classification.

Bulgur has been consumed for many years only as conventional nutriment of the Mediterranean region and reached to the United States by immigrated people from the Middle East. In the mid-1900s extensive research was carried out on the nutritional and technical features of the bulgur treat and modern nutritionists explored what the ancients already knew: the value of bulgur as a “perfect food” in terms of nutrients, deliciousness and maintain quality (Anonymous, 2018).

Bulgur is accepted source of both protein and calories in the ancient word. Throughout history, bulgur has been identified by a number of various names. The Roman word for bulgur is ‘cerealis’, after Ceres, the goddess of harvest; Israelites called it ‘dagan’, a word meaning ‘bursting kernels of grain’; other Middle East people called it ‘arisah’ and bulgur is mentioned with the name, ‘arisah’ in the Bible as well. Biblical scholars translate ‘arisah’ as ‘the first of the coarse meal’ and, according to Biblical archeologists, was a porridge or gruel prepared from parboiled and sun-dried wheat and written in various forms such as burghul, burghoul, balgour and boulgur etc. The name of bulgur came from thousands of years ago, just like the bulgur itself. In many Western languages, bulgur is called as "bulgur" as the people of the Middle East called it. Bulgur is called “burgul” in Arab countries due to its Arabic pronunciation (Bayram and Öner, 2002). In the Middle East, bulgur was produced only in homes to meet the needs of families in small-scale and traditional methods, due to the transition from village life to urbanization, production of this type of food materials was carried to factories. The first factory of bulgur production at the industrial base was founded by Rıza Küçükoğlu in Karaman to meet the requirement of the military during World War I (Seçkin, 1968).

The production and consumption of bulgur reached to significant level in Turkey as well as in the world. Its annual producing capacity of bulgur over 1 million ton by 150 plants, therefore Turkey is the leader of wheat bulgur manufacturer in the world. Around 20% of the bulgur production is exported. Also, there is high quantity of bulgur production at different countries (250,000–300,000 tonnes at industrial scale by 15–20 bulgur plants in the United States and Canada, 60,000–80,000 tonnes by 4–6 factories in the EU and 100,000–120,000 tonnes by 10–15 plants in the Arabic countries) (Bayram and Öner, 2007; Yıldırım et al., 2008a).

In the new and developing markets all over the World, bulgur demand increased due to its high nutritional value, long shelf life and inexpensiveness (Savaş and Basman, 2016). The average annual consumption of bulgur in Turkey is approximately 12 kg per person. The amount of consumption in the eastern regions is significantly huge than western regions. While average annual consumption of bulgur in the eastern and southern parts of Turkey, Syria, Iraq, Iran, Israel, Lebanon, Arabia, i.e., Midde East countries is approximately 25-30 kg per person, the consumption in the Aegean and Marmara regions is about 7-8 kg per person. Therefore, the Middle East is an important market for bulgur (Bayram, 2007a; Polat, 2010).

The variety of wheat is the most important parameter affecting the quality of the bulgur. While it can be produced from hard, soft, hard red and hard white wheat varieties, best quality bulgur is traditionally produced Durum wheat (Jones, 2010). It is favorable for macaroni and other preparations like couscous and bulgur due to its strong gluten elasticity and uniform golden color (Singh and Singh, 2010).

Processing steps during making wheat into bulgur contribute the gaining of the some functional features on the final product as i) resistance against mold contamination and insect infestation, ii) inactivation of enzymes through cooking operation, iii) stopped respiration activity result in inactivation of microorganisms with blanching and drying stages (pasteurised), iv) numerous nutritional benefits, protection of originally found nutrients in wheat kernel, v) low fat, high protein, high dietary fiber contents, whole grain food, vi) tasteful, vii) easy preparation and semi or ready to eat food, vii) low price and economical, ix) unabsorption of radiation, x) long lasting, starch is gelatinized and the kernel is almost cooked, thus it is more stable than wheat in hot and humid environments, xi) consumable as individually due to its nutritional benefits and it is a good source for folic acid, xii) parboiling of wheat is the best processing method to reduce the available phytic acid content even though rising the bran content (Bayram et al., 2004b; Singh et al., 2014).

General ingredient of bulgur contained: 9-12 % water, 10-16 % protein, 1.2-1.5 % fat, 76-78 % carbohydrates, 1.2-1.4 % ash and 1.1-1.3 % fiber. Amount of protein, calcium, iron, B1 vitamin and niacin substance of bulgur are richer from the other cereal products like bread and pasta. Protein, calcium and iron contents of bulgur are greater compared to wheat. However, crude fat, fiber and ash content of bulgur are lower than wheat. In the course of cooking, many nutrients leach out of wheat kernel but some nutrients are re-absorbed back into the grain. Consequently, the losses of water-soluble nutrients like vitamins are partially inhibited (Ertaş, 2017). Consequently, water-soluble components like vitamins are preserved.

Bulgur is widely accepted as a functional food due to its nutrients such as B vitamins, folate, unsaturated fatty acids, minerals, dietary fibre and its low glycaemic index. Morever, the high amounts of minerals (phosphorus, zinc, magnesium and selenium) and cellulose fibre in bulgur reduce risk of cardiovascular disease, type 2 diabetes, obesity, constipation and colon cancer (Tacer, 2008).

Bulgur is a significant wheat product as dietary fibre resource, involving 18.3 g dietary fibre per 100 g. Its dietary fibre content is 15.3, 9.2, 7.0, 6.8, 4.3, 3.5, 2.3, 1.8, 1.3 and 1.1 times higher than tomato, turnip, spinach, wheat flour, pasta, rice, whole wheat bread, oat meal, soybean and barley respectively (Bayram and Öner, 2007; Dreher, 2001).

Bulgur kernel is cracked into coarse pieces and sieved into different sizes to create the different textures and cooking properties for various uses. Particle size of bulgur changes between 3.5-0.5 mm. After screen analysis, coarse, pilaf, fine pilav, fine, ultra-fine and by-product bulgur (bulgur flour) is classified as 3.5/3.00, 3.00/2.80, 2.80/2.50, 2.50/1.60, 1.60/0.50 and 0.50/+, respectively (TSE, 2017).

Bulgur is contributed to Turkish and Middle Eastern cuisine for ages with 250 sorts of traditional recipes since its nut-like flavor, extended shelf life, low cost, ease of preparation and high nutritional value. Bulgur is pre-cooked wheat product hence it is categorized as semi-ready-to-eat and ready-to-eat food (Bayram and Öner, 2005). It is a unique food source in pilaf, salad, kısır, casseroles, stuffings, soups, baked goods, and as a meat substitute in vegetarian meals (Mohapatra and Rao, 2005).

1.3 The Studies about Bulgur

Bulgur is a unique and appealing whole wheat product, which is broadly obtained as explained previously, by dry and wet cleaning, soaking, cooking, drying, tempering, and then dehulling by friction, crushing, optionally polishing and sifting into distinct sizes.

Kemahlıoğlu and Demirağ (2010) introduced that durum wheat is preferred for bulgur production process than other wheat types in terms of quality characteristics due to its uniform water absorption, good texture and chewing characteristics, rich in nitrogen and color pigments and good crushing properties. The amount of high nitrogen content provides the formation of a harder and firmer structure of starch granules in the final product by combining with proteins. Extreme color pigments create a more attractive bright yellow color on the bulgur.

Yousif et al. (2018) focused on characterization of volatile compounds of bulgur produced from Durum wheat. The Headspace Solid Phase Microextraction (HSSPME) and Gas Chromatography–Mass Spectroscopy (GS-MS) methods were used to determine the volatile flavor compounds of bulgur. Fourty-seven volatile components were determined in Durum wheat such as 1-Hexanol, styrene and hexanoic acid which are responsible of macaroni, spaghetti, bread, bulgur and other Durum wheat products flavor. It was stated that when making of bulgur 16 volatile compounds were lost because of thermal process such as soaking, cooking, drying operations. And also, debranning and polishing process can influence the composition of volatile due to most of the flavor components present in bran layer of wheat.

In another study, the effect of basic thermal operation on the water-soluble vitamins content of bulgur was performed by Kadakal et al. (2007). They appraised the impact of atmospheric cooking (90 and 100 ^{o}C) and pressure cooking by using autoclave at 121 ^{o}C for 17 min and drying in a hot-air oven (60, 70 and 80 ^{o}C) or sun drying on the water-soluble vitamins like thiamin, niacin, panthothenic acid and riboflavin. Amount of water-soluble vitamins of bulgur were significantly reduced with increasing cooking and drying temperatures. The result showed that, pressure cooking led to greater decrease on the thiamin, niacin, panthothenic acid, pyridoxine, and riboflavin content of the bulgur, when compared with atmospheric cooking at 90 and 100 ^{o}C. The highest losses of water-soluble vitamins were observed with the sun drying and the 70 ^{o}C hot-air oven drying treatment resulted in a slight decrease concentration of water-soluble vitamins. As a result, the hot-air drying at 60 ^{o}C was found most favorable to protect water-soluble vitamins during bulgur production.

A lot of quality parameters were provided by Bayram (2006) during boiling operation such as cooking degree, size, shape, colour etc. In conventional bulgur producing, the centre cutting of the wheat kernel by blade, color of evaporated water or the smelling of steam from cooker are used to terminate the cooking operation. Owing to these methods depend on practice and hardware of operator, which increases process expenditures, alternative automated methods should be upgrade to control the cooking operation for the bulgur production.

Köksel et al. (1999)'s research, three barley cultivars (*Hordeum vulgare L.)* were processed into bulgur by pressure cooking or cooking at atmospheric pressure and explored the effect of processing on levels of thiamine, riboflavin, minerals (Fe, Cu, Zn, Mn, Ca, Mg) as well as the phytic acid and b-glucan. Ash, riboflavin and thiamine contents during bulgur processing were significant decreased. When compared to crude barleys, the Mn and Ca, total P and phytate P contents of the bulgur were found significantly lower. During the bulgur production, the protein content of bulgur did not changed. And also, levels of b-glucan were appeared high in barley bulgurs. The most of the nutritional value of raw barley was protected in bulgur processing particularly soluble dietary fibre.

Balcı and Bayram (2015) pronounced that color (CIE b*; yellowness) was regarded for judge of bulgur quality in both aesthetics and nutritional value. The color of bulgur mainly arisen from natural pigments (carotenoids), which were present at different levels in wheat. Two different tempering methods (spray and steam) before sun and UV- light polishing applications were employed in order to improve the yellowness in bulgur. The moistened bulgur samples were exposed to sun and UV-light treatment for 12, 24, 36, 48, 60 and 72 h. After these applications, the basic chemical properties, total carotenoid content in terms of lutein equivalent (TCC) and color values (CIE L*; lightness, CIE b*; yellowness, CIE a*; redness and CIE YI; yellowness index) were determined. It was observed that UV-light was more effective on the CIE L* and CIE b* values compared to the sunlight. Both moistening methods were markedly increased the CIE L*, CIE b* and CIE YI values and especially steam tempering has an obvious effect on the CIE b* values as well as

UV and time of UV exposure. Consequently, the spray tempering and UV-light exposure supplied the highest value of TCC i.e. 6.31 µg/g and they had a positive effect on the color of bulgur.

A research done by Koca and Anıl (1996) to survey the effect of two different wheat types (*Triticum aestivum and Triticum durum*) and simmering routes (atmospheric cooking method; pressure simmering route I: 110 ^{o}C for 15 minutes; pressure simmering route II: 121 ^{o}C for 5 minutes) on physical (hectoliter weight, bulgur yield, grain hardness), chemical (ash, protein, crude fat, crude fiber starch contents) and organoleptic traits of bulgur. It was invented that the hectoliter weight, total bulgur yield, pilav bulgur yield, ash, crude fat, crude fiber, starch contents in *Tr. aestivum* bulgur and grain hardness, amount of protein and organoleptic characteristics in *T. durum* bulgur were obtained higher. The ash, protein contents and organoleptic properties were found to be higher in the bulgur cooked with atmospheric conditions. Moreover, ash and protein contents, crude fat and total bulgur yield in the bulgur cooked by pressure simmering route I were found to be higher than bulgur which cooked by pressure simmering practice II.

Bayram (2005b) denoted that three gelatinization measuring methods for bulgur production i.e. centre cutting, light scattering and amylose/iodine were utilized to adjudge termination of cooking procedure and detect cooking degree of kernels. Nonlinear models were derived (Sigmoid, Logistic, Gompertz, Hill and Chapman models) to indicate the cooking operation using centre cutting, light scattering and amylose/iodine values and deformation degree of the intact wheat kernel. According to the results, it was declared that the best fitting models were the Sigmoid, Chapman and Gompertz for centre cutting and light scattering, amylose/iodine and deformation degree, respectively. 100 % gelatinization without any deformation on the wheat kernel was ensured by the 40 min. And also, cooking degree from amylose/iodine method was found higher than the centre cutting and light scattering methods up to 40 min due to differences in measuring procedures of each method.

Helical disc mill was used to ground bulgur with among 1.9-0.4 mm different disc gaps in the study of Yıldırım et al. (2008a). Screen analysis (%), color (lightness, redness, yellowness and yellowness index), yield, loss, energy consumption, capacity, bulk density, ash and moisture contents of bulgur were analysed. The milled samples were sorted as coarse, pilaf size, middle, fine and by-product (undersize bulgur). The decreasing gap of helical disc mill from 1.90 to 0.40 mm decreased the yield from 95.96 to 13.13 %, bulk density from 87.37 to 81.68 kg/hl, capacity from 705 to 322 kg/h, ash content from 1.34 to 1.24 % (d.b.), redness from 5.03 to 4.82, percent masses of coarse (+/3.5 mm) from 1.29 to 0 % and pilaf (3.5/2.0 mm) from 86.58 to 0.05 %. The maximum amount of middle size (2.0/1.0 mm) bulgur (59.26 %) was attained at 0.5 mm disc gap. As the abrasion at narrow disc gap heat generation was observed, this caused the evaporation of water from bulgur so moisture content of kernel decreased.

Yılmaz (2012) manufactured bulgur with Siyez and Durum wheats using three different cooking (traditional, microwave and autoclave) and two different drying (oven and microwave) methods. It was observed that, both of two wheats, L (brightness) and b (yellowness) values were increased, a-value (redness) was decreased when wheat samples cooked. The optimum cooking times were assessed as 6.5 and 14 minutes for Siyez and Durum bulgur, respectively. While the bulgur had much more water absorption, which dried in microwave, the bulgur cooked in autoclave had less cooking time than the microwave and traditional cooking methods. The general acceptance of bulgur did not changed by cooking and drying methods also general acceptance of durum bulgur was found higher than Siyez bulgur according to the sensory analyze results. The more hardness and adhesiveness features were monitored with autoclave and microwave cooking methods than traditional, respectively. It was discovered that effect on chewiness was significant increased by using microwave drying and autoclave cooking methods during bulgur manufacturing. The amount of total phenolic compounds Siyez wheat was found greater than durum wheat before it was processed but its amount of total phenolic compounds were lost during making bulgur than durum wheat. And also, microwave cooking method was caused the highest; autoclave cooking method was lead to lowest total phenolic compounds and total yellow pigment. The amount of total yellow pigment was found about twice more at siyez than durum wheat. Drying in oven method provided best result in terms of total phenolic compound and total yellow pigment. Although Siyez wheat has higher bioactive compounds, during processed it was exposed to more damage than durum wheat thus it was evaluated unsuitable for bulgur production.

Bulgur can be used as basic ingredient of different products. Yüksel et al. (2017a) produced couscous-like product by using undersize bulgur instead of semolina. It was prepared 0, 25 and 50% of bulgur including couscous-like samples to detect the optimum processing parameters and formulations. The packed bed and microwave dryers were handled and the color, protein and ash contents, sensory properties, bulk density, total phenol and flavonoid contents were specified. According to yields, color (L*, a*, b*) values and sensory features (color, odor, general appearance), optimum parameters were estimated as 50% of undersize bulgur for packed bed (60 ^{o}C) and microwave (180 W) drying with 50% (w/w) of water. The yields of packed bed drying at 60 ^{o}C were 54.28±3.78, 47.70±1.73 and 52.57±7.04% for 0, 25 and 50% bulgur flour containing samples, respectively. L (lightness) values of couscous-like samples significantly were reduced by increasing the quantity of undersize bulgur after both drying operations. According to the sensory analysis results, using bulgur flour (undersize bulgur) instead of semolina for the production of couscous were more preferable for consumers. In another study made by Bayram and Bozkurt (2007), bulgur was utilized as instead of animal fat and red meat to produce a vegetarian sucuk (Turkish dry-fermented sausage). Yellow (115 g/kg) bulgur and black/brown (121 g/kg) bulgur were mixed into the sucuk dough as fat and meat imitations respectively. The yellow and black bulgur samples were attained from *Triticum durum* and *Triticum aestivum*, respectively by cleaning, cooking, drying, dehulling, milling, pearling and classification operations. In this trial, olive oil was used to lubrication. The other ingredents (spices, sugar, salt, cumin, black and red pepper, garlic) were added the dough and the bulgur-sucuk was matured at 60–95% relative humidity and 18–25 ^{o}C for 15 days. During ripening, pH, moisture content and textural, sensory and color changes were followed. They were monitered before ripening. pH and moisture content of the bulgur-sucuk were 5.81 and 493 g/kg, respectively and during ripening pH (4.14), moisture content (280 g/kg) and color values L, a, b and YI decreased because of the lack of nitrate and nitrite in the recipe. According to the sensory analysis such as flavor, color and slaughter of the bulgur-sucuk, yellow and black bulgur were found suitable as a meat replacement in the sausage production.

Ünüvar (2009) probed that effect of dehulling operation and granulation distribution on qualitative and nutritional properties of bulgur using two different type durum wheats (Kızıltan 91 and Çeşit 1252). It was observed that after milling and classification, the protein content of fine bulgur and bulgur flour (by-product) is found highest. Also as expected, the protein content of pilaf bulgur was found greater than whole grain bulgur. This even indicated that while pilaf bulgur contains endosperm fractions of the kernel completely or very high, fine bulgur or bulgur flours include protein rich and external layers of the bulgur grain. The outer layers and crust of grains were further crumbled into fine bulgur and flour fractions during grinding procedure, thus between the bulgur granulations ash quantity distribution was found like protein distribution. While amount of oil for pilaf bulgur was found less according to the unbroken whole grain bulgur, for fine bulgur and flour were observed high. This can be explained the separation of embryo (fat-richer) from endosperm part by breakage, to be more precise embryo part by crushing passed into a sample with fine granulation. The amount of crude cellulose was found over for pilaf, coarse, fine bulgur and bulgur flour, respectively. This is due to the crumbled shell and outer layers (richer in cellulosic material) of kernel had a relatively higher share in the samples with fine fractions. In the study observed that the fine bulgur had richer than coarse bulgur in terms of nutrition physiology and bulgur flour was much richer than the others. And also bulgur flour and fine bulgur had more advantageous than coarse and pilaf bulgurs mainly because of the following reasons: high protein, mineral and fat content, relaxing effects of the intestines, digestive facilitator with the contents of high cellulosic materials. Peeling process was considerably decreased amount of protein, fat, ash, mineral matters, cellulosic materials and color (red and yellow) intensities in all bulgur.

The effect of the cooking time and temperature on the dimensions and crease of the wheat kernel was searched during bulgur production by Bayram et al. (2004b). The change of the length (a-dimension), two widths (b- and c-dimensions), weight, volume and density during cooking in the wheat kernel were determined at 87, 92 and 97 ^{o}C for 140 min. They discovered that: the b-dimension (crease side width) increased gradually at each cooking temperature between 6.95–68.05% and also the crease side width of the wheat kernel was affected by cooking time: the secondary width (c-dimension) was influenced by cooking temperature and time (between 9.95–69.00%) and big alteration was seen obviously at 97 ^{o}C: the volume of the kernel increased (27.35–185.20%) during the cooking and had bigger percent change value than the weight of kernel (19.25–160.70%) since high amount of swelling of the wheat kernel therefore density of kernel changed negatively.

1.4 Bulgur Production Techniques

Bulgur is still manufactured by the traditional routes in small villages in the Eastern Mediterranean: huge cauldron is used to blanching of wheat until completely cooked, drying by utilization the sun, then grinding kernels into coarse particles and sieving into distinct sizes for diversity uses.

The production of bulgur at industrial scale has recently reached to a critical level overall the world. The main factors of manufacturer's interest in bulgur are low production costs, raw materials and product quality, processing time and longevity of product. In general, bulgur is commercially obtained by cleaning, cooking wheat kernels in water, drying under sunlight or in high drying towers. These dried grains are debranned by friction and crushed to distinct sizes (Caba et al., 2012). Industrially, bulgur is manufactured using two techniques in Turkey such as Karaman (Mut) and Antep. According to industry, both production systems are showned in Figures 1.2 and 1.3. Cleaning, cooking, drying, dehulling, milling, and classification operations are principal steps in Antep type bulgur production. In the Karaman manufacturing technique, processing steps are in the order of dry and wet cleaning, steaming, drying, tempering, stone debranning and grinding, then re-drying and classification. Antep type system is used in 70% of the total world’s of bulgur production because of uncomplicated processing, controllability, shelf-life extension and control of moisture content (Bayram and Öner, 2002).

The main difference of the production methods of Karaman (Mut) and Antep are tempering time and moisture level. After the cooking and drying operations, wheat is tempered up to 15–17% and 20–24% moisture during 15–20 min and 10–14 h for Antep and Karaman (Mut) methods, respectively. For Antep system, dried cooked wheat is debranned and milled using a vertical emery dehuller and disc or hammer mills, respectively. In the Karaman (Mut) system, dehulling and grinding stages are performed simultaneously using a stone mill. Karaman type bulgur is more popular and consumed compared to Antep type bulgur due to high nutritous value, light yellow color and uniform oval shape (abrasive effect of stone mill) (Bayram and Öner, 2005).

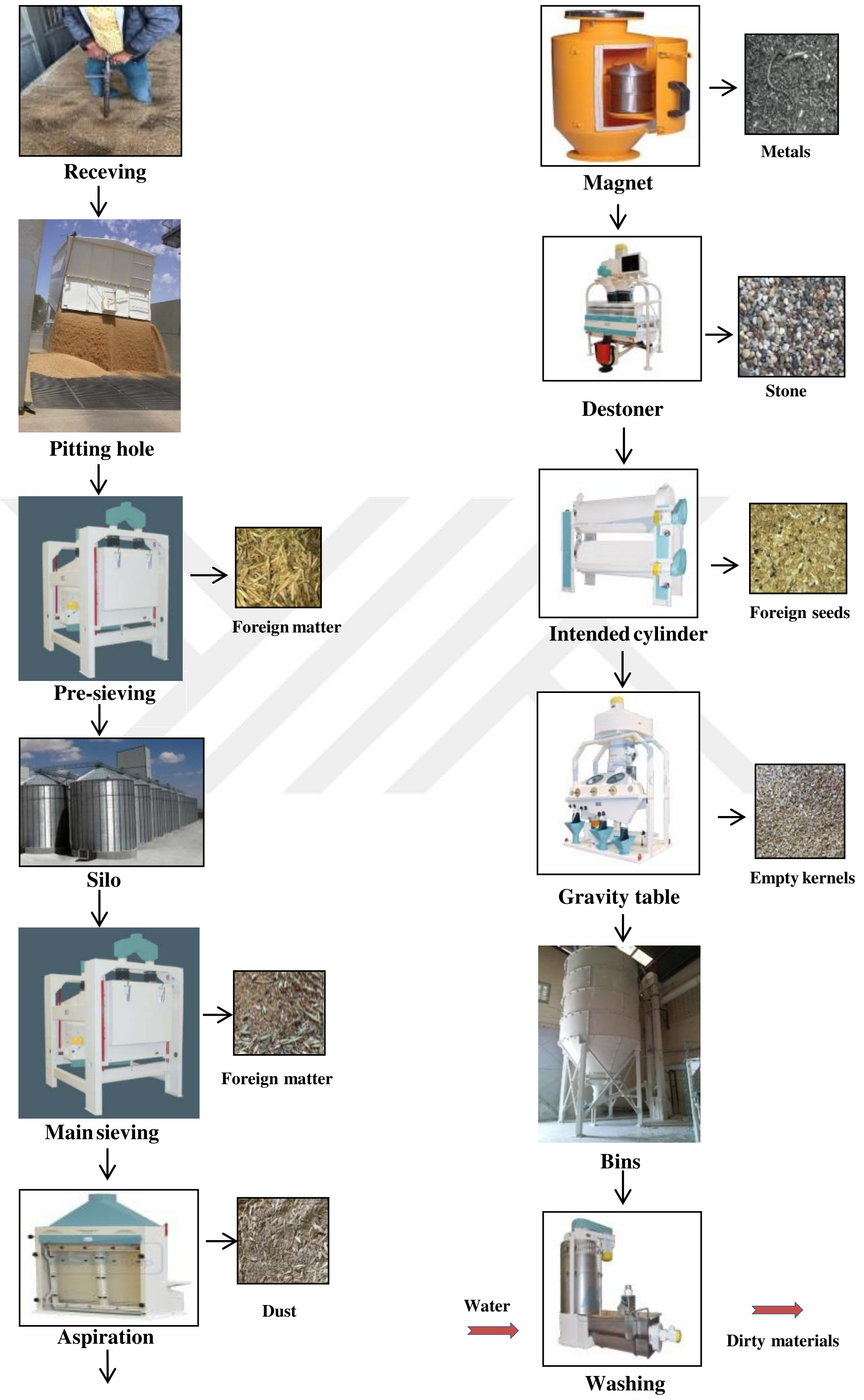


Figure 1.2 Antep type bulgur production

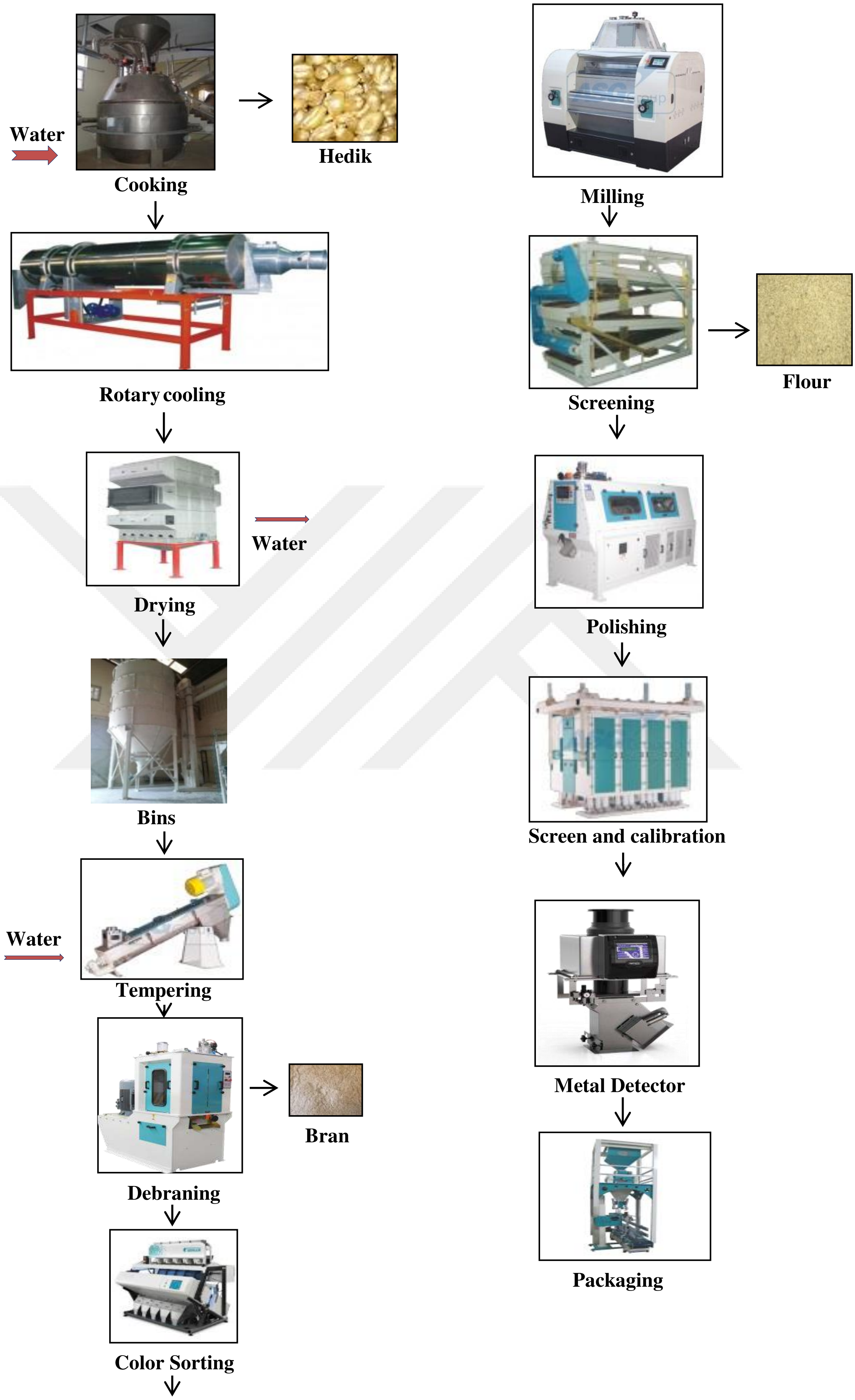


Figure 1.2 Antep type bulgur production (continue)

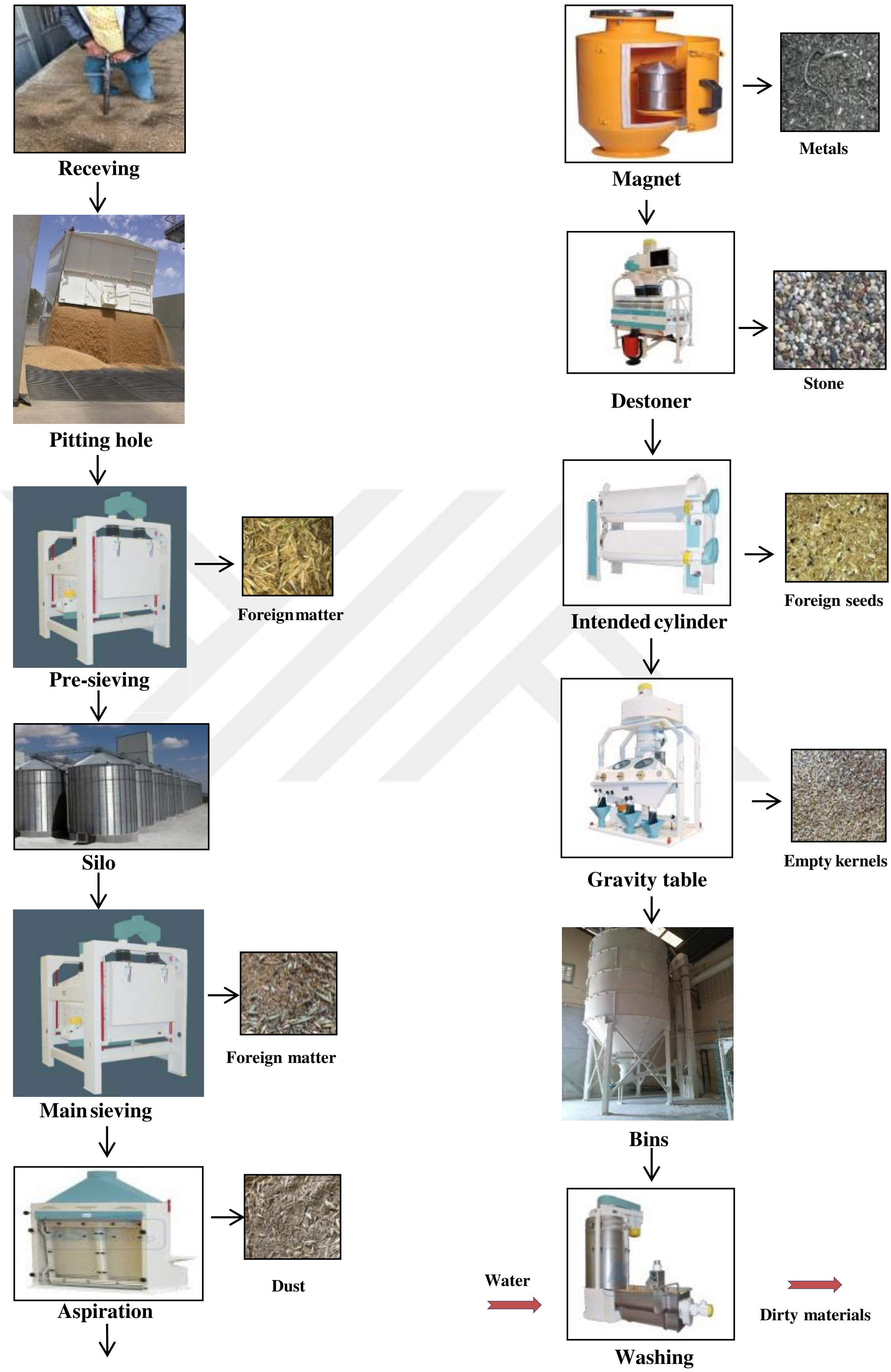


Figure 1.3 Karaman/Mut type bulgur production

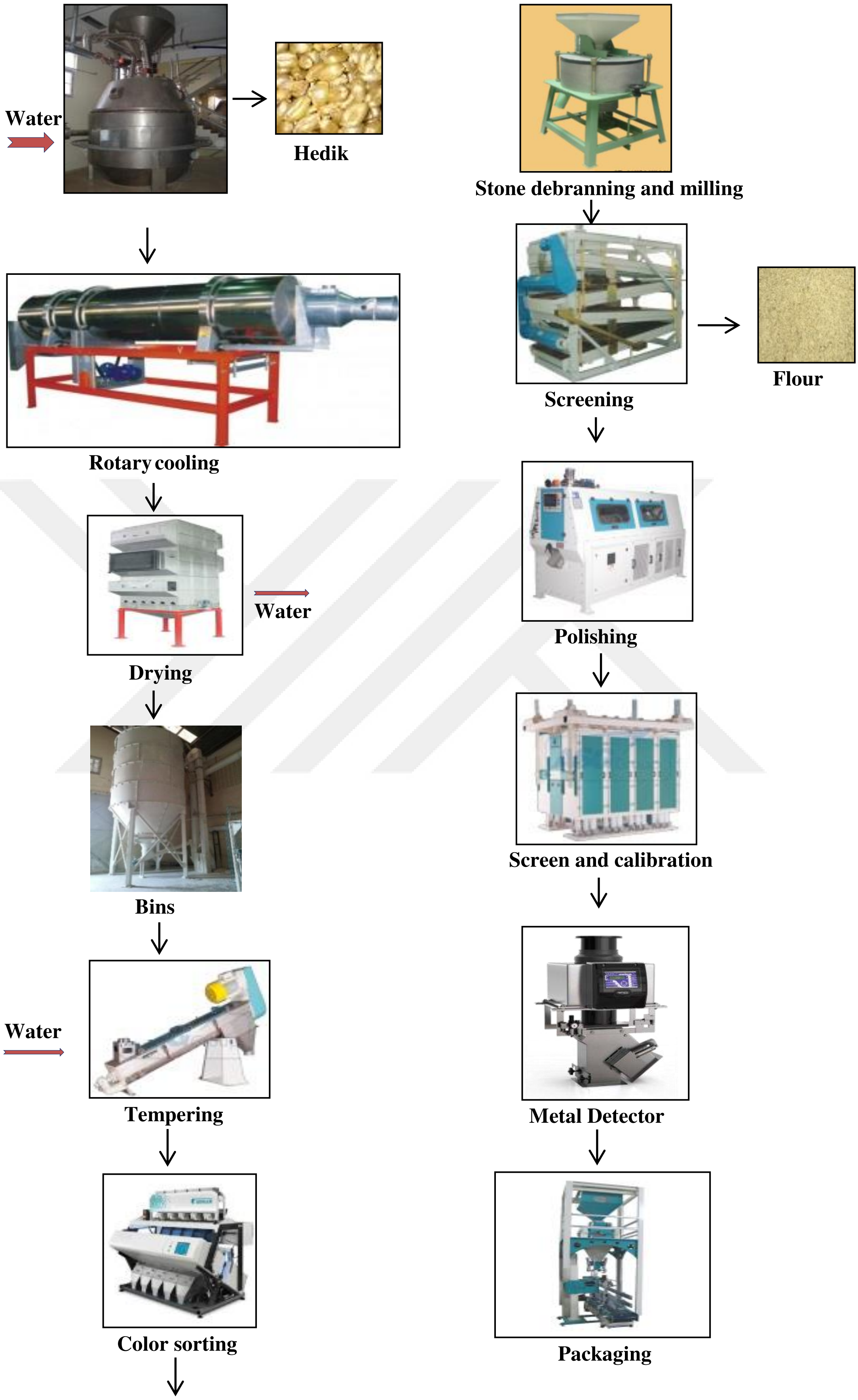


Figure 1.3 Karaman/Mut type bulgur production (continue)

1.4.1 Cleaning of Raw Material

Cleaning is the first stage in making bulgur. Apart from healthy kernels, broken wheat, stones, soil, stalks, stems, husk, straw, metal fragments, insect residues and weeds seeds and other cultivated plants like maize, sorghum are defined as foreign substances. The amount of foreign matter in wheat is important for safe storage of grain, improve milling output and quality of the final product.

The main intent of the precleaning process is to separate the grain from coarse and fine impurities by sifting, to utilize the destoner to remove stones, to eliminate the low-density particles and dust through aspiration, to separate and sort the round and long grains from granular materials with the intended cylinder (Stoenescu et al., 2010). Then the precleaning stage, wheat is washed before cooking by vertical washer machine to remove the dust and dirty materials from the surface to reduce contaminants in the cooking water and wheat. Thus, the damage of outside of kernel is prevented. On the commercial scale, washing is made by centrifuge and free bulk water is removed with separator. Cleaning step is finished with washing and moisture content of wheat is increased up to 15% (Bayram, 1997).

1.4.2 Soaking of Wheat

Soaking of wheat is an optional step prior to cooking. This technique is especially used before pressure cooking to increase moisture content of wheat. The hot water is used for shorter soaking time. In contrast, traditional soaking process is made using water at room temperature and takes 1 to 2 days (Igathinathane et al., 2005). During the soaking operation, grains are notably hydrated and kernel softened. Therefore, a much shorter cooking time is required for the soaked samples than for the unsoaked ones. Soaking may lead the breakdown of several components, within the grains, into simpler compounds, which are capable of causing alterations in the texture, flavor, aroma and taste of the final products but also increases the bioavailability of nutrients by destroying the anti-nutritional factors with heat, eliminate completely the toxic factors contained in the raw seeds and improves protein digestibility (Mathew et al., 2018).

During the soaking of wheat in the production of bulgur, water spreads through the hull and bran; most of the water-soluble nutrients in bran and aleurone structures are transported into the endosperm so nutritional values of wheat increase (Bayram, 1997; Bayram et al., 2004a; Bayram et al., 2004c).

1.4.3 Cooking Operation

Cooking process is one of the most significant step in bulgur production. A lot of quality and physical characteristics (cooking degree, colour, size, shape, shelf life etc.) of wheat grain are changed during this critical process.

The cooking of wheat to produce bulgur is traditionally carried out by the addition of water at a ratio of 1.5-2.0 or by pressurized cooking of soaked wheat at high temperature and pressure in an autoclave. Since the conventional cooking temperature does not exceed 85-90 ^{o}C, bright yellow color bulgur is obtained whereas deformation of the wheat kernels can not be prevented. The soaking of wheat prior to autoclave cooking prolongs production time and high pressure and temperature cause the darkening of final product color, which is undesirable. Despite these drawbacks, the autoclave cooking provides no dispersing, non-aggregation, undeformed kernel so it is widely preferred in industrial scale (Koca and Anıl, 1996).

The main purpose of the cooking in the bulgur production is to convert native starch to a digestible form. The starch of wheat is composed of two glucose polymers: amylose and amylopectin. It is present in the form of granules. During the cooking step, native starch granules are heated in the presence of excess water so they absorb water and swell to some extent. In this stage, the crystal and uniform structures of the granules are deteriorated (loss of X-ray crystallinity and birefringence) and the amylose part is slightly separated from the amylopectin part and leaches out of granules. These phenomena are called as gelatinization (Dceda et al., 2001).

Traditionally, the gelatinization degree of starch in wheat during the cooking operation is determined by cutting wheat centres with a razor blade. If complete gelatinization of starch granules occurs the endosperm is translucent, whereas if the gelatinization is only partial, complete gelatinization will not be achieved so kernel centres will show up as milky-white or opaque spots. For the production of bulgur, white centre count below 5% was deliberated to be sufficient gelatinized and rated as excellent; a count below 10% as good, below 20% as fair, and above 20% as poor (unacceptable) (Singh and Dodda, 1979; Smith et al., 1964).

Ercan (1986) reported that basic objective of the cooking of wheat is ensured adequate water absorption at the appropriate temperature and time interval by adjust time and temperature together.

The amount of addition water, cooking time and temperature, complete gelatinization of starch in wheat, absorption of added water and moisture content at the end of cooking seriously effect to determine cooking conditions during bulgur making (Bayram and Öner, 1996). If the excessive amount of water is added, the loss of soluble nutrients occurs because wastewater is decanted at the end of the cooking operation. If the unsufficient amount of water is used, gelatinization is incomplete and white spots can occur in the kernel. The remaining water should not be found in the kettle or pot so the amount of addition water must be calculated which changes with respect to the kind of wheat is used (Bayram, 2000).

The cooking temperature should be lower than 95 ^{o}C to protect the nature of nutritional compounds. Wheat starch gelatinization starts at 67.5 ^{o}C during boiling and shape of wheat starch does not change, but it swells. Çömden (1986) remarked that the most important necessity at the end of cooking operation, the moisture content should be higher than 40%. At the end of cooking, softened and swollen wheat which is a semi-finished form of bulgur is traditionally recognized as ‘hedik’ (Turhan et al., 2003; Yousif et al., 2018).

Dimensional change occurs during the cooking process. Wheat kernel crease opens and kernel widths are increased. If crease of the wheat kernel is exposed to excess the cooking operation, it can be disrupted, inner part and gelatinized starch are leached out. During the cooking operation, the wheat kernel disruption and the leaching of the starch cause product loss, stickiness, the changing of the kernel size, color and the quality losses of the finished product and also these problems affect the subsequent processing steps i.e. drying, peeling, milling etc. Thus, the cooking conditions should be selected carefully to ensure the complement gelatinization without darkening the product or making it so sticky as to interfere with the following the drying process (Bayram, 2005b; Bayram et al., 2004b).

Two most important criteria should be executed in cooking operation. The first one is protection wholeness of wheat kernel i.e. no deformation and the second is getting complete cooking of wheat, which is recognized by the absence of an opaque white centre (Figure 1.4).

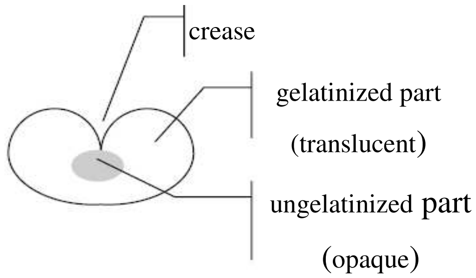


Figure 1.4 Top view of divided wheat kernel

Tacer (2008) and Bayram (2006) stated that respiration, enzymatic and microbial activities of wheat are restricted during the cooking operation therefore bulgur is more durable than wheat in hot and humid environmental conditions.

In the study made by Bayram (2006), to designate the cooking degree of kernel based on starch gelatinization in the bulgur production are used amylose/iodine and light scattering methods as alternative to traditionally used centre cutting method. The cooking process was conducted at 97 ^{o}C using *Triticum durum* wheat for 130 minutes. Cooking and deformation degree of all wheat grains were controlled by using the three methods and gelatinization values achieved from the amylose/iodine method to be higher than the others up to reaching 100% cooking degree. While the results were found same for cutting and light scattering methods, the optimum cooking time was identified as 40 min. In the course of cooking, it was realized that overcooking causes vital deformation in all wheat berries. The amylose/iodine and light scattering can be used to control of cooking system and the light scattering method may be selected in the automation having bulgur production systems.

1.4.4 Drying

Drying is another most critical step in the bulgur production. It may not only a process used to desired reduction in the moisture content of the cooked wheat grain, but may also significantly affect numerous properties such as flavor, color, texture, and nutrient retention (Hayta, 2002).

According to literature, drying can be made by fluidized bed, spouted bed, rotary, sun, microwave, infrared, tray, tower and tunnel dryers. Cooked bulgur is dried until 10-13 % of moisture. In general, the bulgur producers use tower dryers because of its high capacity, low energy consumption and good air usage (Bayram, 2003).

Wheat bulgur is traditionally dried by sun drying in open air and it may cause quality degradation and infestation on the product. In commercial scale, hot air drying is generally preferred which provides large production capacity and sanitation benefits and also eradicates the addiction on climatic conditions in the bulgur production (Kahyaoğlu et al., 2012).

Studies comparing the effect of different drying processes on the bulgur production in the literature are limited. The comparison of the effects of different drying techniques (tray, microwave, solar and sun drying) on the physicochemical (moisture content, bulk density, protein extractability, pilaf and fine bulgur yield, water and oil absorption and color) and the sensory properties of bulgur was made by Hayta (2002). The bulk density of bulgur were significantly affected by solar and microwave drying methods. It was found that the pilaf bulgur yield was lowest for sun-dried, followed by tray, microwave and solar-dried bulgur samples, respectively. The drying method influenced protein extractability, bulgur yield and water and oil absorption values of bulgur. While lightness (L) value of pilav and fine bulgur were highest for the solar-dried bulgur samples, the pilav and fine bulgur values were lowest for the microwave-dried bulgur samples. It was reported that although drying methods did not show any difference on flavor, mouthfeel, and appearance of bulgur, physicochemical properties were affected by the drying methods.

Kahyaoğlu (2009) compared the spouted bed and microwave assisted spouted bed drying on quality parameters of parboiled wheat and bulgur. Drying was conducted by using different temperatures (50, 70, and 90 ^{o}C) and microwave powers (288 and 624 W). After drying, bulk and apparent density, bulk and apparent porosity, sphericity, color, microstructure and pore size distribution of parboiled wheat were determined. The drying times were decreased 60 and 85 % as compared to spouted bed drying by using microwave assisted spouted bed drying at powers of 288 W and 624 W, respectively. Yield and water absorption capacity were defined in bulgur samples. The effect of air temperature on physical properties of product except color was not significant in spouted bed drying. More porous structure was observed in wheat samples dried in microwave assisted spouted bed compared to air dried ones. Sphericity, interior kernel porosity, bulk density and L (lightness) value of dried cooked wheat were higher when high temperature was combined with high microwave power. In microwave assisted spouted bed drying, similar yield value but lower water absorption capacity, bulk and apparent density, higher sphericity and lighter were observed as compared to spouted bed drying.

1.4.5 Tempering and Debranning

Tempering is a vital step before debranning operation, which is accomplished by the dried grains are subjected to water for some time to make sure that the entire grain absorbs water.

In the bulgur processing, the objectives of tempering are to toughen the bran parts so it can resist being broken into small pieces and softening the endosperm of the kernel. While bran will be kept in larger fragment, the endosperm part of kernel easier to mill thus, the bran and milled bulgur products may be readily separated by sieving. Also, the tempering operation provides that all materials leaving the grinding rolls are in optimum conditions and reducing the power consumption of the break rolls (Andersson, 2011).

Tempering is considered a very important stage since improving the efficiency of wheat milling ability. One of the main goals of tempering wheat is to distribute water in the kernel (water is added with a fine spray) as uniformly as possible and development light yellow color. Structure, cultivar, dimension, initial moisture content of wheat as well as season of year influence rate of moisture uptake of wheat (Kweon et al., 2009). In the current bulgur production, bulgur is rested in bins up to 15-17% and 20–24% moisture during 25-30 min and 10-14 h for Antep and Karaman (Mut) bulgur production methods, respectively.

Bizzarri and Morelli (1980) stated that if wheat is hard and dry must be tempered longer than soft wheat since it takes more time for the water to penetrate into the hard grain. It is preferred to moisten a hard grain several times with a little water, rather than once with a lot of water. Because hard, smooth grains absorb water more slowly. Best condition wheat is obtained for grinding through repeated dampening and tempering in the tempering bins. Seed coat is becomed sufficiently resistant not to be decreased in the breaking treatment and yet seperates itself easily from the farinaceous kernel of adjusting the moisture content in general and the distribution of moisture in particular. Therefore, the kernel not need too damp but uniformly friable enough to allow itself to be worked by the corrugated cylinders with a minimum of pressure. And also researchers indicated that at the same degree of hardness, a vitreous grain will be moistened much more than a less vitreous grain.

The intention of debranning procedure is to eradicate branny layers from grain by friction or abrasion operations. The removal of the bran prior to milling results in higher quality of the finished product and the grinding break system is significantly shortened.

Aluerone is a protective layer for endosperm; therefore this layer should not be destruction pending debranning. As the cellulose is high in pericarp of grain, a large portion of cellulose is removed with dehulling; generally 7% of weight of dried wheat is decreased. Ash content of the product is also decreased result in debranning process. Abrasive type mill, stone mills and konoz dehullers are used in bulgur production (Bayram, 2000; Yıldırım, 2004).

Contamination of cereals is concentrated in the outer regions of kernels. At the same time, degree of contamination is reduced by using debranning and it effects stability and shelf life of grains (Andersson, 2011).

Bayram and Öner (2005) reported that bran can be entirely removed the cooked kernel prior to milling. The penetration rate of water into the kernel is increased by removal of bran. Accordingly, water absorption into the tempering uncooked wheat kernel is more slowly than the cooked wheat for flour or semolina production.

The effectiveness of peeling on the physico-chemical, cooking, pasting and textural properties of common and durum wheat varieties were revealed by Singh and Singh (2010). Also the effect of disappear the bran from grain to the extent of 4 and 8% on these properties was also evaluated. They were found that Durum wheat varieties had higher protein content (d.b.) and lower L* and b* values when compared to common wheat. The dehulling of wheat kernels increased L* value, gruel solids loss and decreased a* value, cooking time and textural parameters. Meals from debranned grains had pastes with higher peak viscosity, breakdown and final viscosity and lower pasting temperature. Meals from whole and debranned common wheat showed higher breakdown viscosity compared to those of durum wheat. Durum wheat peeling to 4% level had better cooking and textural properties compared to that of common wheat, therefore, better suited for bulgur making.

1.4.6 Milling

The essence principle of bulgur milling is the creation of new surface by dividing of whole dried wheat kernel into two or more particles. In making bulgur, the cooked kernel is milled to give particles with a range of dimensions which are then classified by sieving (Bayram and Öner, 2005). Also, the stone mills are traditionally used. The disc and roller mills are used industrially.

While grains are broken in different ways, but only four of them are commonly used in size reduction machines. These are compression, impacting, attrition or rubbing and cutting. Ordinarily, compression is preferred for coarse reduction of hard solids to give relatively few fines; impacting causes coarse, medium, or fine products; attrition is used for very fine products from soft and nonabrasive materials. Cutting causes the particles of a uniform size, sometimes with a defined shape, with few or no fines (Bayram and Öner, 2007; Yıldırım et al., 2008b).

Milling quality of bulgur is affected by physical, chemical and structural characteristics (kernel size distribution, hardness, ash content, protein content) and as well as set of parameters such as gap, velocities, the type and condition of surface (Yıldırım et al., 2008a).

As given previously, disc mill is used in the manufacturing of bulgur. Mills utilizing attrition or shear forces have a significant role in size reduction for fine grinding. This type of grinder is considered unique application in the food industry because majority of milling execute for the production of very small particle sizes (Bayram and Öner, 2007; Yıldırım et al., 2008b). It 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 (Yıldırım, 2004). The grains are caught and broken among rolling members in a roller mill, i.e., face of a ring or casing. Additionally, cylindirical rolls press outward with great force against a stationary anvil ring or bull ring with the cutting effect of tooth in the roll mill. It is commonly used in the production of flour and semolina.

During the milling operation, there may be some problems such as (i) abrasive type mill cause to deformation, scratching and formation of burr on the surface of bulgur particle (ii) the creation of sharp edges on granular bulgur particles which occasions adhesiveness, breaking, flour formation and quality loss; (iii) the loss of translucency and polish of bulgur; (iv) the yield is decreased because of flour formation during the breakage of disc milling , (v) losing oval and smooth shape result in formation of sharp edges, (vi) the formation of different sized bulgur particles (not uniform sizes). Thus, a new milling system is essential to obtain the best milling quality (Yıldırım et al., 2008a, 2008b).

According to the literature, the researches on wheat milling increase recently. Bayram and Öner (2005) compared the effects of stone, disc and hammer milling on the quality of bulgur. They studied on the particle size distribution, bulk density, surface structure, appearance, 1000 particles weight and dimensions. They remarked that the appearance and surface characteristics of the bulgur particles were markedly affected by hammer milling. The milling yields were determined as 98.3, 97.4 and 96.5 % for the hammer, stone and disc mills, respectively. The different distribution of kernel (between coarse, medium and fine fractions) was obtained from each mill. The results indicated that hammer milling is not suitable for bulgur production due to the loss of quality. In another study, the effects of roller, double disc and vertical disc mills on the quality of bulgur (surface characteristics, bulk density, one-thousand particles weight, particle volume and dimension) determined by Bayram and Öner (2007). The highest milling yield (99.19%) with nonuniform shape was observed with the roller mill due to irregular cutting of the particles. In contrast, they obtained ovoid or elliptical shape with double disc mill and it had the highest bulk density of 74.12 g/100 ml. Besides, the vertical disc mill was decreased the retention time of bulgur particles in the milling zone so ovoid of bulgur particles was lower than the double disc mills.

Yıldırım et al. (2008b) investigated the effect of ternary roller mill (four rolls and three gaps) on the selected quality parameters of bulgur. Researchers were evaluated particle size, color, ash content, hectoliter-weight, yield and loss for the roller mill. It was observed that fine bulgur had brighter yellow color than coarse one with the roller mill. The yields were found between 87.86 and 99.75 % for the roller mill at different gap adjustments. When the particle size decreased, the ash content decreased from 2.28 to 1.46 % since increase in abrasion effect. The ternary roll mill provided high production yield and capacity with low energy consumption. Moreover, uniform particle size was supplied due to multiple milling stages by preventing the escape of kernels from the gaps.

1.4.7. Polishing

The bright yellow colour, homogeneity, purity and oval shape of bulgur are stated as visual quality parameters and request of consumers. These criterias affect the choice or rejection of the product by the consumers. But nowadays, standard production technologies of bulgur are not sufficient to supply these properties.

Bulgur producers tried many ways to advance the attractiveness of bulgur such as addition dyes and using natural additives. A mechanical kneading operation (it is named as polishing) is greatly used in bulgur industry after drying and dampening (addition about 0.2-0.6 % of water) in order to enhance the color of bulgur. Tempering or dampening is accomplished to increase the effectiveness of polishing process. Bulgur is polished by mechanical kneading polisher with special squeezing technique. Briefly, the heat is generated by friction via mechanical kneading whereby the machinery including the pallet system and heating is ensured using electrical resistance heater. During the polishing operation, the sharp corners of bulgur are rounded by friction. Thus, polished bulgur looks more attractive as bright, yellow and ovoid shape (Balcı and Bayram, 2017).

1.4.8 Sieving and Classification

Screening is the unit operation to assest the particle size distribution. Milled bulgur is in different sizes and they are classified by passing over a screen. Screen is comprised of a number of equally sized apertures.

In perform an analysis a set of standart screens are placed with the finest mesh at the bottom and the largest at the top and tight fitting pan or receiver is located below the bottom sieve and a lid is placed on top of the coarsest sieve. The sample is settling down on the top screen and the stack shaken for a definite time mechanically. The particles hired on each screen are removed and weighed, and the masses of the individual screen increments are converted to percent mass or mass percentages of the total sample (Wills and Finch, 2015).

Particle size of bulgur fluctuates between 3.5–0.5 mm. Yıldırım et al. (2008a, 2008b) stated that after screen analysis, bulgur is classified as coarse (>3.5 mm), pilaf (3.5-2.0 mm), middle (2.0-1.0 mm), fine (1.0-0.5) and undersize bulgur (by-product) (>0.5 mm). During the milling process by-product such as bran and bulgur flour are obtained. This nutritionally valued product is generally used as an animal feed.

1.5 Handling Properties of Solid

Throughout the world, the solid handling plays major roles in a wide range of industries, particularly in the agriculture, bulk and fine chemicals, pharmaceutical, food, mining, plastic and coal power plants. Solid materials can be produced with a variety of different properties. Storage and handling of solid requires knowledge of its individual characterization and bulk behavior, which is crucial to design of equipment, machines and food plant (piping, silo, processing equipments and packaging etc.)

Food products are generally consist of liquid (milk, fat, juices) and solid products (cereals, fruits, vegetables, nuts, oilseeds, pulses). In terms of these food products, 60-70 % of the food sector is composed of solid foods. In contrast, in the literature, it is seen that the operations and machine designs are mostly related to the processing of liquid foods. However, the studies on the processing solid food products are relatively limited.

Handling properties include measurement of bulk and particle densities, sphericity, angle of repose, sliding angle, flowability, minimum fluidization velocity, voidage and surface friction of solid. These features can be changed with environmental conditions such as moisture, temperature, particle size and chemical composition in order to condense physical and chemical issues related to the solids during manufacturing and distribution.

Many new products cannot be manufactured or marketed because of serious difficulties such as flow problems (flow obstructions, segregation, irregular flow, flooding, etc.). That is because in most cases handling unit is neglected during the design of a new production line. Therefore, handling and processing systems should be designed and operated to obtain the maximum efficiency and reliability of product.

1.5.1 Bulk density and Porosity

Bulk density is one of the properties used as part of the defining characteristic for a certain final product, which is measured to adjust storage, processing, packaging and distribution conditions in the industry (Barbosa-C´anovas et al., 2006).

The collection of sample in a certain volume and weighing the sample after taring the container volume are merely necessary for the determination of bulk density and it can be described as the mass of the solid divided by its total volume (volume includes particle and voids) (Grossel et al., 2005).

The preparation, treatment and storage of the sample (i.e. how it was handled) affect the bulking properties of solids. Anonymous (2012) stated that the particles can be filled to have a range of bulk densities and the bulk density of solid material may change by reason of slightest failure. Therefore, the bulk density of solids is extremely difficult to measure with good repetability and it requires indicating how the determination of bulk density is performed in reporting the results. The measuring bulk density may have been passed through a sieve into a graduated cylinder, or by measuring the mass of a known volume of powder that has been passed through a volumeter into a cup or a measuring vessel.

Two methods are used to determine the bulk density that has become conventional: ′tapped (shaked) and loose (free)′. Selection of method bases on the treatment to which the solid is subjected. Loose or poured bulk density can be defined as the sample of product is carefully poured without any consolidation into a measuring cylinder to determine its volume (Woodcock and Mason, 2012). The tapped or packed bulk density measurement, as referred by its name, is described as the state obtained when the vessel containing the solid particles are to be repeatedly dropped a specified distance at a constant drop rate until the apparent volume of sample in the vessel becomes almost constant. If the vessel is tapped or jolted (i.e., solid particles are packed by vertical vibration), in most cases, the bulk density ascendes with the settlement of solid particles due to adding more particles to achieve the initial volume once again.

When solid particles are packed without considering regular or irregular shape, there will be a certain amount of free space between them. Therefore, a bulk solid is exactly consisted of particles and space. The percentage of the total volume not invaded by the particles generally being expressed to as the voidage or void fraction. The particle porosity can be predicated as the ratio of the volume of pores within a particle to the total volume of the particle (included of pores) (Woodcock and Mason, 2012).

1.5.2 Particle Density

The density of a particle or specific gravity of solid is stated as the ratio of the total mass (g) of solids particles to their total volume (cm^3). The assessment of particle density requires the measurement of the mass of a quantity of solid and of the volume occupied by its composed particles, the greatest challenge usually emerge during the measurements of the volume. Density is regarded that is quite affected the other particle features such as bulk solid structure and particle size (Barbosa-C´anovas et al., 2006).

The particle density for products is simply determined which of large particle size by sighting the substitution of a fluid with a certain density and is dependent on the liquid entirely surrounding each individual particle. Fine and coarse materials require the use of a specific-gravity flask (liquid pycnometer) or air-comparison pycnometer. The pycnometer is a small flask settled with a ground-glass plug. The extreme fluid is overflowed by the plug, which has a capillary holl running axially. The liquid should be a special solvent that does not dissolve, react or penetrate the particulate food solid. The usage of the bottle begins with the determination of its volume by carefully measuring the mass of special solvent to just charge it for the normal process.

The particulate material of specific mass is then positioned in the bottle and by gauging, the volume of solvent required to just fill the pycnometer is determined. The volume of the particle sample to be calculated can be found by subtracting of this volume from the previous calculated volume of the empty bottle. The air-comparison pycnometer is preferred for products which are soluble, fragile or very light (Woodcock and Mason, 2012).

1.5.3 Angle of Repose

In the design of the discharge and transport systems, angle of repose is essentially used for the characterization of bulk materials. The bulk solids can flow like liquids during transport or storage such as cereals, milk, flour, salts and sugars, etc. But also, when particles are poured onto a flat surface, a stable conical pile or heap is occasionally formed owing to internal forces (e.g. friction). The angle of repose is known as the angle between the slopes of the free surface to the horizontal of a bulk solid pile. Angle of repose (AoR) is considered as a predictive factor in the design of conveyors and bins so the behavior of solid material is affected by the value of the angle of repose during transport and discharge. It depends on friction between moving particles, which is based on moisture, granulometric composition, shape, dimension, and surface texture of the individual grains (Wójcik et al., 2018).

The relation between flowability of particles with some physical measures were evaluated by Raymus (1985). They noted that angle of repose below 30^o indicate good flowability, 30^o-45^o some cohesiveness, 45^o-55^o true cohesiveness, and >55^o sluggish or very high cohesiveness and very limited flowability.

In a study, made by Ileleji and Zhou (2008), angle of repose is to designated. The bulk corn stover particles prepared to four particle sizes (chopped and particles sieved by using 6.4, 3.2 and 1.6 mm screens) at two moisture contents (dry, <10% and wet, >20%). According to result, particle size and moisture content were found as significant variables that influenced the angle of repose for all three methods (piling AoR loose-base, piling AoR fixed-base and sliding AoR) investigated. Generally, the increasing moisture content increases the angle of repose.

The angle of repose is defined by Chakraverty and De (1981) as the angle between the base of seeds cone and the slope of the cone formed on a free vertical fall of the grain mass to a horizontal plane. The angle of repose of wheat, barley and rice samples ranged from 23-28^o, 28-40^o and 30-45^o, respectively. Also it was expressed that the friction coefficient between solid materials is coequal to the tangent of the angle of internal friction for material.

In another study was performed based on the particle properties (size, shape, flowability and moisture content) in sugar, agglomerated and fine milk and glass particles of varied size (Teunou et al., 1995). It was reported that the angle of repose increases with decreasing particle size, due to smaller particles tend to adhere much more strongly to each other.

1.5.4 Sliding Angle

The angle of slide is the minimum angle to the horizontal of a flat sloping surface that will allow a bulk solid to flow from rest under its own weight. This angle is believed to be useful in designing stationary chutes which is severely associated with the angle of repose. The material of construction of the chute, the amount of material on it and moisture highly influence the measured sliding angle value.

The individual particles movement depends the nature of the solid surface. Whereas highly roughened surfaces lead to shear within the flowing stream, smooth ones cause sliding at the surface (Barbosa-C´anovas et al., 2006).

Lawton (1980) determined the coefficient of friction of seven materials used in the building of agricultural hopper walls for wheat and barley at distinct degree of moisture content. Analyzes were carried out by rotating angular plates on the grain surface. It was noted that the coefficients of friction ascends with increasing moisture contents, and varied between, approximatelly, 0.11 for Teflon on the driest barley to, nearly, 0.5 for concrete on the dampest wheat. The coefficients with wheat were up to 0.1 higher than with barley at corresponding moisture contents.

1.5.5 Sphericity

The emphatic characteristic of particles in a bulk is shape and it has a great effect on particles packing and flow behavior. Particularly, determination non-spherical particles shape is essential. The describing of non-spherical particles shape is complicated by using mathematical terms. However, in order to demonstrate the degree which particles differ from the spherical, many enterprises have been conducted to install the use of shape factors (Woodcock and Mason, 2012).

As one of the most important shape parameter for non-spherical objects is expressed 'sphericity'ϕ_s and it is independent of particle size.

Eq. (1) is mostly preferred to evaluate the sphericity. According to this equation the sphericity is found 1, 0.874 and 0.806 for a sphere, cylinder where the diameter equals to length, and cube, respectively (Bayram, 2011; Geankoplis, 2003).

$$\phi_s = 6\ V_p\ /\ D_p\ S_p \tag{1}$$

where ϕ_s, Vp, Dp and Sp are particle sphericity, particle volume, equivalent or nominal diameter of particle and surface area of one particle, respectively.

The diameter of a sphere of equal volume is known as equivalent diameter. Determining exact volume and surface area to achieve the equivalent diameter of granular materials is not easy. It is generally received to be the nominal size depends on sieve analyses, visual length measurement, image analysis, paper coating on surface, surface dust coating or microscopic examination. Bayram (2005a) derived an alternative new simple method owing to the challenges to use Eq. (2), which is called as MBayram-1 equation (Eq. (2))

$$\phi_s = \frac{\sum (D_i - \bar{D})^2}{(\bar{D} N)^2} \tag{2}$$

where ϕ is sphericity value, D_i is any measured dimension, $\bar{D}$ is average dimension or equivalent diameter and N is the number of measurement (Bayram, 2011). The dimensions of wheat kernel are shown in Figure 1.5.

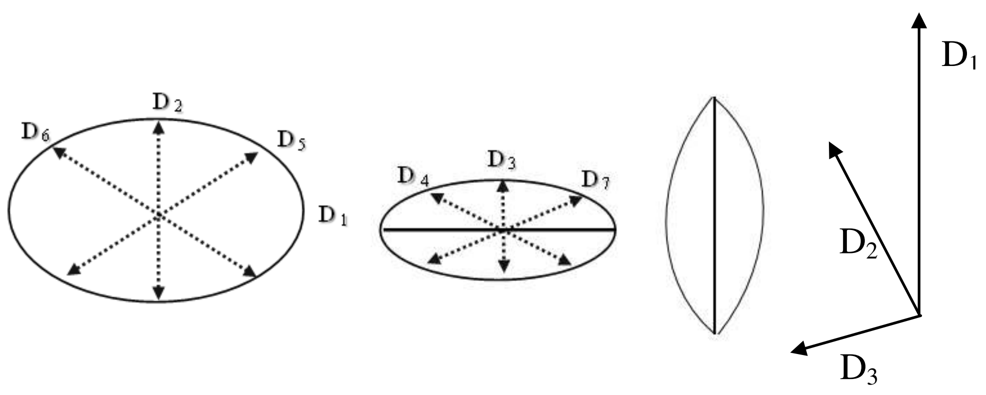


Figure 1.5 Dimensions of sample (Bayram, 2011)

Bayram (2005a) emphasized that, sphericity is constant and independent of size for certain shapes at 0, 0.00271 and 0.00155 for sphere, cube and cylinder (length =

diameter), respectively. According to the result, the sphericities of wheat, bean, intact red lentil, chickpea and coarse bulgur were determined as 0.01038, 0.00743, 0.00641, 0.00240 and 0.01489, respectively. Also it was found that, as expected, chickpea had the best, and coarse bulgur had the worst sphericity due to their specific shapes.

1.5.6 Minimum Fluidization Velocity

During a liquid or a gas flow upward via a packed bed of solid particles at nominal velocities, the particles stay stationary. If the fluid velocity is perpetually raised, the pressure drops on individual particles increase. Upon further increases in velocity, conditions finally occur where the force of the pressure drop times the cross-sectional area just equals the gravitational force on the mass of particles minus the buoyant force of the displaced fluid. Herewith, the particles start moving like a fluid and this is the initial of fluidization or minimum fluidization. The gas velocity at which fluidization begins is the minimum fluidization velocity v'_{mf} in m/s based on the empty cross section of the tower (superficial velocity) (Geankoplis, 1983; McCabe et al., 1985).

The minimum velocity at which a bed of particles fluidizes is a significant index obligatory for the design of any fluidization operation. It is impressed by numerous factors such as shape, size, density, and polydispersity of the particles. The net gravitational force acting on the particle is entirely altered by density and hence, the minimum drag force, or velocity, required to elevate a particle. The relevance between the drag force and velocity not only mutates particle shape, but also the packing characteristics of the fixed bed, the associated void spaces and velocity of fluid through them (Anonymous, 2017).

1.5.7 Silo Discharge Rate

Silos and hoppers are extensively used in many industries, such as mining and food etc., which are vessels to protection, storage and handling of particulate solids. Generally, silos or bins are great containers preferred for long-range storage either at the beginning of a process to store raw materials or at the final products. Although most silos are circular, square or rectangular silos are frequently utilized owing to fabrication ease and saving space area of process (Grossel et al., 2005).

Hoppers must be designed by considering the flow properties of solid materials. The properties of granular material include grain nature, size, shape, moisture content, temperature, adhesion and cohesion etc. If these properties are ignored when designing storage hoppers, it can be cause product degradation and shut-down periods in production line due to segregation, flooding, arching and erratic or no flow. These problems can be minimised with appropriate bulk solids discharge from bins and hoppers. The measurement of solid handling properties that are required for silo design to prediction filling and emptying flow rate and this expenditure is so lowly compared to the costs, which emerge due to wrong plant design such as quality problems, production stoppages, building adjusments and complete reconstructions (Schulze, 2008).

When a bulk solid discharged under gravity through an opening at the bottom from a silo, the failure to beginning the flow after intermission or storage can be observed. The reasons of this failure are considered as bin design, shape and the location of the opening, apart from the flowing features of the solids. Due to exist in very few solids that are free flowing and that will initiate flowing again after an extended period at rest, the design of hoppers or silos in terms of their ability to discharge the solids from the silo without any aid is based on solid mechanics theories considering only the hopper of the container (Barbosa-C´anovas et al., 2006).

Two different flow patterns can be achieved by any hopper, silo or containers when it is being emptied. These flow patterns are mass flow and funnel flow (Figure 1.6) (also generally known as core flow or plug flow), which can be influenced by the design of the storage container or by a discharge device, which controls the flow from the vessel (Hoyle, 2001).

In mass flow pattern, every particle of the bulk solid is moving at every point within the silo whenever outlet is opened. The hopper is designed for mass flow by the sufficient steep and smooth wall to ensure flow of all the solids in the silo without stagnant or steady regions during unload (Barbosa-C´anovas et al., 2006).

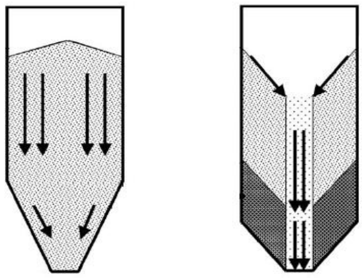


Figure 1.6 Flow regimes (a: Mass flow and b: Funnel flow)

In this mode of flow has lots of beneficial properties such as, the flow is uniform, the bulk density of the feed is nearly independent of the head of solids in the silo, channelling, hang-ups, surging and flooding are absent, no dead regions within the bin and minimum segregation. Moreover, the first-in, first-out sequence of flow makes mass-flow bins are regarded as the ideal for storing solids that degrade with time (Woodcock and Mason, 2012).

The prediction discharge rate of a cohesive bulk solid is used by Johanson Equation (Eq.3). This method is applied for the mass flow rate of solid from circular outlet;

$$W= \rho_b (\pi/4) B^2 (gB/4 \tan \theta_c)^{0.5} \quad (3)$$

where B is the outlet diameter of the hopper (m), ρ_b is the bulk density of the discharging material (kg/m^3), and g is the gravitational constant, θ_c is the angle of hopper from vertical.

In another flow pattern as called funnel flow, which is suitable for coarse free-flowing materials. The discharge of the bulk solid is basically irregular in the funnel flow regime from a bin due to the stored material flows toward the outlet through a vertical channel forming within stagnant solids. Funnel flow is regarded as undesirable flow regime because of flow characteristics, which may be listed as follows: the particle velocity is found at center of silo is bigger than velocity of particle found at wall of silo thus, center discharges as first and first-in is not first out: the flooding problems or uncontrolled discharge can raise owing to some solid materials can aerate when discharge through the flow channel: cohesive solids usually necessary broader outlets for secure flow because plug flow bins are more prone to create arching of them than mass-flow bins. Moreover, core flow bins are unsuitable for solids that degrade with time in the stagnant regions and may excite segregation of solids (Barbosa-C´anovas et al., 2006).

The prediction of the discharge rate is importantance for the design of reliable and controllable transport system. For funnel flow the estimation of the discharge rate is described by the so called Beverloo Equation (Eq.4)

$$W = 0.58\ \rho_b\ g^{0.5}\ (B - kd_p)^{2.5} \tag{4}$$

where W is the discharge rate (kg/sec), g is the gravitational constant, ρ_b is the bulk density (kg/m^3), B is the outlet size (m), k is a constant (typically 1.4), d_p is the particle size (m) (Madrid et al., 2017).

1.5.8 Surface Friction

The roughness of particles plays an important role in determining of surface friction. The rough surfaces generally have high friction coefficients than smooth surfaces of particles. Surfaces with different degree of roughness have different friction features Ampere measurement can be applied to identify the degree of surface roughness. And also power is obtained can be multiplying the ampere value with the voltage value.

1.6 The Objectives of Study

Bulgur is a well-known solid food product, the knowledge of natural bulgur characteristics is an essential consideration when the efficiently and reliably design of equipment, processing machines, design of the bulgur factory and improve the final products quality for its handling or storage. The numberless problems are encountered in the bulgur industry during the bulgur production because that producer insufficient interested in physical, chemical and handling properties of bulgur. Flow obstructions, segregation, irregular flow, flooding, failure of wheat or bulgur samples to discharge from bins, blockage of a pneumatic conveying line, plugging in piping system and uncontrollable flushing of material through a weigh-feeder are ordinary of such problems. In the literature, there is no study about solid handling properties of bulgur. In addition, there is no research to determine the effect of production modes on the handling of bulgur during bulgur manufacturing. In this thesis, firstly, different bulgur samples were produced from Durum and bread wheat using different two production techniques (Antep and Karaman/Mut) and then solid handling properties of bulgur samples were determined in each production stages.

The aim of this study was;

- ✓ to determine solid handling properties of bulgur and by-products during Antep and Karaman (Mut) processing starting from raw material to the final product,
- ✓ to evaluated sphericity, particle size and distribution of bulgur particles,
- ✓ to determine repose angle and sliding angle of bulgur,
- ✓ to investigate the void fraction, bulk and particle densities of bulgur,
- ✓ to establish the minimum fluidization velocity of bulgur,
- ✓ to observe the influence of quality properties (color, moisture, ash and protein content),
- ✓ to find out the flow regimes of bulgur products (Johanson and Beverloo's equation) and to evaluate certain and prediction rate of silo discharge (at different height and at different orifice),
- ✓ to define surface friction (during mixing; Ampere, Voltage and Power),
- ✓ to contribute to the literature, industry, environment, economy and health of people by determining handling characteristics of bulgur.

CHAPTER 2

MATERIALS AND METHODS

2.1 Materials

Durum and bread wheat types were handled as the raw materials for the bulgur production. *Triticum durum* (Burgaz, harvesting year 2017) and *Triticum aestivum* (Ceyhan-99, harvesting year 2017) wheats were supplied from Dayıoğlu Bulgur Factory and Dayıoğlu Flour Factory in Gaziantep/Turkey, respectively. The wheat samples were storaged in the plastic bins at 4 °C. Distilled water was used for the washing, cooking and tempering operations.

2.2. Methods

In the study, two bulgur production methods (Antep and Karaman/Mut) were used and the solid handling properties of the products (main and by-products) at each stage were determined (Figures 1.2 and 1.3).

2.2.1 Bulgur Production Stages

2.2.1.1 Cleaning of wheat

Durum and bread wheat samples were screened through 1.60 mm and 4 mm sieves to remove the foreign materials such as insect residues, stones, straw, seeds, broken kernels, dust and other cultivated plants like maize, sorghum, barley and corn.

2.2.1.2 Washing of Wheat

In this stage, the wheat samples were washed in a beaker by mixing with a bagette for 3 mins to remove adhesive materials and husk to obtain clean raw materials. The amount of water was the half of that of wheat during washing. The washed wheat samples were filtrated to separate excess water.

2.2.1.3 Soaking of Wheat

The soaking process is sometime applied before the cooking operation in the industry. It is completed in a shorter time depending on the temperature of the soaking operation. One kilogram Durum and bread wheat samples were added in the soaking chamber at 45 ^{o}C and the retention times were determined (until reach to 35 % moisture content) as 3.5 and 2.5 hour, respectively.

2.2.1.4 Cooking

The cooking of wheat was carried out using the atmospheric cooking operation (~97 ^{o}C). One-kilogram cleaned wheat and 1 liter of water were used in this process. Durum and bread wheat were poured into the boiling water (~97 ^{o}C) and the boiling time was determined for entire starch gelatinization, as a cooking degree at 45 and 35 minutes, respectively. The cutting method was used to decide the termination of the cooking operation. The cooked kernels were cut with a razor blade to ensure complete gelatinization (Bayram, 2006). If the center of cut wheat was imaged completely transparent, the cooking process was regarded as finished.

2.2.1.5 Drying

Drying is a vital step to decrease the moisture content of the cooked wheat. The drying process was accomplished by using an artifical dryer e.g. packed bed (MK II, Sherwood Scientific, UK). The initial drying air temperature was 90 ^{o}C and then its temperature was decreased to 50 ^{o}C step-by-step at 20 ^{o}C discrete, which was paralel to decrease in the moisture content. The air velocity was 1.2 m/s during the drying operation. In the study, Durum and bread cooked wheat samples were settled into the packed bed column (chamber diameter was 150 mm) and the weight of hedik (cooked wheat) was recorded at the beginning of the drying process (Figure 2.1). The fluidized bed colomn was shacked in three minute intervals by hand and weighted until the moisture content of the wheat kernels were reduced to 12 % in wet basis.

Figure 2.1 Fluidized of bed drying

2.2.1.6 Tempering

The dried cooked wheat was moistened prior to the debranning operation in order to help the bran separation. According to the bulgur industry, tempering time and moisture content are different for Antep and Karaman/Mut bulgur production methods. For Antep type bulgur production, Durum and bread cooked and dried wheat samples were moistened to 16-17 % (w.b.). The samples were rested for 25 mins. In Karaman/Mut type bulgur, both samples were tempered to 22-24 % (w.b.) for 8 hours.

2.2.1.7 Debranning

The bran layers were softened by sprinkling the dried wheat with water and the debranning operation was conducted by a vertical emery stone debranner (Merba Makine, Turkey) for Antep type bulgur productions. The bran was separated with a vibro-screen sieve and an aspiration system (Figure 2.2). Also, the debranning and milling processes were performed simultaneously for Karaman/Mut type bulgur by using a stone mill.

Figure 2.2 Debranning machine for Antep type bulgur production

2.2.1.8 Milling

After the debranning operation, the samples were milled by using a laboratory disc mill (Model 4E, Qaker city mill, Philadelphia, USA) (Figure 2.3a) and a traditional stone mill (Figure 2.3b), for Antep and Karaman /Mut types products, respectively.

(a) (b)

Figure 2.3 Milling operation (a: disk miller, b: traditional stone mill)

2.2.1.9 Polishing

The samples were polished by using a mechanical kneading polishing system (Figure 2.4). The polisher was a specially designed and had pallet system involving a digital thermometer, a motor, four electrical resistance heaters and ampere-meter. The pallet system adjusted to get maximum squeezing. When the system was operated, the temperature of the samples increased to 45 ^{o}C due to friction.

Figure 2.4 Mechanical kneading machines (polisher)

2.2.1.10 Classification

The bulgur samples were sieved by using 3.55, 3.00, 2.50, 2.00, 1.60 and 0.50 mm square screens. After screen analysis bulgur samples were classified as coarse (3.55-2.00 mm, 3.55/2.00), medium (2.00-1.60 mm, 2.00/1.60), fine (1.60-0.50 mm, 1.60/0.50) and undersize bulgur as called by-product (<0.5 mm, 0.5/+).

2.2.2 Experimental

2.2.2.1 Determination of Bulk Density

In this experiment, the packed and loose bulk densities were measured. The graduated cylinder was used by filling it with Durum and bread wheat samples. The samples were packed well by hitting the cylinder manually to decrease free gaps between free wheat particles. For the loose (free) bulk density measurement, the wheat particles poured into graduated cylinder without any shaking or consolidation. Then, the samples filled graduated cylinders were weighted by an analytical balance and the packed and loose bulk densities were determined by the ratio of weight to volume of sample as kg/m^3.

2.2.2.2 Voidage Measurements

Bulk porosity (ε) was calculated using the relationship between bulk (ρ_b) and particle density (ρ_p) according to Barbosa-C´anovas et al. (2006) as follows (Eq.5):

$$\varepsilon = \frac{\rho_p - \rho_b}{\rho_p} \tag{5}$$

2.2.2.3 Determination of Particle Density

A pycnometer was used to determination of fine and coarse bulgur particles density, which depended on the volume of pycnometer bottle. The pycnometer was filled with xylole (C_8H_{10}) solution. The particle density ρ_p is clearly the net weight of dry bulgur particles divided by the net volume of the bulgur particles (Figure 2.5), obtained from the volume of the pycnometer, and subtracting the volume of the xylole solution, (Eq.6):

$$\rho p = \frac{(m_s - m_o)\,\rho}{(m_1 - m_o) - (m_{s1} - m_s)} \tag{6}$$

where m_s is the weight of the pycnometer filled with the specific amount of bulgur, m_o is the weight of the empty pycnometer, ρ is the density of the xylole (ρ_{xylole} : 0.85 g/cm^3), m_1 is the weight of the bottle filled with the xylole solution and m_{s1} is the weight of the pycnometer filled with both the bulgur samples and xylole solution (Barbosa-C´anovas et al., 2006).

a b

Figure 2.5 Pycnometer was filled with xylole (a); xylole + samples (b)

2.2.2.4 Angle of Repose Measurement

Angle of repose was determined in a slowly rotating cylinder apparatus with horizontal axis (Figure 2.6). This measurement was based on the finding the angle of initial particle sliding on the surface of product.

Figure 2.6 Angle of repose instrument

2.2.2.5 Determination of Sliding Angle

The sliding angle is flow angle on a surface of certain materials e.g. metal, plastic and wood etc. The principle of this analysis was based on reading the angle at which the products were first motion by placing them on metal and plastic plates with a specific amount. Durum and bread wheat products were putted on plates. The plastic and metal plates were lifted up slowly up to 90 % of product on the plates start to slide (Figure 2.7).

Figure 2.7 Sliding angle plate

2.2.2.6 Determination of Sphericity

The shapes of wheat products were presumed as ellipsoid. Dimensions of the all wheat products (D1, D2, D3, D4, D5, D6 and D7 (mm)) were measured using an electronic caliper (Insize, Series 1112, Japan) in millimeter, which is shown in Figure 2.8. The measurements were performed through crossing the origin of kernels by determining origin with measuring the distance of a line through the origin.

Randomly three kernels were used to measure length, width, thickness and then the sphericity was calculated using MBayram-1 Equation (Eq.7)

$$\phi_s = \frac{\sum (D_i - \bar{D})^2}{(\bar{D} N)^2} \tag{7}$$

a b

Figure 2.8 Dimension of length (a) and width (b) of wheat kernel

2.2.2.7 Determination of Minimum Fluidization Velocity

Four hundred grams samples were weighted by an electronic balance and loaded into the fluidized bed column to detect the minimum fluidization velocity. It was similar to Figure 2.1 as the system. The blower was started and the speed was gradually increased until observe first bubble of wheat and bulgur samples. The minimum fluidization velocity was measured by an anemometer (Testo 416, Germany). The minimum fluidization velocity results were the average of different nine points of column.

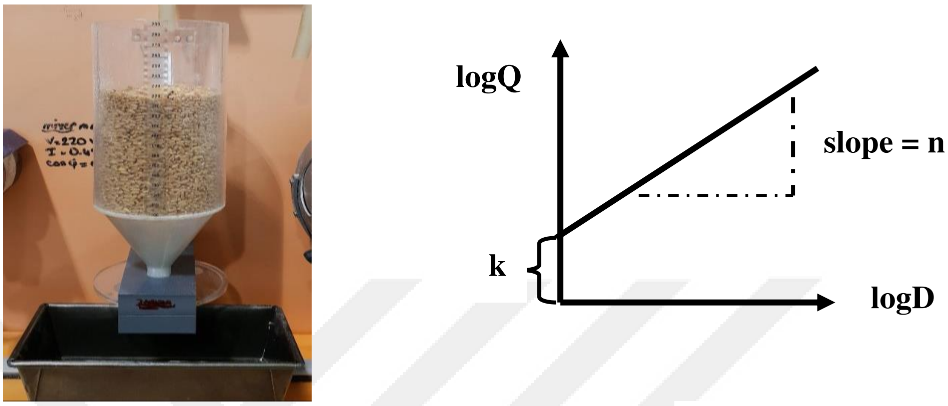
2.2.2.8. Measurement of Silo Discharge Rate

Hopper was filled about 2/3rds full with the wheat particles (Armfield, UK). The orifice diameters of hopper were used as 6, 9, 12 and 15 mm. The wheat particles were discharged within 10 second by the opening selection orifice and the pan was weighed to observe the amount of discharge wheat products (g/sec). This procedure was repeated using each of the four different orifices (6, 9, 12, and 15 mm) (Figure 2.9). Then, n and k coefficients were calculated by using the following equation (Eq.8 and 9) by graphical solution;

$$Q = k\,D^{n} \tag{8}$$

$$\log Q = \log k + n \log D \tag{9}$$

where Q is the silo discharge rate (g/s), D is the orifice diameter (mm), n and k are constant.



(a) **(b)**

Figure 2.9 Silo discharge rate at different orifices (a), a straight line which is used to determine k and n values

2.2.2.9 Determination of Flow Regime

Silo was filled with wheat products and orifice diameter was adjusted to 15 mm. When opening orifice of silo, the flow regime was observed as mass or funnel flows.

2.2.2.10 Surface Friction

One kilogram of wheat samples were loaded into the Ribbon type (screw) mixer (Armfield, UK) and started the mixer at constant rpm (by counting the revolution per minute). During mixing, the ampere and voltage were measured to calculate power and energy (Figure 2.10).

(a) (b)

Figure 2.10 Ribbon type mixer (a), Voltmeter/Ampermeter (b)

2.2.2.11 Determination of Moisture Content

The moisture contents were determined at 130 ^{o}C by using oven method (AOAC, 1990). The analyses were conducted in triplicate.

2.2.2.12 Determination of Ash Content

Association of Official Analytical Chemists (AOAC) method was used for the detect of ash content (%, d.b.) of samples at 900 ^{o}C (AOAC, 1990). The analyses were performed in triplicate.

2.2.2.13 Determination of Protein Content

The protein content (%, d.b.) of samples was determined by using Kjeldahl method (AOAC, 1990). The analyses were made in duplicate.

2.2.2.14 Measurement of Color Values

HunterLab Colorflex (Model No. 45/0, USA) was used to the determine the color values. The color of wheat and bulgur samples were obtained by measuring the CIE L* (100=white; 0=black), a* (+: red; -: green) and b* (+: yellow; -: blue) and YI (Yellowness Index) values using with illuminate D65/10 as reference. Four measurements were made and their average values were used (Balcı and Bayram, 2017).

2.2.2.15 Sieve Analysis

Sieve analysis was made to determine particle size distribution by using the principle of geometry similarity. It was conducted for all bulgur production line (except for washing, soaking and cooking stages) as the 200 g samples were sifted with 3.55 and 2.80 mm screens (screen aperture was square) (Armatest, Ankara) and each fraction was calculated by weighing the remaining samples on each sieve (>3.55 mm, 3.55/2.80 mm and 2.80 mm>) (Yıldırım et al., 2008a).

2.2.2.16 Statistical analysis

One-way analysis of variance (ANOVA) was conducted with SPSS statistical software (version 22.0) (IBM Software, NY, USA). Using ANOVA at $p \leq 0.05$ significance level. Duncan's multiple range tests were used to determine the differences between the samples.

CHAPTER 3

RESULTS AND DISCUSSION

Information on the physical, chemical and flow properties of wheat is required in the design and adjustment of machines used during harvesting, separating, cleaning, handling and storing of wheat and converts them into wheat based products like bulgur. The Durum and bread wheat types were preferred as raw material to produce different bulgur (Antep and Karaman/Mut) types. The effects of the processing stages and bulgur production techniques were determined in order to assess solid handling properties of bulgur. Particularly, the wheat and bulgur samples were analyzed based on dimensional properties such as particle size and density, sphericity, bulk density, angle of repose and voidage etc. where are important for the engineering applications, designs and calculations. The experimental results of the study are given in Figure A1-A14.

3.1 Properties of Raw Material

In this study, Durum and bread wheat samples were analyzed before the cleaning operation due to propound their characteristics. It was found that the types of wheat (Burgaz and Ceyhan-99) were significantly ($p \leq 0.05$) effective on the b*(yellowness) value, bulk density, moisture and protein content of raw materials in contrast to the L* (lightness), a* (redness), YI (Yellowness Index) values, voidage and ash content (Table 3.1). According to Bayram (2000), wheat type is the most important parameter to the production of high quality bulgur and generally *Triticum durum* (hard) type is selected for making bulgur because of light yellow color and containing more protein content than other types of wheat. And also, Dick and Matsuo (1988) noted that kernel hardness is desired for the production of semolina and bulgur. If there is insufficient Durum wheat, bread wheat (soft) is sometimes used to meet requirements of raw material in making bulgur.

In the study, the initial moisture (w.b.), ash (d.b.) and protein contents (d.b.) of Durum and bread wheat types were measured as 5.79, 1.53 and 16.38 % for durum for wheat; 7.12, 1.71 and 11.39 % for bread wheat, respectively. Both Tipples (1969) and Bafklow et al. (1973) reported that in soft wheat strength of adhesion is low between the protein matrix and starch granules (low protein content).

It was found that color values of Durum and bread wheat types were 53.02, 52.20 for L*, 8.64, 8.32 for a*, 25.48, 24.68 for b* and 73.23, 72.00 for YI, respectively. The general quality parameters and solid handling properties of Durum and bread wheat types are presented in Table 3.1.

Angle of repose and sliding angle are very important properties for the design the machineries, silo and piping system for solid food products (in flour, semolina, wheat, bulgur factories or for any solid particle food products). In a study was conducted by Frączek et al. (2007) to assessment of angle of repose of granular materials on wheat, barley, and oats varieties within the different levels of grain moisture. It was found that angle of repose 27.1^o, 29.5^o, 25.6^o and 28.8^o for winter wheat (m.c. 11.8 %), spring barley (m.c. 9.2 %), winter barley (m.c. 9.7 %) and oats (m.c. 11.0 %), respectively. According to experimental results, whereas angle of repose of durum wheat type were found 38^o, bread wheat was 42^o. The sliding angle on metal and plastic plates was measured as 26^o and 22^o for durum wheat; 25^o and 23^o for bread wheat type, respectively.

In the industry, the determination of bulk density is necessary to adjust storage, handling, packaging and distribution conditions of solid materials. It depends on solid material composition, particle shape and size, specific density of individual particles, particle size distribution and moisture content (Lam et al., 2008). The physical properties of some agricultural grains and particle density of wheat varieties were found (Gürsoy and Güzel, 2010) ranged from 1373 to 1441 kg/m^3 compared to 1395 to 1409 kg/m^3 for lentil varieties, 1402 to 1406 kg/m^3 for chickpea and 1320 to 1339 kg/m^3 for barley varieties.

Sieving is the most popular method to observe particle size distribution, especially with relatively coarse materials. Sieve generally consists of a woven wire screen (with square, oval and circular apertures) rigidly mounted in a shallow frame. However, for coarse materials the sieve screen is more usually a perforated plate with either round or square holes (Woodcock and Mason, 2012). In this study, two sizes (3.55 and 2.80 mm) of sieves were used and the percentage of wheat kernels that would not pass endwise through each sieve was determined. And each fraction of Durum and bread wheat types was 7.2 and 4.3 % (wt/wt) for +/3.55 mm; 53.5 and 76.2 % (wt/wt) for 3.55-2.80 mm; 39.3 and 19.6 % (wt/wt) for 2.80/+ mm, respectively.

Table 3.1 Chemical, physical and solid handling properties of raw materials

	Wheat Type		Durum Wheat	Bread Wheat
Quality Parameters	Moisture content (%, w.b.)		5.79±0.12	7.12±0.13
	Ash content (%, d.b.)		1.53±0.16	1.71±0.36
	Protein content (%, d.b.)		16.38±0.18	11.39±0.38
	L*		53.02±0.68	52.20±0.49
	a*		8.64±0.19	8.32±0.31
	b*		25.48±0.21	24.68±0.16
	YI		73.23±1.14	72.00±0.98
Solid Handling Properties	Particle Density (g/mL)		1329.78	1333.32
	Bulk Density (kg/m^3)	Packed	816.80±4.07	863.46±2.06
		Loose	779.26±4.61	825.84±6.17
	Void fraction	Packed	0.3858±0.0031	0.3788±0.0014
		Loose	0.4140±0.0035	0.4059±0.0044
	Angle of Repose (^{o})		38	42
	Sliding Angle (^{o})	Metal surface	26	25
		Plastic surface	22	23
Screen Analysis (%, wt/wt)	+/3.55 mm		7.2	4.3
	3.55/2.80 mm		53.5	76.2
	2.80/+ mm		39.3	19.6

±: standart deviation, d.b. : dry base, w.b. : wet base.

3.2. Effect of Cleaning Operation on Physical, Chemical and Solid Handling Properties

The cleaning operation is primary stage in the processing of bulgur. Pence et al. (1964) reported that the physical properties of the raw material, the presence of foreign materials and foreign seeds are a consideration because water absorption, temperature and time during cooking and drying are related to the homogeneity of the raw material. Additionally, while removal of the dangerous wild seeds through the cleaning operation provides prevention of consumer health risk, the bulgur quality, product acceptability, and production flexibility can be increased and also production machines are protected from stone, metal and dust etc.

Durum and bread wheat samples were analyzed after dry cleaning in order to acquire clean raw material and understand impact of dust, chaff, husk, foreign seeds, stone and metals as well as immature and broken kernels etc. on the wheat quality and properties. According to the statistical analysis, moisture content, sphericity, particle size, a*, b* and YI values were significantly different ($p \leq 0.05$) for cleaned Durum and bread wheat types (Table 3.2).

The moisture levels of solid materials are very important in the large and varied industry concerned with the handling, processing and storage of bulk solids. As well as moisture can be cause chemical changes deterioration of quality, it can have a dramatic influence on the flow behaviour of bulk solids (Woodcock and Mason, 2012). Therefore, the moisture content analysis is one of the most frequently performed during the bulgur production. The moisture content (w.b.) was found as 5.60 and 7.09 % for cleaned Durum and bread wheat types, respectively.

The protein content of raw material is very important property to get the perfect textural characteristics of final product like chewing and punching etc. Durum and hard wheat contain more protein (12-16 %) than soft wheat (8-10 %) (Sayaslan et al., 2006). In present study, while the protein content of Durum wheat decreased by the removing the involuntary materials, the protein content of bread wheat samples slightly increased. It can be explained that the protein content of Durum wheat foreign materials has high protein value foreign seeds. The ash and protein content were determined as 1.34 and 14.35 % (d.b.) for Durum wheat and 1.53 and 11.98 %

(d.b.) for bread wheat types, respectively. These result were similar to the results of Savaş and Basman (2016).

Generally, by the rejecting the undesired materials from the raw material increases the L*value (lightness) while decreasing a* (redness) value of wheat. It was observed that while L* value for both wheat type was decreased, a* value of Durum wheat is increased in contrast to a* value of bread wheat.

Chen et al. (2015) denoted that the angle of repose depends on the particle characteristics such as particle shape, particle size and surface roughness of granular materials. The angle of repose was found as 40 and 45^{o} for cleaned Durum and bread wheat types, respectively. Theoretically, when the particle size increases, surface area and friction between particles decreases, therefore the angle of repose decreases. It may be due to another reason such as bread wheat surface (especially head of kernel) has hairs (hairs of brush) (Figure 1.1), therefore it may cause low stand to flowability. Sliding angle is expressed as sliding angle of particles from a surface. It was observed that sliding angle of Durum and bread wheat types was 25.5 and 24^{o}, and 22 and 21^{o} for metal and plastic surfaces, respectively.

For Durum and bread wheat types, bulk density and void fraction was insignificantly ($p>0.05$) different. Bulk density is always less than the particle density of solid material and in its calculation, it must be considered that the void between individual particles of bulk solids. (Schulze, 2008). It was observed that the packed and loose bulk densities of bread wheat type were higher than Durum wheat. This result is unexpected because of with increasing particle size increases bulk density and it can be originated from using inhomogeneous raw material such as presence weak, broken, wrinkly and different size kernel in both wheat types. Theoretically, Durum wheat has higher bulk density. But, in this study, the result is different. It may be due to the difference in particle size. According to Table 3.1, the portion of particle in size between 3.55/2.80 mm screens were bigger for bread wheat than Durum wheat. Therefore, Durum wheat used in the study had small particle size.

Burubai and Amber (2014) stated that geometric properties such as shape and size are one of the most important physical properties considered for the design of sieve apertures for the cleaning and sorting operations as well as the development of chutes and hoppers. In theoretical calculations, grains and seeds are assumed to be spheres or ellipse because of their irregular shapes. Therefore, particle size and sphericity of Durum and bread wheat types were identified according to MBayram-1 equation (Eq.2) by a digital micrometer as 6.05 mm and 0.0156, 4.79 mm and 0.0076, respectively.

The degree of surface roughness was determined by measuring the ampere of the wheat samples. Ampere is also measured continuously in industry for the protection of equipment (over loading of motor). The ampere value (roughness) of bread wheat type was found higher than durum wheat type (0.40 A). The voltage values of Durum and bread wheat types were observed as 15 and 13 V, respectively. Power (W) and energy (Wh) were calculated as 4.5 W and 0.076 Wh for Durum wheat; 5.2 W and 0.088 Wh for bread wheat types, respectively. The high value of bread wheat in A, V and P were due to surface properties of bread wheat (hairs on surface).

The particle size distribution is critical in determining particulate behaviour during transport and handling. Sieve analysis showed that, within each wheat types, the percent amounts of wheat samples having particle size between 3.55 and 2.80 mm screens, which were the highest. The percentages were found as 86.1 and 77.3 % (wt/wt) for Durum and bread wheat types, respectively.

As explained previously, bins, bunkers, silo or tanks are generally used as containers for storage of bulk solids. Bayram and Balcı (2011) declared that the loading and unloading of the silos is critical for the safety of silo and its full capacity usage while loading of silo, it should be filled as possible as close to the center. Otherwise, the risk of tipping on to its side can be observed. Two primary flow modes can develop when a bulk solid discharges from a bin: funnel and mass flow. Flow regime of both cleaned wheat types was observed as mass flow during discharge from silo and therefore, the prediction silo discharge capacity (W) was calculated according to Johanson equation (Eq.3). The diverse in particle size and shape, inhomogeneous solid distribution, irregular velocity profile complicates the prediction of discharge capacity (Liu et al., 2014a). The experimental (Q) and predicted (W) discharge rate of cleaned Durum and bread wheat types at four different orifice diameter (6, 9, 12 and 15 mm) are given in Table 3.3. According to results capacity of discharge is related to the orifice diameter. Additionally, the k and n values of discharge constant were obtained by using sketching log graph and these values of Durum and bread wheat types were 0.000140 and 4.372 for cleaned Durum wheat and 0.000070 and 4.730 for bread wheat types, respectively.

Table 3.2 Chemical, physical and solid handling properties of cleaned Durum and bread wheat types

	Wheat Type		Durum Wheat	Bread Wheat
Quality Parameters	Moisture content (%, w.b.)		5.60±0.53	7.09±0.57
	Ash content (%, d.b.)		1.34±0.12	1.53±0.13
	Protein content (%, d.b.)		14.35±0.32	11.98±0.80
	L*		50.67±0.21	50.89±0.15
	a*		9.06±0.14	8.03±0.05
	b*		25.18±0.12	24.34±0.09
	YI		75.32±0.54	72.12±0.20
Solid Handling Properties	Sphericity (ϕ)		0.0156±0.0018	0.0076±0.0007
	Particle Size (mm)		6.05±0.15	4.79±0.02
	Bulk Density (kg/m^3)	Packed	871.74±2.97	879.44±2.88
		Loose	831.72±0.34	838.72±8.03
	Particle Density (g/mL)		1378.05	1365.68
	Voidage	Packed	0.3674±0.0021	0.3649±0.0020
		Loose	0.3965±0.0002	0.3943±0.0058
	Angle of Repose (^{o})		40	45
	Sliding Angle (^{o})	Metal surface	25.5	24
		Plastic surface	22	21
	Min. Fluidization Velocity (m/s)		0.58	0.53
	Power =I (Ampere)*V (Voltage)		P = 0.30*15 = 4.5 W	P = 0.40*13 = 5.2 W
	Energy = P (Power) * t (time)		E = 0.076 Wh	E = 0.088 Wh
Screen Analysis (%, wt/wt)	+/3.55 mm		3.5	4.7
	3.55/2.80 mm		86.1	77.3
	2.80/+ mm		10.6	18.3

Table 3.3 Flow properties of cleaned Durum and bread wheat types

Wheat Type		Orifice Diameters (mm)							
		Durum Wheat				Bread Wheat			
		6	9	12	15	6	9	12	15
Flow Properties	Flow type	Mass				Mass			
	W (kg/s)	0.001829	0.005039	0.010345	0.018071	0.001844	0.005082	0.010432	0.018223
	Q (g/s)	0.461±0.008	1.241±0.057	8.055±0.145	22.679±0.075	0.369±0.025	1.919±0.019	9.088±0.073	27.280±0.154
	k	0.000140				0.000070			
	n	4.372				4.730			
	R^2	0.960				0.996			

Q: certain silo discharge capacity, W: predicted silo discharge rate.

3.3 Properties of Wastes/By-products

Durum and bread wheat types were cleaned and obtained foreign materials such as dust, husk, leaf, insect, foreign seeds, straw, stone, broken and empty kernels. The presence of these materials in the bulgur production line causes the economical losses with decreasing bulgur yield and it is not accepted by consumer. Bayram and Öner (2006) declared that insufficient cleaning had the decreasing effect by 5% (price level) on economic value of bulgur and preferability of bulgur (by using raw material with high amount of foreign grain seeds (rye, barley etc.) and other undesired materials in bulgur production line). In addition, these wastes/by-products should be transferred to special silos or hopper, therefore their solid handling properties should be known during the design of the plant or machineries. Although moisture content, packed and loose bulk densities, a*, b* and Yl values were significantly ($p \leq 0.05$) different for Durum and bread wastes, L* value, ash and protein contents were not significantly ($p > 0.05$) different (Table 3.4). The angle of repose was found as 45 and 46^{o} for Durum and bread wastes, respectively. While the sliding angle of Durum waste was 28 and 24^{o} with metal and plastic surfaces, bread waste was measured as 26 and 23^{o}, respectively.

Table 3.4 Properties of Durum and bread waste

	Waste Type		Durum Waste	Bread Waste
Quality Parameters	Moisture content (%, w.b.)		8.23±0.12	9.18±0.04
	Ash content (%, d.b.)		2.43±0.13	3.25±1.10
	Protein content (%, d.b.)		15.45±0.90	12.58±0.50
	L*		56.20±1.36	54.36±0.66
	a*		6.07±0.26	4.82±0.48
	b*		22.68±0.17	19.60±0.48
	YI		62.10±1.57	55.64±1.91
	Bulk Density (kg/m^3)	Packed	607.94±0.70	728.78±0.70
		Loose	515.46±9.81	650.98±3.02
	Angle of Repose (^{o})		45	46
	Sliding Angle (^{o})	Metal surface	28	26
		Plastic surface	24	23

3.4 Effect of Washing Operation on Solid Handling Properties

Wet cleaning was made after dry cleaning stage by water to remove soil, dust, herbicide, insecticide from surface of wheat kernel. It was found that sphericity, particle size, loose bulk density and void fraction were found significantly ($p \leq 0.05$) different in contrast to packed bulk density and void fraction for washed Durum and bread wheat types. The solid handling properties after washing operation were made and the results are submitted in Table 3.5. Frączek et al. (2007) revealed that water causes both quantitative and qualitative changes of physical properties while penetrating into the grains. This affects the diversification of kernel properties because of greater friction forces among the grains (internal friction).

Particle density is a good parameter to show the physical property of a solid material. It was determined using the xylole displacement method. According to the experimental result, the particle density of washed Durum and bread wheat types was 1302.27 and 1265.61 g/mL, respectively. The angle of repose of Durum and bread wheat types was measured 67 and 57^{o}, respectively. That's why, the more spherical-like the grains are, the more regular the cone that forms (sphericity value of washed bread wheat smaller than Durum wheat (0.0088)). Sliding angle is used to determine the pipe angle in plant design and silo conical part angle. After washing operation, sliding angle of Durum wheat on metal and plastic surfaces were measured higher than bread wheat. Besides, the loose bulk density of Durum and bread wheat types decreased from 831.72-838.72 to 719.24-691.16 kg/m^3, whereas the void fraction or porosity of wheat kernels increased with the increase in moisture content from of wheat outer surface. Similar results have been reported by Işık (2007) for soybean grains.

Minimum fluidizing velocity is called as the lowest fluid velocity required ensuring that a material is the onset of fluidization. The minimum fluidization velocity was observed as 0.81 and 0.82 m/s for washed Durum and bread wheat types, respectively.

Table 3.5 Solid handling properties of washed Durum and bread wheat types

	Wheat Type		Durum Wheat	Bread Wheat
Solid Handling Properties	Sphericity (ϕ)		0.0144±0.0006	0.0088±0.0007
	Particle Size (mm)		6.00±0.30	5.15±0.15
	Bulk Density (kg/m^3)	Packed	800.18±6.99	781.46±0.71
		Loose	719.24±0.91	691.16±1.36
	Particle Density (g/mL)		1302.27	1265.61
	Voidage	Packed	0.3855±0.0053	0.3825±0.0006
		Loose	0.4477±0.0007	0.4538±0.0011
	Angle of Repose (^{o})		57	67
	Sliding Angle (^{o})	Metal surface	57	51
		Plastic surface	53	46.5
	Min. fluidization velocity (m/s)		0.81	0.82

3.5 Effect of Soaking Operation on Physical, Chemical and Solid Handling Properties

The soaking operation was performed by distillated water to provide enough water absorption into wheat kernels before cooking, to eliminate completely the toxic factors contained in the raw seed and to decrease the cooking time. The moisture content is critical for wheat kernel and when the moisture content is higher than 35 %, water reaches to the center of kernel. During soaking, the optimum soaking time was selected by trials for Durum and bread wheat types (Figure 3.1).

According to the result, the optimum soaking time was determined as 2.5 and 3.5 hour at 45 ^oC for Durum and bread wheat types, respectively. Similarly, the soaking time of wheat was determined by Özboy and Köksel (2002) as 3 h to raise moisture content to about 45% at 60 ^oC. Besides, the optimum soaking process condition was found by Ertaş and Türker (2012) as 12 h soaking time and pH=8 soaking water at room temperature for the obtaining highest nutritional properties of common bean bulgur.

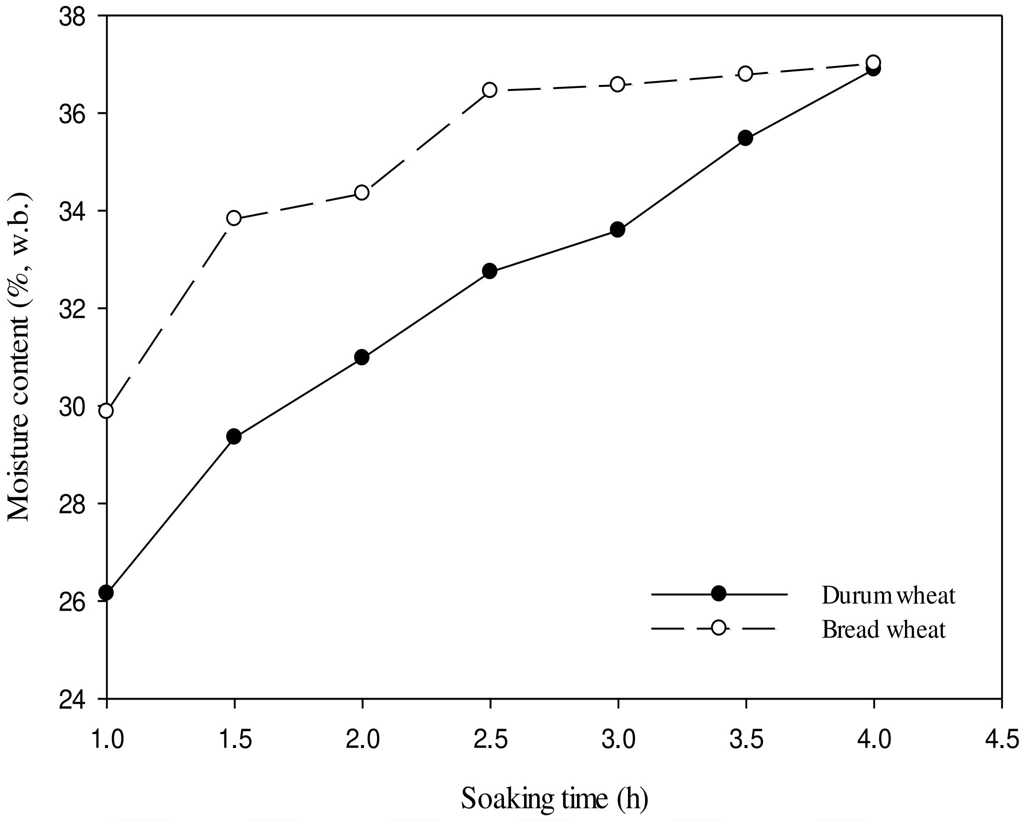


Figure 3.1 Soaking time and moisture content of Durum and bread wheat types

At the end of the soaking operation, the changes in L*, a*, b*, YI, the sphericity and particle size values of Durum and bread wheat types were found significantly ($p \leq 0.05$) different. The general quality and solid handling properties of Durum and bread wheat types are represented in Table 3.6. The moisture (w.b.), ash (d.b.) and protein (d.b.) contents were determined as 35.47, 1.32 and 14.70 % for soaked Durum wheat and 36.44, 1.50 and 11.70 % for soaked bread wheat, respectively. As seen in the results, the protein content for both soaked wheat types reduced due to the leaching of protein into water during soaking procedure. This result shows that the protein loss occurs during this stage.

Bayram et al. (2004c) examined the kernel size is the most important property for obtaining an acceptable bulgur size and milling quality. Moreover, the design of soaking system should be controlled to prevent over swelling (the degree of increase in the size and moisture of the kernel). During bulgur production (cooking and milling operations) the kernel size could be swell excessively and disperse due to increasing in the kernel size more than the optimum level while the soaking phase.

Particle size of soaked Durum and bread wheat types were measured as 6.12 and 5.16 mm, respectively.

Sliding angle is utilized to the design of pipe to convey the product from one floor to another down floor for subsequent production line. It was found that sliding angle of soaked Durum and bread wheat types was measured 58 and 55^o for metal and 55 and 50^o for plastic surfaces, respectively.

The angle of repose packed and loose bulk densities for Durum wheat type were 57^o, 777.48 and 691.90 kg/m^3; for bread wheat, they were found as 69^o, 781.92 and 720.78 kg/m^3, respectively. These decreases in the bulk densities and increases in the angle of repose and voidage values were expected due to increase in the moisture content of soaked Durum and bread wheat types. Similarly, Kanawade et al. (1990) evaluated the effects of the moisture content on the repose angle of pigeon pea, chick pea, cowpea, green gram, black gram, as well as soybean and moth bean seeds at five moisture levels. They concluded that the higher the moisture content caused the larger the angle of repose.

The particle density analysis after the soaking operation was made and the reduction of density was observed with increasing moisture content. It was measured as 1257.87 and 1246.40 g/mL for Durum and bread wheat types, respectively.

The particle shape of bulk solids is considered the most important characteristic due to it has a significant influence on their packing and flow behaviour. Therefore, some means are required to define the shape of a non-spherical particle. Sphericity is used as of shape factors to indicate the extent to which particles differ from the spherical (Woodcock and Mason, 2012). It was determined sphericity value of soaked Durum and bread wheat as 0.0148 and 0.0092, respectively. Similar sphericity results with geometric mean were reported by Ravi and Venkatachalam (2015) for paddy rice. It was observed that sphericity increased from 0.4109 to 0.4218 with increase in moisture content from 11.86 and 23.61 % (d.b.). Besides, the minimum fluidization velocity of wheat varieties were different because of it may be their kernel mass, surface area and sphere values and their moisture contents were different.

Table 3.6 Chemical, physical and solid handling properties of soaked Durum and bread wheat types

	Wheat Type		Durum Wheat	Bread Wheat
Quality Parameters	Moisture content (%, w.b.)		35.47±0.24	36.44±1.13
	Ash content (%, d.b.)		1.32±0.15	1.50±0.07
	Protein content (%, d.b.)		14.70±0.24	11.70±1.24
	L*		54.11±0.47	50.02±0.76
	a*		8.58±0.50	9.12±0.21
	b*		32.74±0.60	28.12±0.21
	YI		83.97±0.99	81.19±1.00
Solid Handling Properties	Sphericity (ϕ)		0.0148±0.0025	0.0092±0.0004
	Particle Size (mm)		6.12±0.31	5.16±0.26
	Bulk Density (kg/m^3)	Packed	777.48±3.507	781.92±6.96
		Loose	691.90±1.90	720.78±18.70
	Particle Density (g/mL)		1257.87	1246.40
	Voidage	Packed	0.3819±0.0028	0.3726±0.0056
		Loose	0.4499±0.0015	0.4217±0.0150
	Angle of Repose (^{o})		57	69
	Sliding Angle (^{o})	Metal surface	58	55
		Plastic surface	55	50
	Min. fluidization velocity (m/s)		0.96	0.68

3.6 Effect of Cooking Operation on Physical, Chemical and Solid Handling Properties

In the study, the most important changes of the wheat kernel were occurred in the cooking stage by gelatinization of starch. During the cooking operation, the most critical point is the selecting optimum cooking time to ensure complete gelatinization without any dispersing and deformating wholeness of the wheat. The complete starch gelatinization is required, which affects wheat bulgur quality (Kahyaoğlu et al., 2012). Additionally, cooking is a well-known way to destruct microorganisms, insect, insect eggs and larvaes for food safety therefore; bulgur is more stable than wheat during storage. Also, it increases the digestive property of food with starch gelatinization, protein gelation and textural softening (Bayram, 2007b).

Molina et al. (1975) mentioned to inverse relationship between cooking time and protein quality for soaked and unsoaked samples. After the soaking operation at 45 ^{o}C, Durum and bread wheat types were cooked under the atmospheric conditions as 45 and 35 minutes, respectively. The cooking degree was determined by using the center cutting method. If the center of the cut wheat was entirely transparent, the starch in wheat was accepted as gelatinized. The effect of the cooking operation on general quality and the solid handling properties of Durum and bread wheat types is given in Table 3.7. One-factor ANOVA results for the cooked Durum and bread wheat types showed that the effects of wheat type on the sphericity, particle size, packed bulk density, packed void fraction, L*, a*, b* and YI values, the moisture and ash contents of the cooked wheat samples were found to be significant ($p \leq 0.05$) while the protein content and loose voidage were insignificant ($p > 0.05$). The relationship between bulk density and particle density depends on porosity, which is the ratio of the void volume (voids between particles and voids within particles). The packed void fraction of cooked Durum and bread wheat types was 0.3526 and 0.3285, respectively. For cooked Durum and bread wheat, the loose voidage was measured as 0.4216 and 0.4132 g/mL, respectively. It was found that particle density of cooked Durum and bread wheat types were measured as 1204.66 and 1178.44 g/mL, respectively. Ravi and Venkatachalam (2015) reported that when the moisture content of paddy rice increases, the bulk density increases in contrast to the particle density of paddy. It was observed that whereas the particle density of paddy decreased from 1069.03 to 994.13 kg/m^3, the bulk density increased from 568.51 to

613.68 kg/m^3, with the moisture content increased from 11.86 to 23.61 % (d.b.). Furthermore, there is a direct proportional relationship between paddy volume, moisture content, mass and bulk density. It can be explained that the increase in the paddy volume is lower than the increase in the paddy mass. Theoretically, when the moisture content of wheat kernel increases, the packed and loose bulk densities decrease.

The sphericity and particle size cooked Durum and bread wheat types were measured as 0.0101 and 6.48 mm and 0.0056 and 5.45 mm, respectively.

Simons and Şentürk (1992) stated that repose angle is the angle of slope formed by particulate material under the critical equilibrium condition of incipient sliding. Angle of repose and sliding angle are affected by particle size, shape, smoothness, friction, moisture content and adhesiveness. The angle of repose and minimum fluidization velocity of cooked Durum and bread wheat types were 66^o and 1.09 m/s and 72^o and 1.21 m/s, respectively. The results obtained for the minimum fluidization velocity of wheat varieties in the study were similar to the results obtained by Gürsoy and Güzel (2010). Whereas sliding angle on metal plate surface of cooked Durum and bread wheat types were 57 and 58^o, they were observed as 48 and 49^o for plastic plate surfaces for durum and bread wheat types, respectively. These increases in the angle of repose, sliding angle and minimum fluidization velocity of cooked both wheat types were expected because of increasing moisture content and adhesiveness of cooked kernel due to starch gelatinization occurred in wheat by cooking.

Table 3.7 Chemical, physical and solid handling properties of cooked Durum and bread wheat types

	Wheat Type		Durum Wheat	Bread Wheat
Quality Parameters	Moisture content (%, w.b.)		49.61±0.51	50.83±0.53
	Ash content (%, d.b.)		1.47±0.94	1.85±0.14
	Protein content (%, d.b.)		14.98±0.14	12.59±1.07
	L*		48.35±0.47	45.59±0.50
	a*		7.67±0.16	7.64±0.09
	b*		30.15±0.68	26.58±0.21
	YI		83.97±1.58	80.57±0.80
Solid Handling Properties	Sphericity (ϕ)		0.0101±0.0015	0.0056±0.0020
	Particle Size (mm)		6.48±0.14	5.45±0.32
	Bulk Density (kg/m^3)	Packed	761.84±7.64	791.36±3.80
		Loose	680.62±1.67	691.52±3.11
	Particle Density (g/mL)		1204.66	1178.44
	Voidage	Packed	0.3526±0.0065	0.3285±0.0032
		Loose	0.4216±0.0014	0.4132±0.0026
	Angle of Repose (^{o})		66	72
	Sliding Angle (^{o})	Metal surface	57	58
		Plastic surface	48	49
	Min. fluidization velocity (m/s)		1.09	1.21

3.7 Effect of Drying Operation on Physical, Chemical and Solid Handling Properties

The cooked bulgur storage is very difficult without drying due to its high moisture content. Additionally, drying is a subsequent operation during bulguration after the cooking operation. Therefore, cooked wheat should be dried. In the study, the cooked wheat kernels of Durum and bread wheat types (45-50 % of moisture, w.b.) were dried to 12-13 % of moisture content. Drying is one of the most important processes in the bulgur production because it affects general quality parameters and solid handling properties as well as the storage properties of bulgur.

Furthermore, Bayram (2007b) declared that microorganisms cannot grow and foods will not spoil when foods are adequately dehydrated (dried). Therefore, its shelf-life increases.

Statistical analysis was performed to compare between dried Durum and bread wheat types on the general quality parameters. It was found that, both dried wheat types had significant ($p \leq 0.05$) effect on the sphericity, particle size, ash and protein contents (%, d.b.), L*, a*, b* and YI values, the packed and loose bulk densities and the void fractions (Table 3.8).

The ash and protein content was found as 1.60 and 14.63 % (d.b.) for dried Durum wheat and, 1.02 and 11.46 % (d.b.) for bread type, respectively. After drying, the L*, a*, b* and YI values of Durum and bread wheat types were observed as 48.44, 8.51, 28.63 and 82.58 and 46.64, 8.06, 23.70 and 74.92, respectively. Browning reactions can be responsible for decreasing in b* value (yellowness) of dried wheat samples. In general browning reactions largely depend on moisture content, drying temperature and time (Kahyaoğlu et al., 2012).

In literature, the moisture content is regarded as very effective parameter on the sphericity value of wheat (Al-Mahasneh and Rababah, 2007). The minimum fluidization velocity, sphericity, particle size and particle density were determined as 0.72 m/s, 0.0135, 5.95 mm and 1289.79 g/mL for Durum and, 0.43 m/s, 0.0068, 5.06 mm and 1140.56 g/mL for bread wheat types, respectively.

The bulk density depends on the state of compaction or compression of the bulk solid, i.e., the magnitude of the consolidation stress acting on the bulk solid. With increasing consolidation stress, porosity decreases and bulk density increases, since with the compaction of a bulk solids the volumes of the voids between the particles, but usually not the particle volumes, decrease (Schulze, 2008). Ünal and Saçılık (2011) measured bulk density as 418.22 and 485.78 kg/m^3 for dried einkorn and emmer bulgur samples, respectively. Kahyaoğlu (2009) found that bulk density, particle density and porosity for dried cooked wheat on spouted bed dryer as 691.56 kg/m^3, 1190.5 kg/m^3 and 0.42 for 50 ^{o}C, 689.83 kg/m^3, 1206.4 kg/m^3 and 0.42 for 70 ^{o}C and 667.36 kg/m^3, 1149.6 kg/m^3 and 0.42 for 90 ^{o}C, respectively.

The results showed that while packed bulk density was found higher than loose bulk density as expected, the packed void fraction was measured as lower than the loose voidage for all dried wheat types. Also, the voidage value of dried Durum and bread wheat types was found higher than cooked wheat types. However, the void fraction of paddy was observed by Ravi and Venkatachalam (2015), when the moisture content lowered from 23.61 to 11.86 % (d.b.), the void fraction of paddy was decreased from 46.82 to 38.27 %. The reason for this, as the paddy grains moisture increase, its volume increases, thus the number of grains in a fixed volume decreases. Additionally, the increase in swelling volume is bigger than the increase in weight of wheat kernel.

Cheng and Zhao (2017) revealed that in principle, angle of repose can be considered to be the maximum angle at which grains can stand without becoming unstable. After drying, the angle of repose and sliding angle on metal and plastic plate surfaces of Durum and bread wheat types were determined as 42, 31 and 23 and 44, 24 and 21^o, respectively. Both angles depend on; particle size, adhesiveness, moisture content, shape of particles, smoothness of particle surface, compactness and sphericity of particles etc.

Barbosa-C´anovas et al. (2006) stated that particle size distribution measurement is a common method in any physical, mechanical or chemical process which is used to determine the material behaviour and the physical properties of products. Especially, sieve diameter is dependent on the maximum width and maximum thickness of the particle. The percentage amounts of dried Durum and bread wheat particles were the highest at 3.55/2.80 and +/3.55 mm sieve apertures, respectively.

The particle shape can make a significant effect on the flow pattern and discharge capacity of products. In particular, the increase of deviation from spheres can decrease the mixed region adjacent to the side wall, and increase the stagnant zone at the bottom corner. After the drying operation, the flow mode was determined as mass flow for both dried wheat types. It is superior than the funnel flow due to all solid particulate in the hopper is in motion so more consistent flow is provides, effects of radial segregation is reduced, full bin capacity is utilized and first-in-first-out occurs. The predicted silo discharge rate (W), which was calculated by using Johanson equation, the flow rate (Q) for 6, 9, 12 and 15 mm orifice diameters, k and n values as discharge constants are disclosed in Table 3.9.

Table 3.8 Chemical, physical and solid handling properties of dried Durum and bread wheat types

	Wheat Type		Durum Wheat	Bread Wheat
Quality Parameters	Moisture content (%, w.b.)		12.54±0.81	12.80±0.38
	Ash content (%, d.b.)		1.60±0.75	1.02±0.13
	Protein content (%, d.b.)		14.63±0.78	11.46±0.64
	L*		48.44±0.30	46.64±0.39
	a*		8.51±0.68	8.06±0.34
	b*		28.63±0.34	23.70±0.47
	YI		82.58±0.26	74.92±0.89
Solid Handling Properties	Sphericity (ϕ)		0.0135±0.0005	0.0068±0.001
	Particle Size (mm)		5.95±0.25	5.06±0.31
	Bulk Density (kg/m^3)	Packed	745.80±7.91	690.72±2.15
		Loose	720.48±1.36	662.68±5.60
	Particle Density (g/mL)		1289.79	1140.56
	Voidage	Packed	0.4218±0.0061	0.3944±0.0018
		Loose	0.4414±0.0011	0.4190±0.0049
	Angle of Repose (^{o})		42	44
	Sliding Angle (^{o})	Metal surface	31	24
		Plastic surface	23	21
	Min. fluidization velocity (m/s)		0.72	0.43
Screen Analysis (%, wt/wt)	+/3.55 mm		27.3	66.1
	3.55/2.80 mm		69.9	31.8
	2.80/+ mm		2.8	2.2

Table 3.9 Flow properties of dried Durum and bread wheat types

		Orifice Diameters (mm)							
Wheat Type		Durum Wheat				Bread Wheat			
		6	9	12	15	6	9	12	15
Flow Properties	Flow type	Mass				Mass			
	W(kg/s)	0.001584	0.004365	0.008961	0.015654	0.001457	0.004015	0.008242	0.014398
	Q (g/s)	0.398±0.008	1.244±0.024	7.256±0.023	21.228±0.132	0.316±0.073	1.095±0.09	5.667±0.433	16.523±1.466
	k	0.000114				0.000096			
	n	4.429				4.407			
	R^2	0.973				0.982			

Q: certain silo discharge capacity, W: predicted silo discharge rate.

3.8 Effect of Tempering Operation on Physical, Chemical and Solid Handling Properties

Temperig is made to improve the efficiency of debranning and milling of wheat during the bulgur production. Durum and bread wheat types were tempered to determine the effect of tempering time (short and long) and moisture level on the general quality characteristics and the solid handling properties. In the bulgur production overall the World, two methods are used as Antep and Karaman/Mut types (Yousif et al., 2018). According to both methods, tempering time and subsequent debranning and milling operations are different.

According to Figure 1.2, Antep type bulgur was produced by using Durum and bread wheat types. The moisture content and resting time was adjusted as 16-17 % (w.b.) and 25-30 minutes, respectively. In contrast to Antep type bulgur production technique, the moisture content was increased to about 22-24 % (w.b.) after a long tempering (8 hours) for Karaman/Mut type bulgur production technique. As a note, the quantity of added water was calculated according to total dried wheat weight to obtain desired moisture content. The differences between Antep and Karaman/Mut tempering types of Durum and bread wheat are illustrated in Table 3.10. According to Duncan's multiple range tests, all tempered wheat samples were found significantly different ($p \leq 0.05$) on all responses (except for protein content) of tempered wheat samples.

Woodcock and Mason (2012) revealed that many bulk solids flow rate can be highly impressed by moisture content. The surface tension can be affected due to the presence of the water on the outer shell of bulk particles. Thus, the movement of the particles becomes harder due to increasing of cohesion forces between each others and thus decrases in their flowability. While the moisture contents of Antep types tempered of Durum and bread wheat were 16.68 and 16.94 % (w.b.), it was found that for Karaman/Mut type tempered wheat samples as 21.79 and 21.81 % (w.b.), respectively. The ash and protein contents were determined as 1.89 and 14.45 % (d.b.); 1.65 and 13.34 % (d.b.); 1.44 and 12.07 % (d.b.); 1.21 and 11.11 % (d.b.) for Durum Antep, Durum Karaman/Mut, bread Antep and bread Karaman/Mut tempered wheat types, respectively.

The changes in L*, a*, b* and YI values based on long or short tempering of cooked dried wheat were also determined. The color values of Durum and bread wheat from tempered Antep and Karaman/Mut methods were 51.40, 49.29 and 50.24 and 49.76 for L*, 7.82, 8.11 and 7.44 and 7.52 for a*, 26.17, 26.83 and 24.65 and 24.10 for b* and 74.73, 78.21 and 72.54 and 71.98 for YI, respectively. Balcı and Bayram (2015) investigated the effects of the tempering methods on color. They found that tempering methods significantly increased the lightness (CIE L*) and yellowness (CIE b*) values of the bulgur samples.

According to the results obtained, the particle density of tempered wheat samples was lower than cleaned, cooked, soaked and dried wheat samples with increasing the moisture content, particle size and volume of wheat samples. Similar results obtained by Bayram (2011) whom compared unsplit inshell pistachio (UIPN) and shelled kernel pistachio nut (SKPN). The particle density, sphericity and volume were measured as 0.000851 g/mm^3, 0.00882 and 1278.31 mm^3 for UIPN and 0.000940 g/mm^3, 0.00825 and 457.09 mm^3 for SKPN, respectively. It was explained that this difference of particle density was due to the gap between the kernel and shell, and this space caused the increase in the volume.

Angle of repose were found high as 62, 59, 57 and 54^o in order of bread Karaman/Mut, bread Antep, Durum Karaman/Mut and Durum Antep tempered wheat samples. Where the angle of repose for all tempered wheat types gradually decrease as the mean size increases, indicating that all samples change from cohesive to more free flowing with increasing mean size (Geldart et al., 2006). It was determined that sliding angle on metal and plastic plate surfaces were measured as 43 and 37^o, 43 and 40^o, 50 and 45^o and 44 and 39^o for tempered Antep and Karaman/Mut types from produced Durum and bread wheat types, respectively.

Dick and Matsuo (1988) reported that the higher bulk density is due to the greater the percentage endosperm. Bulk density is a measure of kernel soundness, and fully mature, plump kernels undamaged by disease or by the environment are high in bulk density. The packed and loose bulk densities and the voidages of Durum Antep and Karaman/Mut samples, and bread Antep and Karaman/Mut samples were determined as 669.78 and 612.60 kg/m^3, 0.4709 and 0.5160, 686.30 and 658.64 kg/m^3, 0.4505 and 0.4726, 548.40 and 510.48 kg/m^3 and 0.4939 and 0.5289 and 646.18 and 594.96

kg/m^3, 0.4295 and 0.4747, respectively. These, as expected. Similar to the results of cooked wheats. The moisture content affected the bulk density (decreasing) due to much increase in swelling volume of particles.

Particle size significantly increased ($p \leq 0.05$) for all tempered wheat kernels and the changes in the size of kernel with increase in the moisture content may be due to hygroscopic nature.

Screen analysis gives reliable and reproducible size analysis. It was found that the size distributions during the screen analysis were found as 39.7 and 77.3 % (wt/wt) for +/3.55 mm, 57.8 and 21.0 % (wt/wt) for 3.55/2.80 mm, and 2.1 and 1.8 % (wt/wt) for 2.80/+ mm sieves about Antep type tempered Durum and bread products, respectively. It was found for Karaman/Mut type tempered products such as 51.6 and 78.5 % (wt/wt) for +/3.55 mm, 47.3 and 19.9 % (wt/wt) for 3.55/2.80 mm, and 0.7 and 1.6 % (wt/wt) for 2.80/+ mm sieves, respectively.

Bhise et al. (2014) studied on the changes of the physical properties of wheat grain depend on the moisture content. It was monitered that bulk density, angle of repose, particle density and porosity of wheat grain was found to vary from 695.75-646.45 kg/m^3, 23.09-25.28^o, 1236.91-1304.80 kg/m^3 and 44.35-48.09 % respectively, when the moisture level increases from about 10 to 18 % (d.b).

Flow properties of all tempered wheat types are presented in Table 3.11. Particle shape has a significant effect on the discharge rate. Spheres of unity aspect ratio have the highest flow rate, the lower or higher aspect ratio and the smaller the flow rate (Liu et al., 2014a). In the study, the values of sphericity increased with the tempering operation and were found that the highest for Karaman/Mut tempering from produced Durum wheat. The predicted (W) and experimental (Q) capacities of discharge of Antep and Karaman/Mut type tempered Durum and bread wheats were calculated by using Johanson equation due to approving flow pattern as mass flow for all tempered (except for Durum Karaman/Mut) wheat samples. Experimentally, flow obstruction was observed for Durum Karaman/Mut wheat samples (it has big particle size and high moisture content) due to arching occur. Schulze (2008) stated that arching problem can occur in mass flow, which a stable arch forms above the silo outlet so that discharge is stopped. Coarse grained bulk solids can build up arches due to interlocking and wedging of particles. This kind of arching can be avoided if the diameter of the circular outlet of a conical hopper is at least 6 to 10 times the maximum particle size.

Table 3.10 Chemical, physical and solid handling properties of tempered Durum and bread wheat types

			Wheat Type			
			Durum Wheat		Bread Wheat	
			Bulgur Production Technique			
			Antep	Karaman / Mut	Antep	Karaman / Mut
Quality Parameters	Moisture content (%, w.b.)		16.68±0.19[a]	21.79±0.23[b]	16.94±0.34[a]	21.81±0.04[b]
	Ash content (%, d.b.)		1.89±0.46[b]	1.65±0.096[ab]	1.44±0.06[ab]	1.21±0.13[a]
	Protein content(%, d.b.)		14.45±1.20[b]	13.34±1.36[ab]	12.07±0.18[ab]	11.11±0.14[a]
	L*		51.40±0.36[c]	49.29±0.34[a]	50.24±0.40[b]	49.76±0.22[ab]
	a*		7.82±0.08[b]	8.11±0.06[c]	7.44±0.53[a]	7.52±0.54[a]
	b*		26.17±0.14[c]	26.83±0.29[d]	24.65±0.20[b]	24.10±0.13[a]
	YI		74.73±0.24[b]	78.21±0.53[c]	72.54±0.33[a]	71.98±0.50[a]
Solid Handling Properties	Sphericity (ϕ)		0.0136±0.0020[c]	0.0150±0.0012[c]	0.0050±0.0002[a]	0.0084±0.0017[b]
	Particle Size (mm)		6.09±0.10[c]	6.05±0.30[c]	5.24±0.05[b]	4.73±0.17[a]
	Bulk Density (kg/m^3)	Packed	669.78±7.67[c]	686.30±1.50[c]	548.40±8.49[a]	646.18±10.71[b]
		Loose	612.60±1.24[c]	658.64±1.16[d]	510.48±3.28[a]	594.96±8.66[b]
	Particle Density (g/mL)		1265.79	1249.00	1083.67	1132.59
	Voidage	Packed	0.4709±0.0060[c]	0.4505±0.0012[b]	0.4939±0.0078[d]	0.4295±0.0095[a]
		Loose	0.5160±0.0001[b]	0.4726±0.0013[a]	0.5289±0.0030[c]	0.4747±0.0076[a]
	Angle of Repose (^{o})		54	57	59	62
	Sliding Angle (^{o})	Metal surface	43	43	50	44
		Plastic surface	37	40	45	39
	Minimum fluidization velocity (m/s)		0.70	0.74	0.46	0.61
Screen Analysis (%, wt/wt)	+3.55 mm		39.7	51.6	77.3	78.5
	3.55/2.80 mm		57.8	47.3	21	19.9
	2.80/+ mm		2.1	0.7	1.8	1.6

The letters show significant difference at ($p \leq 0.05$) between samples each parameter.

Table 3.11 Flow rate properties of tempered Durum and bread wheat types

Wheat Type	Bulgur Production Technique	Equation (Flow Type)		Orifice Diameters (mm) 6	9	12	15
Durum Wheat	Karaman /Mut	No Flow	W (kg/s)	No Flow			
			Q (g/s)				
			k				
			n				
			R^2				
	Antep	Mass	W (kg/s)	0.001347	0.003712	0.007619	0.013310
			Q (g/s)	0.292±0.020	0.824±0.063	4.1±0.006	13.825±0.320
			k	0.000113			
			n	4.242			
			R^2	0.966			
Bread Wheat	Karaman /Mut	Mass	W (kg/s)	0.001310	0.003600	0.007400	0.012930
			Q (g/s)	0.260±0.009	1.196±0.08	3.584±0.144	10.496±2.598
			k	0.000210			
			n	3.964			
			R^2	0.998			
	Antep	Mass	W (kg/s)	0.001122	0.003093	0.006349	0.011092
			Q (g/s)	0.202±0.028	1.043±0.094	4.152±0.192	10.524±0.881
			k	0.000078			
			n	4.358			
			R^2	0.999			

Q: certain silo discharge rate, W: predicted silo discharge rate.

3.9 Effect of Debranning Operation on Physical, Chemical and Solid Handling Properties

Debranning or wheat kernel peeling is increasingly recognised by the milling industry as an important stage in the bulgur processing. Debranning is the process, prior to milling that with the application of abrasion and friction that removes effectively only the bran layer from the wheat grain, allowing nutritious parts, such as the aleurone layer to remain in the intact kernels. This pre-treatment potentially could also improve the milling yields of superior bulgur quality (Mousia et al., 2004). During Antep type bulgur production, wheat is debranned by using a vertical emery dehuller, however, in Karaman/Mut type bulgur making dehulling stage are performed simultaneously by using a stone mill. The effect of debranning before milling was investigated and the physical, chemical and solid handling properties of debranned Durum and bread wheat types are shown in Table 3.12.

After the removing bran layer of wheat kernel, the moisture content was determined as 14.78 and 15.75 % for Antep type debranned Durum and bread wheat samples, respectively.

The protein contents of debranned Durum and bread wheat types were 13.80 and 12.07 % (d.b.) respectively. The reduction of Durum wheat protein content is attributed to both slight leaching (during soaking and cooking stages) and dehulling operation losses. The similar result was observed for some Nigerian wheat bulgurs by Njoku et al. (2007).

The ash content significantly ($p \leq 0.05$) reduced from 1.89-1.44 % to 1.51-1.03 % in the debranned Durum and bread wheats due to removal of outer bran layer.

The sphericity, packed and loose bulk densities were significantly ($p \leq 0.05$) different for Antep type debranned Durum and bread wheat samples. As explained previously, bulk density depends on particle size, moisture content, particle shape, particle surface smoothness, compactness and sphericity of particles. On the other hand, the loose and packed porosities (voidage) were not significant ($p > 0.05$) for debranned wheat types. According to the experimental results, the packed and loose voidages of debranned bread wheat were higher than the debranned Durum wheat. It can be explained that the voidage increases with decreasing particle size of bread wheat kernel (4.74 mm).

The sliding angle was measured for debranned Durum and bread wheat types with metal and plastic plate surfaces as 41 and 36^o, and 38 and 34^o, respectively. Moreover, the sliding angle of the metal plate was found to be greater than the plastic plate. It may be explained due to the friction coefficient of metal surface, which is higher than plastic. Therefore flow or sliding on metal plate is considered as more difficult than plastic. Additionally, the angle of repose was obtained as 52 and 57^o for Durum and bread wheats, respectively.

Flow regime was observed as mass flow for both debranned wheat types and W value was calculated according to Johanson method (Table 3.13). Liu et al. (2014b) noted that silo discharge predictability decreases with shape increasing deviation from spheres. The sphericity value showed that tempered bread wheat more spherical than Durum wheat type. For debranned Durum sample, W and Q values were determined as 0.001274 kg/s and 0.252 g/s for 6 mm, 0.003511 kg/s and 0.871 g/s for 9 mm, 0.007207 kg/s and 3.513 g/s for 12 mm and 0.012590 kg/s and 6.539 g/s for 15 mm orifice diameters, respectively. However, for debranned bread wheat type W and Q values were 0.001169 kg/s and 0.383 g/s for 6 mm, 0.003221 kg/s and 0.876 g/s for 9 mm, 0.006612 kg/s and 2.896 g/s for 12 mm and 0.01155 kg/s and 7.012 g/s for 15 mm orifice diameters, respectively. Also k and n values of debranned Durum and bread wheat samples were found as 0.000309 and 3.694, and 0.001073 and 3.186, respectively.

Table 3.12 Chemical, physical and solid handling properties of debranned Durum and bread wheat types

	Wheat Type		Antep Durum	Antep Bread
Quality Parameters	Moisture content (%, w.b.)		14.78±0.13	15.75±0.13
	Ash content (%, d.b.)		1.51±0.60	1.03±0.10
	Protein content (%, d.b.)		13.80±0.37	12.07±0.12
	L*		56.5±0.11	54.68±0.90
	a*		6.71±0.08	6.47±0.21
	b*		27.10±0.18	24.09±0.42
	YI		70.65±0.47	66.45±1.25
Solid Handling Properties	Sphericity (ϕ)		0.0131±0.0008	0.0066±0.0010
	Particle Size		5.58±0.62	4.74±0.19
	Bulk Density (kg/m^3)	Packed	656.2±6.17	583.24±11.26
		Loose	579.46±4.50	531.58±5.97
	Particle Density (g/mL)		1348.58	1276.91
	Voidage	Packed	0.5134±0.0045	0.5432±0.0088
		Loose	0.5703±0.0033	0.5837±0.0047
	Angle of Repose (^{o})		52	57
	Sliding Angle (^{o})	Metal surface	41	38
		Plastic surface	36	34
	Min. fluidization velocity (m/s)		0.70	0.46
Screen Analysis (%, wt/wt)	+/3.55 mm		20.6	34.2
	3.55/2.80 mm		58.8	43.6
	2.80/+ mm		20.3	22.3

Table 3.13 Effect of debranning operation on flow properties of Durum and bread wheat

		Orifice Diameters (mm)							
	Wheat Type	Antep Durum				Antep Bread			
		6	9	12	15	6	9	12	15
Flow Properties	Flow type	Mass				Mass			
	W (kg/s)	0.001274	0.003511	0.007207	0.012590	0.001169	0.003221	0.006612	0.01155
	Q (g/s)	0.252±0.058	0.871±0.012	3.513±0.122	6.539±0.049	0.383±0.011	0.876±0.017	2.896±0.217	7.012±1.039
	k	0.000309				0.001073			
	n	3.694				3.186			
	R^2	0.991				0.972			

Q: certain silo discharge rate, W: predicted silo discharge rate.

Table 3.14 Chemical, physical and solid handling properties of Durum and bread wheat bran (after debranning)

	Bran Type		Antep Durum	Antep Bread
Quality Parameters	Moisture content (%, w.b.)		19.81±0.18	20.92±0.23
	Ash content (%, d.b.)		3.06±0.20	2.07±0.03
	Protein content(%, d.b.)		19.58±0.56	15.49±0.17
	L*		67.15±0.15	62.94±0.81
	a*		4.78±0.11	5.98±0.21
	b*		25.78±0.34	25.58±0.34
	YI		58.97±0.61	62.66±1.31
	Bulk Density (kg/m^3)	Packed	479.80±14.42	371.16±0.11
		Loose	312.20±4.80	246.78±0.37
	Angle of Repose (^{o})		62	68
	Sliding Angle (^{o})	Metal surface	50	51
		Plastic surface	44	43

The outer layer of wheat kernel called as bran, which is generally used as an animal feed. This nutritionally valued product was separated easily by the debranning operation. Its some solid handling properties were shown in Table 3.14.

Bran is more hygroscopic than endosperm because of its higher cellulose content (Hoseney, 1994) and it forms a barrier against ingress of water before the endosperm. The moisture, ash and protein contents were determined as 19.81, 3.06 and 19.58 % and 20.92, 2.07 and 15.49 % for Durum and bread bran, respectively.

According to the statistical results, both bran types were significantly ($p \leq 0.05$) different based on the solid handling parameters except the yellowness (b*) value. The angle of repose and sliding angle with metal and plastic plates were 62, 50 and 44^o for Durum bran; 68, 51 and 43^o for bread bran, respectively.

The packed and loose bulk densities were also found as 479.80 and 312.20 kg/m^3 for Durum bran, 371.16 and 246.78 kg/m^3 for bread bran, respectively.

The discharge rate (Q) with 6, 9, 12 and 15 mm orifice diameters were smaller than the predicted discharge rate (W) (Table 3.15). Also, k and n values of the Durum and bread wheat brans were found as 0.000290 and 3.255, and 0.000025 and 4.337 respectively.

Table 3.15 Flow rate properties of Durum and bread brans (after debranning)

Wheat type	Flow Type		Orifice Diameter (mm) 6	9	12	15
Antep Durum	Mass	W (kg/s)	0.000686	0.001892	0.003883	0.006783
		Q (g/s)	0±0 (no flow)	0.361±0.181	1.009±0.505	1.908±0.954
		k	0.000290			
		n	3.255			
		R^2	0.998			
Antep Bread	Mass	W (kg/s)	0.000543	0.001495	0.003069	0.005362
		Q (g/s)	0.055±0.015	0.364±0.061	1.604±0.044	2.437±0.486
		k	0.000025			
		n	4.337			
		R^2	0.980			

Q: certain silo discharge capacity, W: predicted silo discharge rate.

3.10 Effect of Milling Operation on Physical, Chemical and Solid Handling Properties

According to Bayram and Öner (2007) the milling operation of bulgur is different from the milling of the uncooked wheat products, such as flour and semolina due to the processing properties of bulgur (its cooked and dried whole-kernel form and final granular particle sizes (3.5-0.5 mm)). The significant properties of bulgur such as colour, shape, size etc. is also affected milling techniques (stone, disc, roller etc.) In bulgur production, it is important to obtain ant-head-like (oval) and uniform shape.

Durum and bread wheat samples milled by using stone and disc mills for Karaman/Mut and Antep type bulgur production, respectively. Stone mill has a smooth surface and a regular shape due to the abrasive effect of the stone mill. During stone milling, the bran layer is skinned by the stone circling with a high speed through friction, and the grains are ground through shearing (Ünal and Saçılık, 2011). In the disc mill, the feedstock passes into a narrow gap between a high speed, rotating grooved disc and the stationary casing of the mill. Intense shearing action results in the comminution of the feed. The gap is adjustable, depending on feed size and product requirements (Bayram and Öner, 2007).

According to the statistical analysis, even though wheat types affected significantly ($p \leq 0.05$) the L*, a*and YI values, moisture and protein contents, sphericity, packed and loose bulk densities and voidages, it was not significantly ($p > 0.05$) effective on the ash content, b* value and the particle size distribution of milled bulgur types (Table 3.16). In general, low redness, high lightness and high yellowness colour is required for bulgur by consumers. The results illustrate that the disc mill causes an increase in the L-values.

The quality of bulgur is mainly affected by the moisture content which is consider one of the most effective criteria on the production process. Thus, it is controlled at each step along processing line. The moisture contents of Antep type bulgurs obtained from Durum and bread wheats were 15.35 and 15.82 % (w.b.), respectively. The ash content was found as 1.71 and 1.26 % for Antep type Durum and bread bulgur samples. As a note, bulgur is partially debranned product, therefore the ash content of bulgur is higher than the other cereal products. But, this ash content or bran is wanted due to its inactivated phytic acid (it is antinutrient) property. Additionally, bulgur bran is good for its valuable folic acid content.

It was found that particle density of Durum and bread bulgur produced by using of Antep type method were 1376.69 and 1345.94 g/mL, respectively. Xylole (C_8H_{10}) was used instead of water for determining particle density because it is absorbed by kernels to a lesser extent. There was no difference between angle of repose (53^o) for Antep type Durum and bread types bulgur. The sliding angles on metal and plastic plate surfaces were measured as 37 and 36^o for Durum bulgur; 34 and 31^o were found for bread bulgur. Wen (1966) have pointed out that minimum fluidization velocity increases as sphericity decreases, and minimum fluidization velocity is nearly independent of the particle diameter of kernel. The minimum fluidization velocity of Antep type durum and bread bulgur were found as 0.76 and 0.50 m/s, respectively. Theoretically, the minimum fluidization velocity values were found by Çarman (1996) to be in the range of 7.23 to 7.24 m/s for barley varieties and 10.40 to 10.47 m/s for lentil varieties.

Moisture content, smoothness and compaction effect the bulk density. While packed bulk densities of Antep type Durum and bread bulgur were 663.36 and 602.42 kg/m^3, the loose bulk densities were found as 573.02 and 519.60 kg/m^3, respectively. Compaction is the packing together of the particles of material by the expulsion of airstrikes which, influences the bulk density of the material. According to the results, the void fraction of Antep type durum and bread bulgur samples were determined in order of 0.5181 and 0.5524 for the packed voidage and 0.5838 and 0.6140 for the loose voidage.

Sieving is a simple technique for the separating particles of different sizes. After the size reduction, the highest percent masses of both bulgur types (with bulgur flour) were found with 2.80/+ mm. The particle sizes of Durum and bread bulgurs produced by using Antep technique were found as 2.36 and 2.98 mm, respectively.

The flow properties of milled bulgurs (unscreened) are shown in Table 3.17 and flow regime was determined as mass flow. The actual (Q) and predicted (W) silo discharge capacities of milled Antep Durum bulgur were 0.338 g/s and 0.001260 kg/s, 1.168 g/s and 0.003472 kg/s, 4.840 g/s and 0.007127 kg/s, and 10.888 g/s and 0.012450 kg/s for 6, 9, 12 and 15 mm orifice diameters, respectively.

On the other hand, Q and W values of Antep bread bulgur were 0.295 g/s and 0.001142 kg/s for 6 mm orifice, 0.865 g/s and 0.003148 kg/s for 9 mm orifice, 3.807 g/s and 0.006463 kg/s for 12 mm orifice and 9.617 g/s and 0.011290 kg/s for 15 mm orifice, respectively. It was found that the silo discharge rate constants k and n values were 0.000291 and 3.876 for milled Durum bulgur and 0.000243 and 3.868 for milled bread bulgur by using sketching log (linear) graph, respectively.

Table 3.16 Chemical, physical and solid handling properties of milled Antep type Durum and bread bulgur (unscreened)

	Wheat Type		Antep Durum	Antep Bread
Quality Parameters	Moisture content (%,w.b.)		15.35±0.01	15.82±0.06
	Ash content (%, d.b.)		1.71±0.10	1.26±0.44
	Protein content (%, d.b.)		13.52±0.51	11.66±0.02
	L*		68.36±1.18	58.98±0.46
	a*		4.23±0.48	6.02±0.13
	b*		23.27±0.16	23.58±0.62
	YI		53.55±3.10	61.85±1.49
Solid Handling Properties	Sphericity (ϕ)		0.0704±0.008	0.0115±0.033
	Particle Size (mm)		2.36±0.48	2.98±0.82
	Bulk Density (kg/m^3)	Packed	663.36±0.74	602.42±3.37
		Loose	573.02±4.72	519.60±3.73
	Particle Density (g/mL)		1376.69	1345.94
	Voidage	Packed	0.5181±0.0005	0.5524±0.0025
		Loose	0.5838±0.0034	0.6140±0.0028
	Angle of Repose (^{o})		53	53
	Sliding Angle (^{o})	Metal surface	37	34
		Plastic surface	36	31
	Min. fluidization velocity (m/s)		0.76	0.50
Screen Analysis (%, wt/wt)	+/3.55 mm		1.0	3.3
	3.55/2.80 mm		13.5	22.5
	2.80/+ mm		85.1	74.1

Table 3.17 Flow properties of Durum and bread bulgur types produced from Antep type (unscreened)

Wheat Type		Orifice Diameter (mm)							
		Antep Durum				Antep Bread			
		6	9	12	15	6	9	12	15
Flow Properties	Flow type	Mass				Mass			
	W (kg/s)	0.001260	0.003472	0.007127	0.012450	0.001142	0.003148	0.006463	0.011290
	Q (g/s)	0.338±0.043	1.168±0.045	4.84±0.125	10.888±0.071	0.295±0.000	0.865±0.064	3.807±0.171	9.617±0.363
	k	0.000291				0.000243			
	n	3.876				3.868			
	R^2	0.991				0.979			

Q: certain silo discharge capacity, W: predicted silo discharge rate.

The main principle is the generate of new surfaces by dividing of intact kernel into two or more particles during size reduction for the bulgur production. According to Yıldırım et al. (2008a) stated that the milling stage is a complicated operation due to as well as the size reduction, efficient removal of the bran and germ from the starchy endosperm of the wheat kernel has to be achieved. The cells of the aleurone layer comprise ~7-8 % of the wheat kernel weigh and contain within their walls the major part of the grain micronutrients and phytochemicals. The breakage patterns for each grain depend on the interaction between the physical, chemical and structural characteristics (kernel size distribution, hardness, ash content, protein content) and set of (gap, velocities, the type and condition of surface).

The properties of bulgur samples after the milling operation are given in Table 3.18. The milling process causes increase in the temperature of products, therefore the loss of moisture was observed in all bulgur samples. The moisture content were 13.24, 13.72, 14.23 and 15.11 % (w.b.) for MDA (Antep Durum), MDK (Karaman/Mut Durum), MBA (Antep bread) and MBK (Karaman/Mut bread) bulgur, respectively. The ash content and particle size of the samples were found insignificantly ($p>0.05$) different.

The darkening the processed product is a common problem with the processing of bulgur. Generally, a light yellow color is acceptable for wheat bulgur. Therefore, L* and b* values are preferred in general by consumers in contrast to low values of a*. In this study, the color values of MDA, MDK, MBA and MBK bulgur samples were 62.54, 57.38, 57.81 and 56.66 for L*,5.97, 6.47, 5.98 and 6.38 for a*, 29.45, 26.56, 22.77 and 23.25 for b* and 69.17, 68.74, 61.15 and 63.35 for YI, respectively. Ünal and Saçılık (2011) stated that these color changes can be explained the heat arise as a results of friction caused due to the fact that pigments (carotene, riboflavin, chlorophyll) in wheat undergoes a change by ascending heat.

The packed bulk density order was MDA, MDK, MBK and MBA for bulgur samples. The loose bulk density of Karaman/Mut Durum type bulgur was found highest (622.58 kg/m^3) due to high amount of coarse particles caused a low voidage and surface area. This result is similar to Ünal and Saçılık (2008). As expected, the protein contents of Karaman/Mut bulgur samples were found higher than Antep type bulgur samples.

Woodcock and Mason (2012) noted that particle size and density and also particle size distribution can have a significant influence on the behaviour of a bed of fluidized material. In general, the minimum fluidizing velocity decreases with decreasing particle size and density. According to the experimental results, it was observed that the minimum fluidization decreased as the particle size decreased and the highest minimum fluidization velocity value was obtained for Karaman/Mut type bread bulgur (0.68 m/s).

The motion of individual particles depends strongly on the nature of the surface over which they flow; highly roughened surfaces cause shear within the flowing stream, while smooth ones cause slip at the surface (Augenstein and Hogg, 1978). It was monitered that sliding angle of screened milled bulgurs on metal and plastic plate surfaces decreased with separating bulgur flour due to very small particles increases sliding angle.

The sphericity was calculated according to procedure described by Bayram (2005a) and ranged from 0.0646, 0.0269, 0.0065 and 0.0080 for Antep type durum, Karaman/Mut type durum, Antep type bread and Karaman/Mut type bread bulgur samples, respectively. This similar sphericity values of some coffee types were ranged according to MBayram-1 equation from 0.006536 to 0.009452 by Severa (2010).

The sieve analysis of milled bulgur samples showed that, within each bulgur types, the percent masses of bulgur samples having particle size smaller than 2.80 mm which were the highest. The percentages were found as 79.9, 67.7, 54.6 and 35.6 % (wt/wt) for Durum Antep, bread Antep, durum Karaman/Mut and bread Karaman/Mut bulgur types, respectively.

Experimentally, the silo discharge rates (Q) of Antep type Durum bulgur were found highest as 0.375, 0.974, 4.674 and 11.007 g/s with 6, 9, 12 and 15 mm orifice diamaters, respectively (Table 3.19). Moreover, flow regime was observed as mass flow and to find prediction amount of discharge product was calculated according to Johanson equation. Liu et al. (2014a) declared that the particle surface properties, orifice size, particle size, particle shape and the initial packing structures affect the discharge capacity of solids. Additionally, the head of material over the orifice has no detectable effect on the rate of discharge. The prediction discharge capacity values were found to be close with certain discharge values. Also, k and n value were determined as 0.000346 and 3.791 for MDA, 0.000291 and 3.832 for MDK, 0.00013 and 4.072 for MBA and 0.000375 and 3.674 for MBK bulgur samples, respectively.

Table 3.18 Chemical, physical and solid handling properties of milled Durum and bread bulgur types (after milling over screen, +/0.50 mm)

			Wheat Type			
			Durum Wheat		Bread Wheat	
			Bulgur Production Technique			
			Antep	Karaman/Mut	Antep	Karaman/Mut
Quality Parameters	Moisture content (%, w.b.)		13.24±0.19[a]	13.72±0.18[b]	14.23±0.09[c]	15.11±0.20[d]
	Ash content (%, d.b.)		1.36±0.42[a]	1.45±0.20[a]	1.40±0.04[a]	1.18±0.11[a]
	Protein content (%, d.b.)		13.79±0.88[b]	13.85±0.20[b]	11.43±0.51[a]	11.66±0.39[a]
	L*		62.54±0.34[c]	57.38±0.50[ab]	57.81±0.32[b]	56.66±0.97[a]
	a*		5.97±0.11[a]	6.47±0.72[b]	5.98±0.09[a]	6.38±0.18[b]
	b*		29.45±0.20[d]	26.56±0.09[c]	22.77±0.15[a]	23.25±0.15[b]
	YI		69.17±0.16[c]	68.74±0.44[c]	61.15±0.32[a]	63.35±0.83[b]
Solid Handling Properties	Sphericity (ϕ)		0.0646±0.0422[b]	0.0269±0.0130[a]	0.0065±0.0036[a]	0.0080±0.0024[a]
	Particle Size (mm)		2.17±0.54[a]	2.83±0.67[a]	2.95±1.22[a]	3.38±1.68[a]
	Bulk Density (kg/m^3)	Packed	683.90±9.42[b]	675.94±9.08[b]	600.68±0.34[a]	619.00±11.88[a]
		Loose	589.94±10.83[b]	622.58±1.22[c]	512.68±5.43[a]	520.48±14.82[a]
	Particle Density (g/mL)		1378.44	1343.49	1341.85	1273.73
	Voidage	Packed	0.5039±0.0068[a]	0.4969±0.0068[a]	0.5523±0.0002[b]	0.5140±0.0093[a]
		Loose	0.5720±0.0079[b]	0.5366±0.0009[a]	0.6179±0.0040[c]	0.5914±0.0116[b]
	Angle of Repose (^{o})		51	56	56	56
	Sliding Angle (^{o})	Metal surface	33	32	32	40
		Plastic surface	30	27	28	34
	Minimum fluidization velocity (m/s)		0.52	0.61	0.63	0.68
Screen Analysis (%, wt/wt)	+/3.55 mm		0.7	2.9	4.9	23.1
	3.55/2.80 mm		19.6	42.4	27.2	41
	2.80/+ mm		79.9	54.6	67.7	35.6

The letters show significant difference at ($p \leq 0.05$) between samples each parameter.

Table 3.19 Flow rate properties of milled Durum and bread wheat types (after milling over screen, +/0.50 mm)

Wheat Type	Bulgur Production Technique	Flow Type		Orifice Diameter (mm)			
				6	9	12	15
Durum Wheat	Karaman /Mut	Mass	W (kg/s)	0.001370	0.003770	0.007740	0.013530
			Q (g/s)	0.369±0.019	0.816±0.014	3.859±0.003	11.891±0.213
			k	0.000291			
			n	3.832			
			R	0.949			
	Antep	Mass	W (kg/s)	0.001297	0.003574	0.007337	0.012818
			Q (g/s)	0.375±0.019	0.974±0.023	4.674±0.08	11.007±0.052
			k	0.000346			
			n	3.791			
			R^2	0.970			
Bread Wheat	Karaman /Mut	Mass	W (kg/s)	0.001140	0.003150	0.006470	0.011310
			Q (g/s)	0.305±0.035	1.023±0.09	3.26±0.38	8.918±0.518
			k	0.000375			
			n	3.674			
			R^2	0.991			
	Antep	Mass	W (kg/s)	0.001127	0.003106	0.006377	0.011139
			Q (g/s)	0.218±0.077	0.880±0.05	3.339±0.08	8.301±1.203
			k	0.000130			
			n	4.072			
			R^2	0.997			

The letters show significant difference at (p≤0.05) between samples each parameter.

Bulgur flour was obtained from ground products by sieving with 0.5 mm screen (under screen), which is called by-product.

The differences between bulgur flour types are shown in Table 3.20. The moisture contents were 13.48, 11.40, 14.63 and 12.05 % (w.b.) for Durum antep, Durum Karaman/Mut, bread Antep and bread Karaman/Mut bulgur flours, respectively. The ash content was highest for Durum Karaman/Mut type bulgur flour (8.72 %, d.b.). Bran was not separated efficiently by using stone mill in Karaman/Mut type bulgur making method. Therefore, the ash content values were high.

The order of protein content from the highest to the lowest was Antep Durum, Karaman/Mut Durum, Antep bread and Karaman/Mut bread bulgur flour types, respectively.

The L*, a*, b* and YI values bulgur flours were 73.44, 3.40, 22.54 and 48.87 for Durum Antep, 67.56, 3.84, 21.89 and 51.08 for Durum Karaman/Mut, 71.70, 3.86, 20.27 and 46.29 for Antep bread, and 69.24, 3.82, 20.15 and 47.19 for Karaman/Mut bread bulgur flour, respectively. The angle of repose, sliding angle with metal and plastic plate surfaces were measured as 64, 50 and 45^o for Antep Durum, 61, 41 and 38^o for Karaman/Mut Durum, 65, 46 and 43^o for Antep bread and 69, 45 and 43^o for Karaman/Mut bread bulgur flours, respectively.

Yüksel et al. (2017b) focused on the couscous production using bulgur flour. It was observed that the bulk densities of bulgur flour and semolina were 590 and 790 kg/m^3, respectively and this difference was due to difference in their particle sizes. In the present study, the bulk density was measured as packed and loose, which were 501.60 and 375.60 kg/m^3, 460.60 and 340.4 kg/m^3, 483.01 and 479.16 kg/m^3, and 495.60 and 337.60 kg/m^3 for Antep Durum, Karaman/Mut Durum, Antep bread and Karaman/Mut bread bulgur flour types, respectively.

The predicted and actual discharge rates for Antep type bread bulgur flour were found as the highest. The W, Q, k and n values are presented in Table 3.21.

Table 3.20 Chemical, physical and solid handling properties of Durum and bread bulgur flour types (after milling, under screen, 0.50/+ mm)

			Wheat Type			
			Durum Wheat		Bread Wheat	
			Bulgur flour type			
			Antep	Karaman/Mut	Antep	Karaman/Mut
Quality Parameters	Moisture content (%, w.b.)		13.48±0.02[c]	11.40±0.02[a]	14.63±0.97[d]	12.05±0.06[b]
	Ash content (%, d.b.)		3.04±0.27[b]	8.72±0.29[d]	1.57±0.31[a]	5.10±0.36[c]
	Protein content (%, d.b.)		17.33±0.04[c]	16.13±0.46[b]	12.53±0.37[a]	11.81±0.40[a]
	L*		73.44±0.47[d]	67.56±0.16[a]	71.70±0.44[c]	69.24±0.66[b]
	a*		3.40±0.18[a]	3.84±0.14[b]	3.86±0.16[b]	3.82±0.31[b]
	b*		22.54±0.63[b]	21.89±0.55[b]	20.27±0.43[a]	20.15±0.76[a]
	YI		48.87±1.44[bc]	51.08±1.08[c]	46.29±1.11[a]	47.19±2.01[ab]
Solid Handling Properties	Bulk Density (kg/m^3)	Packed	501.60±0.00[c]	460.60±1.98[a]	483.01±0.22[b]	495.60±9.05[bc]
		Loose	375.60±0.00[b]	340.4±7.91[a]	377.12±0.25[c]	337.60±6.22[a]
	Angle of Repose (^{o})		64	61	65	69
	Sliding Angle (^{o})	Metal surface	50	41	46	45
		Plastic surface	45	38	43	43

The letters show significant difference at (p≤0.05) between samples each parameter.

Table 3.21 Flow rate properties of all bulgur flour types (after milling, under screen, 0.50/+ mm)

Raw Material	Bulgur Production Technique	Flow Type		Orifice Diameters (mm)			
				6	9	12	15
Durum Wheat	Karaman /Mut	Mass	W (kg/s)	0.000750	0.002060	0.004230	0.007400
			Q (g/s)	0.053±0.028	0.366±0.195	0.859±0.447	1.557±0.781
			k	0.000096			
			n	3.626			
			R^2	0.987			
	Antep	Mass	W (kg/s)	0.000826	0.002276	0.004672	0.008161
			Q (g/s)	0.069±0.034	0.470±0.235	0.466±0.233	2.002±1.001
			k	0.000200			
			n	3.329			
			R^2	0.909			
Bread Wheat	Karaman /Mut	Mass	W (kg/s)	0.000740	0.002050	0.004200	0.007340
			Q (g/s)	0.058±0.027	0.281±0.019	1.175±0.006	1.778±0.017
			k	0.000165			
			n	3.474			
			R^2	0.984			
	Antep	Mass	W (kg/s)	0.000829	0.002285	0.004690	0.000820
			Q (g/s)	0.067±0.026	0.757±0.014	1.129±0.019	1.630±0.055
			k	0.000506			
			n	3.077			
			R^2	0.905			

Q: certain silo discharge capacity, W: predicted silo discharge rate.

3.11 Effect of Polishing Operation on Physical, Chemical and Solid Handling Properties

According to Balcı and Bayram (2017), bulgur preference, price and acceptability in the market are positively impressed the presence of the bright yellow and homogeneous color. For business competitiveness, the polishing operation has also been a cornerstone operation for the producers due to the color improvement of bulgur. After polishing, bulgur looks more attractive as yellow and bright, which is frequently sought after by consumers.

Mechanical kneading polishing system was used in order to remove adhesive bran, flour and dusts easily and enhances good yellow color of bulgur. Moreover, polisher is used to repair the view of surface by smoothing. The chemical, physical and solid handling properties of unscreened polished samples (mixed with bulgur flour) were determined and results are given in Tables 3.22 and 3.23. The L*, a*, b* and YI values, packed and loose voidage and bulk density, moisture, ash and protein content were found significantly ($p \leq 0.05$) different for the polished unscreened bulgur samples.

The final moisture contents of samples were determined as 11.98, 12.47, 12.95 and 10.36 % (w.b.) for polished Antep Durum (PDA) and Karaman/Mut Durum (PDK), and Antep bread (PBA) and Karaman/Mut bread (PBK) type bulgur samples, respectively. As expected, the moisture content decreased due to generation of heat with friction and evaporation. The decreases in moisture content were similar to the results of the study of Balcı and Bayram (2017).

Whereas the percent (%, d.b.) ash content for polished Antep Durum, Karaman/Mut Durum and Antep bread type bulgur samples decreased, Karaman/Mut bread bulgur samples increased. The decrease in the ash content was expected due to the removal of remain bran particles over the bulgur granules.

During the polishing operation, the protein content of Durum Antep, Karaman/Mut, bread Antep and Karaman/Mut bulgur samples decreased to 13.03, 13.80, 11.30 and 10.94 % (d.b.), respectively.

The polishing operation supplies to the bulgur an attractive color. From the results, L* (lightness) value increased. However, a* (redness), b* (yellowness) and YI (hue angle) values decreased and reduction of b* and YI values were found as interesting.

Woodcock and Mason (2012) reported that the bulk density of a mixture of particles of different sizes will depend upon the extent to which the smaller particles are able to fit into the gaps between the larger ones. The packed and loose bulk densities of polished products were measured as 803.96 and 726.36 kg/m^3 for PDA, 796.00 and 723.00 kg/m^3 for PDK, 722.10 and 649.90 kg/m^3 for PBA and, 701.36 and 631.46 kg/m^3 for PBK bulgur types, respectively. The polishing operation increased the bulk density due to smoothing effect on the surface of bulgur particles. Additionally, some parts of bulgur were broken and filled the gaps between bulgur particles (void filling). Therefore, void fraction of all bulgur types were found lower than the unpolished bulgur samples.

The sphericity was found insignificantly ($p>0.05$) and determined as 0.0101, 0.0114, 0.0216 and 0.0124 for PDA, PBA, PDK and PBK bulgur types, respectively. Theoretically, the angle of repose increased in order of spheres, cylinders and irregulars (Riley and Mann, 1972). It was expected, the angle of repose value was found high for Karaman/Mut bread (51^o), Karaman/Mut durum (48^o), Antep bread (47^o) and Antep Durum (45^o) polished bulgur types, respectively.

Particle size, particle density and minimum fluidization velocity were found as 2.91 mm, 1387.88 g/mL and 0.59 m/s for Antep Durum, 3.68 mm, 1380.85 g/mL and 0.64 m/s for Karaman/Mut Durum, 2.89 mm, 1372.55 g/mL and 0.39 m/s for Antep bread, and 3.11 mm, 1426.26 g/mL and 0.16 m/s for Karaman/Mut bread polished bulgur types (with bulgur flour), respectively. Even, the sliding angle with metal and plastic plate surfaces was measured as 31 and 28^o for Antep Durum, 32 and 29^o for Karaman/Mut durum, 31 and 30^o for Antep bread and 30 and 25^o for Karaman/Mut bread bulgur types, respectively.

After the polishing process, the particle size distribution was observed for PDA, PDK, PBA and PBK bulgur samples as 0.0, 1.5, 2.00 and 10.2 % (wt/wt) for +/3.55 mm, 2.4, 28.8, 10.9 and 25.3 % (wt/wt) for 3.55/2.80 mm, and 97.7, 69.6, 87.2 and 64.7 % (wt/wt) for 2.80/+ mm, respectively. As expected due to size reduction, the amount of 2.80/+ mm (underscreen product) increased for all bulgur types during the polishing operation.

The flow regime was observed as mass flow. Johanson equation was used to calculate the predicted silo discharge rate (Table 3.23). The general experience with bulk solids is that flowability increases with increasing particle size. The flow inside the silo stops and a peak can be occur in wrong designs. When this formation of peak comes to a certain level tons of bulgur may fall back into the silo and may damage it. Experimentally silo discharge capacity (Q) were found lowest for polished Antep type bread bulgur. These results were considered that it can be due to low particle size and/or bulgur flour cause blockage of silo orifice (particle diameter (d_p) = 2.89 mm).

Furthermore, k and n values of discharge constant were obtained by using sketching log graph and these values were 0.000387 and 3.921 for Antep type Durum bulgur; 0.00061 and 3.706 for Antep type bread bulgur, 0.000503 and 3.800 for Durum bulgur produced from Karaman/Mut technique and 0.000313 and 4.009 for Karaman/Mut type bread bulgur, respectively.

Table 3.22 Chemical, physical and solid handling properties of polished Durum and bread bulgur types (after polishing)

			Wheat Type			
			Durum Wheat		Bread Wheat	
			Bulgur Production Technique			
			Antep	Karaman/Mut	Antep	Karaman/Mut
Quality Parameters	Moisture content (%, w.b.)		11.98±0.83[b]	12.47±0.43[c]	12.95±0.94[d]	10.36±0.18[a]
	Ash content (%, d.b.)		0.97±0.14[a]	1.31±0.04[b]	1.44±0.90[b]	1.65±0.12[c]
	Protein content(%, d.b.)		13.03±0.21[c]	13.80±0.15[d]	11.30±0.12[b]	10.94±0.14[a]
	L*		63.26±0.85[b]	61.23±0.97[a]	60.42±0.36[a]	61.71±1.68[ab]
	a*		5.47±0.35[b]	4.26±0.35[a]	5.48±0.10[b]	4.26±0.51[a]
	b*		28.69±0.92[c]	22.67±0.78[b]	22.93±0.35[b]	20.42±0.36[a]
	YI		66.86±2.43[c]	56.48±2.43[b]	59.03±0.79[b]	52.10±2.22[a]
Solid Handling Properties	Sphericity (ϕ)		0.0101±0.0126[a]	0.0216±0.0052[a]	0.0114±0.0082[a]	0.0124±0.0117[a]
	Particle Size (mm)		2.91±1.47[a]	3.68±1.32[a]	2.89±1.48[a]	3.11±1.08[a]
	Bulk Density (kg/m^3)	Packed	803.96±1.36[d]	796.00±0.00[c]	722.10±0.93[b]	701.36±3.68[a]
		Loose	726.36±6.56[c]	732.00±3.73[c]	649.90±3.42[b]	631.46±5.18[a]
	Particle Density (g/mL)		1387.88	1380.85	1372.55	1426.26
	Voidage	Packed	0.4207±0.0098[a]	0.4235±0.0000[a]	0.4739±0.0006[b]	0.5083±0.0026[c]
		Loose	0.4766±0.0047[a]	0.4698±0.0003[a]	0.5265±0.0025[b]	0.5573±0.0036[c]
	Angle of Repose (^{o})		45	48	47	51
	Sliding Angle (^{o})	Metal surface	31	32	31	30
		Plastic surface	28	29	30	25
	Minimum fluidization velocity (m/s)		0.59	0.64	0.39	0.16
Screen Analysis (%, wt/wt)	+/3.55 mm		0.0	1.5	2.0	10.2
	3.55/2.80 mm		2.4	28.8	10.9	25.3
	2.80/+ mm		97.7	69.6	87.2	64.7

The letters show significant difference at ($p \leq 0.05$) between samples each parameter.

Table 3.23 Flow rate properties of polished Durum and bread bulgur types (after polishing)

Wheat Type	Bulgur Production Technique	Flow Type		Orifice Diameters (mm)			
				6	9	12	15
Durum Wheat	Karaman /Mut	Mass	W (kg/s)	0.001610	0.004440	0.009100	0.015900
			Q (g/s)	0.525±0.011	1.563±0.055	7.21±0.04	15.435±0.249
			k	0.000503			
			n	3.800			
			R^2	0.981			
	Antep	Mass	W (kg/s)	0.001597	0.004401	0.009034	0.015782
			Q (g/s)	0.472±0.103	1.699±0.107	8.873±0.348	14.013±0.681
			k	0.000387			
			n	3.921			
			R^2	0.979			
Bread Wheat	Karaman /Mut	Mass	W (kg/s)	0.001390	0.003830	0.007850	0.013720
			Q (g/s)	0.516±0.031	1.451±0.146	6.292±0.525	20.017±0.367
			k	0.000313			
			n	4.009			
			R^2	0.970			
	Antep	Mass	W (kg/s)	0.001429	0.003938	0.008083	0.014121
			Q (g/s)	0.536±0.032	1.491±0.022	7.717±1.157	13.679±0.78
			k	0.000610			
			n	3.706			
			R^2	0.972			

Q: certain silo discharge capacity, W: predicted silo discharge rate.

After the polishing operation, the polished products as mix were sieved with 0.5 mm screen to remove flour, bran etc. The properties are given in Table 3.24. The bulgur production techniques and raw material affected significantly ($p \leq 0.05$) the particle size, sphericity, bulk density, void fraction, color, moisture, ash and protein contents of the polished bulgur samples. The particle densities of screened PDA, PDK, PBA and PBK bulgur types were 1384.77, 1396.3, 1385.07 and 1327.77 g/mL, respectively.

Bin, hopper and silo are designed by using repose and sliding angle values. In open area storage of wheat or any particular food, the quantity of solid material can find easily by using angle of repose value. In silo, top pile is determined with the angle of repose, conical bottom part of silo is determined with sliding angle. The results showed that the angle of repose and sliding angle of the polished bulgur (without bulgur flour) with metal and plastic plate surfaces were measured as 47, 32 and 29^o for Antep Durum, 50, 33 and 28.5^o for Karaman/Mut Durum, 48, 32 and 27^o for Antep bread and 50, 26 and 23^o for Karaman/Mut bread bulgur types, respectively.

The packed and loose bulk densities of polished bread bulgur produced by using Karaman/Mut technique were found lowest as 704.98 and 653.62 kg/m^3, respectively.

Flow regime was established as mass flow. Johanson equation was used to calculate to determine the predicted silo discharge rate (Table 3.25). Barbosa-C´anovas et al. (2006) denoted that in this mode of flow, if the hopper is sufficiently steep and smooth, all the solids can flow easily in the bin during discharge without stagnant or dead regions. The bulk solid is in motion at every point within the bin whenever material is drawn from the outlet. The flow is uniform in mass-flow bins and the bulk density of the feed is almost independent of the head of solids in the bin. Mass-flow guarantees complete discharge of the bin contents at predictable flow rates. When properly designed, a mass-flow bin can remix the bulk of the solid during discharge, minimizing segregation.

The actual (Q) and predicted (W) silo discharge rates of over screen PDA, PDK, PBA and PBK bulgur samples are given in Table 3.25. The k and n constant were found as 0.000240 and 4.1802 for Antep Durum, 0.001590 and 4.334 for

Karaman/Mut Durum, 0.000665 and 3.707 for Antep bread and 0.000464 and 3.788 for Karaman/Mut bread bulgur flour samples, respectively.

Table 3.24 Chemical, physical and solid handling properties of polished Durum and bread bulgur types (after polishing over screen, +/0.50 mm)

			Wheat Type			
			Durum Wheat		Bread Wheat	
			Bulgur Production Technique			
			Antep	Karaman / Mut	Antep	Karaman / Mut
Quality Parameters	Moisture content (%, w.b.)		10.56±0.16[b]	11.47±0.10[c]	13.10±0.05[d]	10.14±0.13[a]
	Ash content (%, d.b.)		0.95±0.05[a]	1.10±0.11[a]	1.11±0.02[a]	1.47±0.13[b]
	Protein content(%, d.b.)		12.64±0.24[bc]	13.14±0.77[c]	11.08±0.21[a]	11.40±0.41[ab]
	L*		60.96±0.40[c]	59.01±0.55[b]	62.73±0.83[d]	54.99±0.21[a]
	a*		6.11±0.34[a]	5.16±0.24[a]	5.31±0.26[a]	6.24±0.14[b]
	b*		29.16±0.88[c]	25.78±0.30[b]	23.83±0.42[a]	23.70±0.51[a]
	YI		69.94±2.01[c]	64.50±1.20[b]	58.97±1.53[a]	65.15±1.15[b]
Solid Handling Properties	Sphericity (ϕ)		0.0194±0.0090[b]	0.0231±0.0085[b]	0.0128±0.0020[ab]	0.0087±0.0028[a]
	Particle Size (mm)		3.50±1.72[a]	4.52±2.24[a]	2.57±1.15[a]	3.00±1.50[a]
	Bulk Density (kg/m^3)	Packed	801.20±5.32[c]	798.78±3.70[c]	720.10±4.78[b]	704.98±3.08[a]
		Loose	725.46±0.37[b]	721.28±2.77[b]	656.24±4.86[a]	653.62±6.19[a]
	Particle Density (g/mL)		1384.77	1396.3	1385.07	1327.77
	Voidage	Packed	0.4214±0.0038[c]	0.4279±0.0026[c]	0.4801±0.0034[b]	0.4690±0.0023[a]
		Loose	0.4761±0.0003[b]	0.4834±0.0020[b]	0.5262±0.0035[a]	0.5077±0.0047[a]
	Angle of Repose (^{o})		47	50	48	50
	Sliding Angle (^{o})	Metal surface	32	33	32	26
		Plastic surface	29	28.5	27	23
	Minimum fluidization velocity		0.46	0.44	0.31	0.22
Screen Analysis (%, wt/wt)	+/3.55 mm		0.4	2.4	1.5	8.1
	3.55/2.80 mm		3.9	22.3	11.2	30.9
	2.80/+ mm		96.1	75.4	87.6	61.2

The letters show significant difference at (p≤0.05) between samples each parameter.

Table 3.25 Flow rate properties of polished Durum and bread bulgur types (after polishing over screen,+/0.50 mm)

Wheat Type	Bulgur Production Technique	Flow Type		Orifice Diameters (mm)			
				6	9	12	15
Durum Wheat	Karaman /Mut	Mass	W (kg/s)	0.001590	0.004370	0.008970	0.015670
			Q (g/s)	0.389±0.074	1.805±0.095	9.957±0.244	17.132±0.358
			k	0.000157			
			n	4.334			
			R^2	0.985			
	Antep	Mass	W (kg/s)	0.001595	0.004395	0.009023	0.015763
			Q (g/s)	0.505±0.032	1.652±0.091	8.549±0.322	21.189±0.195
			k	0.000240			
			n	4.1802			
			R^2	0.981			
Bread Wheat	Karaman /Mut	Mass	W (kg/s)	0.001440	0.003960	0.008130	0.01420
			Q (g/s)	0.475±0.066	1.396±0.096	6.802±0.71	13.349±0.503
			k	0.000464			
			n	3.788			
			R^2	0.978			
	Antep	Mass	W (kg/s)	0.001443	0.003976	0.008162	0.014259
			Q (g/s)	0.590±0.117	1.698±0.056	7.918±0.431	15.637±3.335
			k	0.000665			
			n	3.707			
			R^2	0.979			

The letters show significant difference at (p≤0.05) between samples each parameter.

3.12 Physical, Chemical and Solid Handling Properties of Coarse, Medium and Fine Bulgur

Bulgur is consumed as semi-ready-to-eat or ready-to-eat food product in different sizes to prepare various meals. Therefore, after the polishing operation all bulgur samples were sifted by using 3.55, 3.00, 2.50, 2.00, 1.60 and 0.50 mm of apertures to classified into four sizes as coarse (+3.55/2.00), medium (2.00/1.60), fine (1.60/0.50) and undersize (0.50/+) bulgur. Coarse and medium bulgur is usually boiled or steamed in the presence of meats or vegetables, which is similar to the way in which rice or couscous are prepared. Also, fine bulgur is used in several traditional dishes such as tabbouleh, meatball, kısır and salads etc. According to literature and industrial scale, the amount of the undersize bulgur (bulgur flour) is about 15 % of total produced bulgur and this nutritionally valued product which usually contains bran and bulgur flour obtained in the bulgur production, used as an animal feed or in the formulation of different foods in food industry. Additionally, it is utilized to calculate the overall milling yield. The percent distribution of sieve analyses can be seen in Figure 3.2.

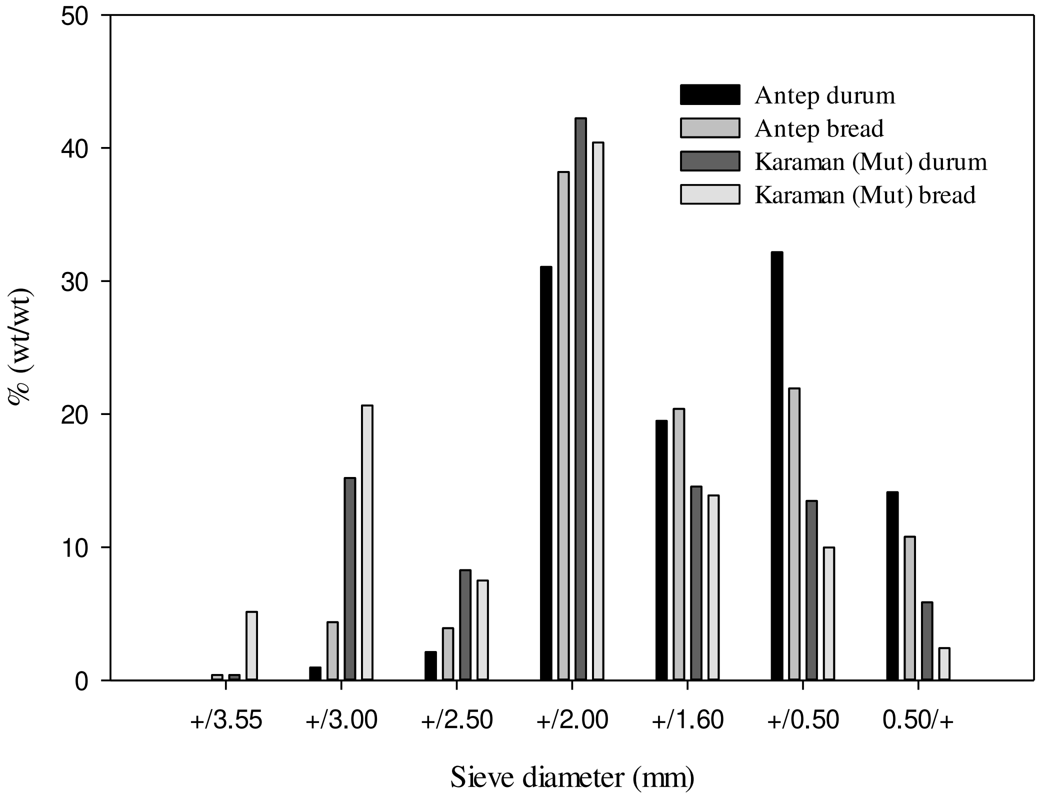


Figure 3.2 Percent distribution after sieve analyses for all bulgur types

For all coarse bulgur (+3.55/2.00 mm) types, the moisture, ash and protein contents, color values (L*, b*, YI), particle size, packed and loose bulk densities and voidage were significantly ($p \leq 0.05$) affected by the production techniques and the raw materials in contrast to a* value and sphericity. The difference between coarse bulgur types are shown in Table 3.26.

The ash contents of Antep Durum, Karaman/Mut Durum, Antep bread and Karaman/Mut coarse bulgur types were determined as 1.01, 1.24, 1.00 and 1.51 % (d.b.), respectively. According to the results, the ash contents of Karaman/Mut type coarse bulgur samples were higher than Antep type coarse bulgur samples due to low debranning efficiency of stone mill. Also, the ash content is important for finished product quality and standarts. According to Turkish Standart Institute (TSE), the ash content should be less than 1.80 % (d.b.) (TSE, 2017). Physicochemical and sensory properties of soymilk-incorporated bulgur were investigated in the study of Hayta et al. (2003). The ash content of pilav bulgur increased significantly with the increase in soymilk content (3, 6 and 9 %) compared with control bulgur (cooked in water).

Angle of repose is confirmed that are good indicators of powder flowability. Angle of repose can also be used for industrial design in the range of low stresses for the following determinations: heap basic height and diameter (valuable for grains and cereals), silo height, hopper angle determination for a good final sewage, conveyor belt dimensioning and forces on a horizontal silo’s walls (Teunou et al., 1995). It was determined that angle of repose and sliding angle on metal and plastic plates were 48, 28 and 25^{o} for Antep durum coarse bulgur, 48, 29 and 24^{o} for Karaman/Mut durum coarse bulgur, 50, 25 and 23^{o} for Antep bread coarse bulgur, 50, 24 and 22^{o} for Karaman/Mut bread coarse bulgur, respectively.

The minimum fluidization velocity for Antep durum, Karaman/Mut durum, Antep bread and Karaman/Mut bread bulgur types were determined as 0.31, 0.62, 0.50 and 0.50 m/s, respectively.

Bulk density, compressibility and flowability of a powder are highly dependent on particle size and its distribution (Barbosa-C´anovas et al., 2006). The packed and loose bulk densities of Karaman/Mut durum type coarse bulgur were the highest (808.64 and 721.28 kg/m^3) because of bulk density dependent on the size of the particles relative to the consequent interstitial volume. Similar to this study, bulk density of coarse bulgur were found by Bayram and Öner (2005) as 663.9, 741.6 and 735.0 kg/m^3 for hammer, stone and disc miller. The void depends on the shape and size of particles and the sharp edges of particles cause big void.

The particle shape affects the flow properties. When considering coarse bulgur particles, which often finds that smooth, spherical particles flow better than rough, sharp-edged and non spherical particles (Schulze, 2008). The sphericity value of Antep type coarse bulgur types produced from bread wheat were found the lowest (0.0093) so this type coarse bulgur were found spherical than the other coarse bulgur types.

The predicted silo discharge capacity with 6, 9, 12 and 15 mm orifice diameters were calculated with Johanson equation because of observing mass flow regime. According to the results, while the actual and predicted silo discharge capacities were determined nearly same for 6, 9 and 12 mm orifice diameters, for 15 mm orifice diameter were found slightly different (Table 3.27). And also, in order to design reliable mass flow silos are necessary required hopper slope, which ensures mass flow and determination of the minimum orifice diameter.

Table 3.26 Chemical, physical and solid handling properties of coarse bulgur

			Wheat Type			
			Durum Wheat		Bread Wheat	
			Bulgur Production Technique			
			Antep	Karaman / Mut	Antep	Karaman / Mut
Quality Parameters	Moisture content (%, w.b.)		9.91±0.85[a]	10.71±0.23[c]	12.21±0.09[d]	10.20±0.11[b]
	Ash content (%, d.b.)		1.01±0.06[a]	1.24±0.08[b]	1.00±0.08[a]	1.51±0.10[c]
	Protein content (%, d.b.)		13.08±0.78[b]	13.16±0.25[b]	11.06±0.13[a]	11.70±0.03[a]
	L*		59.43±0.14[d]	55.04±0.24[b]	56.41±0.45[c]	54.00±0.23[a]
	a*		6.60±0.09[b]	6.41±0.08[a]	6.51±0.13[ab]	6.59±0.14[b]
	b*		29.39±0.14[c]	26.53±0.19[b]	24.10±0.19[a]	23.91±0.18[a]
	YI		72.00±0.19[d]	70.30±0.62[c]	65.22±0.66[a]	66.77±0.68[b]
Solid Handling Properties	Sphericity (ϕ)		0.0129±0.0043[a]	0.0158±0.0040[a]	0.0093±0.0032[a]	0.0104±0.0042[a]
	Particle Size (mm)		3.70±0.83[a]	5.12±0.53[b]	3.37±0.39[a]	3.85±0.43[a]
	Bulk Density (kg/m^3)	Packed	795.00±0.68[b]	808.64±11.31[b]	714.92±1.53[a]	707.06±0.25[a]
		Loose	720.98±14.46[b]	721.28±2.78[b]	643.46±1.44[a]	657.06±0.60[a]
	Particle Density (g/mL)		1406.46	1364.43	1372.21	1344.34
	Voidage	Packed	0.4347±0.0005[b]	0.4073±0.0082[a]	0.4790±0.0011[c]	0.4740±0.0002[c]
		Loose	0.4874±0.0103[b]	0.4714±0.0020[a]	0.5310±0.0011[d]	0.5112±0.0004[c]
	Angle of Repose (^{o})		48	48	50	50
	Sliding Angle (^{o})	Metal surface	28	29	25	24
		Plastic surface	25	24	23	22
	Minimum fluidization velocity (m/s)		0.31	0.62	0.50	0.50

The letters show significant difference at (p≤0.05) between samples each parameter.

Table 3.27 Flow rate properties of coarse bulgur

Wheat Type	Bulgur Production Technique	Flow Type		Orifice Diameters (mm)			
				6	9	12	15
Durum Wheat	Karaman /Mut	Mass	W (kg/s)	0.001590	0.004370	0.008970	0.015670
			Q (g/s)	0.388±0.004	1.52±0.036	7.446±0.772	18.416±0.488
			k	0.000156			
			n	4.296			
			R^2	0.990			
	Antep	Mass	W (kg/s)	0.001585	0.004368	0.008967	0.015665
			Q (g/s)	0.337±0.044	1.381±0.019	8.334±0.133	17.057±2.544
			k	0.000104			
			n	4.449			
			R^2	0.984			
Bread Wheat	Karaman /Mut	Mass	W (kg/s)	0.001440	0.003980	0.008170	0.014280
			Q (g/s)	0.533±0.026	1.427±0.041	7.62±0.332	18.186±0.35
			k	0.000352			
			n	3.971			
			R^2	0.969			
	Antep	Mass	W (kg/s)	0.001415	0.003899	0.008003	0.013981
			Q (g/s)	0.452±0.001	1.358±0.233	7.56±0.186	15.295±0.644
			k	0.000295			
			n	4.003			
			R^2	0.973			

Q: certain silo discharge capacity, W: predicted silo discharge rate.

Statistical analysis was performed to compare between all medium size bulgur (2.00/1.60 mm) on the general quality parameters. It was found that, all bulgur types had significant ($p \leq 0.05$) effect on the particle size, moisture, ash and protein contents, L*, a*, b*, YI, packed and loose bulk densities and void fraction (Table 3.28).

The highest moisture content was observed for Antep bread type medium bulgur (12.50 %, w.b.). The ash and protein contents of bulgur depends on the quality of wheat from which it is produced and the techniques applied in the mill. The ash and protein contents were 0.84 and 12.73 % (d.b.) for Antep Durum medium bulgur (DAM), 1.19 and 12.96 % (d.b.) for Karaman/Mut durum medium bulgur (DKM), 1.28 and 11.01 % (d.b.) for Antep bread medium bulgur (BAM) and 1.50 and 11.12 % (d.b.) for Karaman/Mut bread medium bulgur (BKM), respectively.

The particle size, sphericity and particle density of DAM, DKM, BAM and BKM were 1.79 mm, 0.0356 and 1411.75 g/mL; 2.28mm, 0.0331 and 1406.86 g/mL; 2.70 mm, 0.0128 and 1430.56 g/mL and 2.66 mm, 0.0088 and 1389 g/mL, respectively.

Whereas packed and loose bulk densities of Antep Durum and bread type medium bulgur were measured as 789.68 and 720.46 kg/m^3, and 730.38 and 642.50 kg/m^3, Karaman/Mut durum and bread type medium bulgur were 758.22 and 667.76 kg/m^3 and 671.12 and 593.78 kg/m^3, respectively.

Angle of repose can be used to characterise a wide range of powders in order to monitor their flow behaviour in existing items of the bulgur production units on a day to day basis. The angle of repose and sliding angle on metal and plastic plates were 46, 28 and 25^o for DAM, 47, 26 and 25^o for DKM, 47, 27 and 24^o for BAM and 44, 25 and 23^o for BKM bulgur types, respectively. According to the angle of repose results between coarse and medium bulgur types, the repose angle of medium bulgur types was found higher than coarse bulgur types. McGlinchey (2008) stated that, lower the angle of repose the more flowable a powder becomes, because the angle of repose is a direct indication of the potential flowability of a powder. It was found in the present study, Q and W values with 6, 9, 12 and 15 mm orifice diameters of medium bulgur types were found higher than coarse ones (Table 3.29). Additionally, the flow regime was observed as funnel flow and W value of bulgur flour types were calculated according to Beverloo equation. Funnel-flow, suitable for coarse free-flowing materials, occurs when the hopper is not sufficiently steep or smooth enough to force the bulk solid to slide along the walls. It is also observed when the outlet of the bin is not fully effective due to poor feeder or gate design. In a funnel-flow bin the stored material flows toward the outlet through a vertical channel forming within stagnant solids. The diameter of the channel approximates the largest dimension of the effective outlet. Flow out of this type of bin is generally erratic and gives rise to segregation problems.

In funnel flow, the velocity of particles found at center of silo, bunker or hopper is bigger than velocity of particle found at wall of silo. Therefore, center is discharge as first, and first-in is not first-out. The minimum fluidization velocity was measured as 0.08, 0.22, 0.52 and 0.16 m/s for DAM, DKM, BAM and BKM, respectively. Also, k and n constant were found as 0.000101 and 4.556 for Antep durum, 0.000205 and 4.204 for Karaman/Mut durum, 0.000209 and 4.198 for Antep bread and 0.000193 and 4.225 for Karaman/Mut bread medium bulgur types, respectively.

Table 3.28 Chemical, physical and solid handling properties of medium bulgur

			Wheat Type			
			Durum Wheat		Bread Wheat	
			Bulgur Production Technique			
			Antep	Karaman/Mut	Antep	Karaman/Mut
Quality Parameters	Moisture content (%, w.b.)		10.41±0.05[a]	10.47±0.08[ab]	12.50±0.19[c]	10.68±0.07[b]
	Ash content (%, d.b.)		0.84±0.26[a]	1.19±0.08[b]	1.28±0.12[bc]	1.50±0.08[c]
	Protein content (%, d.b.)		12.73±0.14[b]	12.96±0.27[b]	11.01±0.14[a]	11.12±0.21[a]
	L*		62.27±0.30[c]	56.86±0.24[a]	59.89±0.11[b]	56.87±0.28[a]
	a*		5.74±0.05[a]	6.07±0.11[d]	5.75±0.09[ab]	5.88±0.71[c]
	b*		30.51±0.30[d]	27.08±0.05[c]	23.90±0.20[b]	23.33±0.26[a]
	YI		70.67±0.34[d]	69.43±0.25[c]	61.46±0.48[a]	62.63±0.63[b]
Solid Handling Properties	Sphericity (ϕ)		0.0356±0.0117[a]	0.0331±0.0255[a]	0.0128±0.0020[a]	0.0088±0.0067[a]
	Particle Size (mm)		1.79±0.01[a]	2.28±0.33[ab]	2.70±0.13[b]	2.66±0.46[b]
	Bulk Density (kg/m^3)	Packed	789.68±0.849[d]	758.22±0.198[c]	730.38±2.121[b]	671.12±0.736[a]
		Loose	720.46±8.29[d]	667.76±13.51[c]	642.50±0.02[b]	593.78±0.60[a]
	Particle Density (g/mL)		1411.75	1406.86	1430.56	1389.78
	Voidage	Packed	0.4406±0.0006[a]	0.4610±0.0001[b]	0.4894±0.0014[c]	0.5171±0.0004[d]
		Loose	0.4897±0.0059[a]	0.5253±0.0096[b]	0.5509±0.0000[c]	0.5728±0.0004[d]
	Angle of Repose (^{o})		46	47	47	44
	Sliding Angle (^{o})	Metal surface	28	26	27	25
		Plastic surface	25	25	24	23
	Minimum fluidization velocity (m/s)		0.08	0.22	0.52	0.16

The letters show significant difference at (p≤0.05) between samples each parameter.

Table 3.29 Flow properties of medium bulgur

Wheat Type	Bulgur Production Technique	Flow Type		Orifice Diameter (mm)			
				6	9	12	15
Durum Wheat	Karaman /Mut	Funnel	W (kg/s)	0.00050	0.003110	0.008810	0.018350
			Q (g/s)	0.418±0.01	1.689±0.027	9.1±0.081	16.466±0.819
			k	0.000205			
			n	4.204			
			R^2	0.985			
	Antep	Funnel	W (kg/s)	0.000943	0.004442	0.011483	0.022816
			Q (g/s)	0.357±0.016	2.008±0.077	10.545±0.061	20.249±0.225
			k	0.000101			
			n	4.556			
			R^2	0.991			
Bread Wheat	Karaman /Mut	Funnel	W (kg/s)	0.000270	0.002180	0.006720	0.014560
			Q (g/s)	0.414±0.036	1.621±0.227	8.522±0.014	17.393±1.236
			k	0.000193			
			n	4.225			
			R^2	0.986			
	Antep	Funnel	W (kg/s)	0.000271	0.002297	0.007148	0.015558
			Q (g/s)	0.447±0.075	1.511±0.361	9.685±0.168	17.009±2.31
			k	0.000209			
			n	4.198			
			R^2	0.970			

Q: certain silo discharge capacity, W: predicted silo discharge rate.

The another product obtained during the bulgur production is fine bulgur (1.60/0.50 mm). It was found that the bulgur production techniques and raw materials affected significantly ($p \leq 0.05$) sphericity, bulk density, void fraction, color (L*, a*, b* and YI), moisture, ash and protein contents in contrast to particle size and ash content of all fine bulgur types (1.60/0.50 mm). The general quality parameters and solid handling properties of Antep durum fine (DAF), Karaman/Mut durum fine (DKF), Antep bread fine (BAF) and Karaman/Mut bread fine (BKF) bulgur types are illustrated in Tables 3.30 and 3.31.

The amount of water in grain depends on the relative humidity and temperature of the storage place. According to the Turkish Food Codex Communique of bulgur, the moisture content of bulgur should be maximum 13 %. The moisture contents were found as 10.07, 10.79, 13.25 and 10.80 % (w.b.) for DAF, DKF, BAF and BKF bulgur types, respectively.

Theoretically, when the particle diameter decreases, endosperm part decreases and bran content of bulgur increases. Also Özkaya and Kahveci (1989) noted that ash content of the wheat samples decreased but protein content changed slightly during conversion of wheat to bulgur. The protein content (d.b.) of fine bulgur types ranged from 11.87-14.83 % as compared to a range of 14.35-11.98 % found in the wheat varieties. The ash content (d.b.) and particle size of Antep durum fine, Karaman/Mut durum, Antep bread and Karaman/Mut bread fine bulgur types were identified as 1.25 % and 1.13 mm, 1.63 % and 1.60 mm, 1.46 % and 1.48, mm and 1.83 % and 1.34 mm, respectively.

In terms of bulgur acceptance, color of the product is of first priority. The products with light color and brightness are preferred. The color analyses results shown that while L- value of Antep type bulgur produced from Durum wheat was found the highest. It was found the lowest for Karaman/Mut type produced from Durum wheat.

The fine bulgur types had the lowest performance due to its size and heterogeneous shape. Woodcock and Mason (2012) stated that a material consist of particles of extremely irregular shape, especially if they are also of very small size (i.e. fine cohesive products), the voidage could be much higher. While packed and loose bulk densities of Antep Durum and bread types fine bulgur were determined as 720.46 and 619.40 kg/m^3, and 662.18 and 595.70 kg/m^3, Karaman/Mut durum and bread type medium bulgur were 722.54 and 615.30 kg/m^3, and 639.34 and 554.44 kg/m^3, respectively. Besides, the minimum fluidization velocity and particle density were 0.14 m/s and 1412.18 g/mL for Antep durum, 0.16 m/s and 1403.28 g/mL for Karaman/Mut durum, 0.64 m/s and 1370.34 g/mL for Antep bread and 0.71 m/s and 1374.68 g/mL for Karaman/Mut bread types fine bulgur, respectively. The sphericity value was found the highest (0.0372) for bread Antep type fine bulgur and it means that it is less spherical than the others.

As with almost all powders the angle of repose decreases as particle size increases. This confirm that an increase of particle size of powder mixture is always accompanied by a decrease in cohesiveness (Geldart et al., 2006). The angle of repose and sliding angle on metal and plastic plates were 46, 32 and 30^o for DAF,47, 33 and 30^o for DKF, 45, 32 and 28^o for BAF and 46, 30 and 27^o for BKF bulgur types, respectively.

Flow regime was determined as funnel flow and Beverloo equation was used to calculate for the predicted silo discharge rate. The general experience with bulk solids is that flowability increases with increasing particle size. It was observed that, the fine bulgur discharge rate lower than coarse and medium bulgur types. In most cases the flow properties of bulk solids become more unfavorable (smaller flowability) with increasing fines content. Funnel flow has the advantage of providing wear protection of the bin walls as the material flows against stationary material. However, it is a “first-in last-out” flow pattern that is unsatisfactory for fine bulk solids of low permeability. Such materials can aerate during discharge through the flow channel, and this can give rise to flooding problems or uncontrolled discharge.

Table 3.30 Chemical, physical and solid handling properties of fine bulgur

			Wheat Type			
			Durum Wheat		Bread Wheat	
			Bulgur Production Technique			
			Antep	Karaman/Mut	Antep	Karaman/Mut
Quality Parameters	Moisture content (%, w.b.)		10.07±0.11[a]	10.79±0.97[b]	13.25±0.02[c]	10.80±0.11[b]
	Ash content (%, d.b.)		1.25±0.17[a]	1.63±0.24[a]	1.46±0.63[a]	1.83±0.21[a]
	Protein content (%, d.b.)		13.81±0.19[c]	14.83±0.09[d]	11.87±0.04[a]	13.04±0.18[b]
	L*		66.67±0.35[c]	60.73±0.17[a]	62.62±0.42[b]	60.75±0.29[a]
	a*		4.68±0.05[a]	5.17±0.14[b]	5.33±0.90[c]	5.11±0.006[b]
	b*		30.29±0.39[d]	27.37±0.61[c]	24.34±0.23[b]	23.40±0.10[a]
	YI		66.21±0.37[b]	66.01±1.26[b]	59.93±0.35[a]	59.18±0.31[a]
Solid Handling Properties	Sphericity (ϕ)		0.0065±0.0035[a]	0.0372±0.0244[b]	0.0099±0.0086[a]	0.0049±0.0065[a]
	Particle Size (mm)		1.13±0.22[a]	1.60±0.16[b]	1.48±0.43[ab]	1.34±0.23[ab]
	Bulk Density (kg/m^3)	Packed	720.46±8.29[c]	722.54±9.42[c]	662.18±1.22[b]	639.34±0.88[a]
		Loose	619.40±5.32[c]	615.30±7.16[c]	595.70±0.31[b]	554.44±0.11[a]
	Particle Density (g/mL)		1412.18	1403.28	1370.34	1374.68
	Voidage	Packed	0.4898±0.0059[a]	0.4851±0.0067[a]	0.5168±0.0008[b]	0.5349±0.0006[c]
		Loose	0.5614±0.0038[a]	0.5615±0.0051[a]	0.5653±0.0002[a]	0.5967±0.0001[b]
	Angle of Repose (^{o})		46	47	45	46
	Sliding Angle (^{o})	Metal surface	32	33	32	30
		Plastic surface	30	30	28	27
	Min. fluidization velocity (m/s)		0.14	0.16	0.64	0.71

The letters show significant difference at ($p \le 0.05$) between samples each parameter.

Table 3.31 Flow rate properties of fine bulgur

Wheat Type	Bulgur Production Technique	Flow Type		Orifice Diameters (mm) 6	9	12	15
Durum Wheat	Karaman /Mut	Funnel	W (kg/s)	0.00097	0.00421	0.01053	0.02057
			Q (g/s)	0.282±0.021	1.718±0.035	9.222±0.781	15.755±0.769
			k	0.000081			
			n	4.565			
			R^2	0.987			
	Antep	Funnel	W (kg/s)	0.001463	0.005339	0.012474	0.023477
			Q (g/s)	0.238±0.008	1.644±0.032	9.344±0.251	15.581±0.663
			k	0.000050			
			n	4.751			
			R^2	0.985			
Bread Wheat	Karaman /Mut	Funnel	W (kg/s)	0.00110	0.00432	0.01039	0.01987
			Q (g/s)	0.503±0.009	1.551±0.119	8.751±0.093	18.598±0.079
			k	0.000280			
			n	4.091			
			R^2	0.975			
	Antep	Funnel	W (kg/s)	0.001045	0.004319	0.010618	0.020548
			Q (g/s)	0.394±0.018	1.991±0.088	9.838±0.123	14.818±0.573
			k	0.000240			
			n	4.147			
			R^2	0.982			

Q: certain silo discharge capacity, W: predicted silo discharge rate.

CONCLUSION

In this study, the solid handling properties of bulgur were determined at each processing step during the bulgur production. The processing steps and analysing stages were raw material receiving, cleaning, washing, soaking, cooking, drying, tempering, milling, polishing and classification. The solid properties (sphericity, particle size, packed and loose bulk densities, voidage, particle density, angle of repose, sliding angle, silo discharge rate, minimum fluidization velocity and size distribution) of main and by-products were determined. Two industrial bulgur production methods e.g. Antep and Karaman/Mut were used.

It was found as a result;

- The variety of raw material was important, which effected the solid handling properties.
- Nearly all solid handling properties significantly changed ($p \leq 0.05$) during the bulgur production.
- The water absorption during soaking and cooking was main effect on the solid handling properties of bulgur.
- The drying was also another effect the solid handling properties of bulgur due to evaporation of water.
- The size reduction (milling) was the most important operation for the solid handling properties of bulgur.
- According to the results, the changes in the shape, size, moisture and surface smoothness of bulgur were very important for the solid handling properties.
- The solid handling properties of bulgur is valuable during the design of bulgur plant, the design of pipelines (solid transfer pipes), pneumatic conveying, equipment and silo.

- As expected, the bulk density of bulgur decreased with decreasing particle size.
- The dirty wheat and bulgur bran had low packed and loose bulk densities.
- The bulk densities of bulgur produced by using Karaman/Mut method had bigger values than Antep method due to smooth and round particles of Karaman/Mut method.
- The highest angle of repose and sliding angle values were determined for the cooked wheat (hedik) due to high moisture content and sticky surface of cooked wheat (starchy firm, gelatinized starch on surface, adhesiveness).
- The sliding angle for all samples on metal plate surface was found bigger than plastic plate surface due to high frictional attributes.
- The protein and ash contents of the products decreased continously during the bulgur production (especially during the cooking and debranning operations).

For the future studies, a simulation and design studies can be made to apply the solid handling results on the design applications.

REFERENCES

Al-Mahasneh, M. A. and Rababah, T. M. (2007). Effect of moisture content on some physical properties of green wheat. *Journal of Food Engineering,* **79(4)**, 1467-1473.

Ali, M. J. (2017). *Investigation of Yield, Yield Components and Primary Quality Characteristics of Some Bread Wheat (Triticum Aestivum L.) Genotypes.* (Master Thesis), Bingöl University, Turkey.

Andersson, J. (2011). Whole Grain Wheat- Effects of Peeling and pearling on chemical composition, taste and colour. (Master Thesis), Swedish University, Uppsala.

Anonymous. (2012). Bulk Density and Tapped Density of Powders . World Health Organization. Retrieved 02.04.2018, from http://www.who.int/medicines/publications/pharmacopoeia/Bulk-tapped-densityQAS11_450FINAL_MODIFIEDMarch2012.pdf

Anonymous. (2017). Fluidization: A Unit Operation in Chemical Engineering. Retrieved 21.08.2018, from http://ww2.che.ufl.edu/unit-ops-lab/experiments/FB/FB-manual.pdf

Anonymous. (2018). History of Bulgur Wheat. Retrieved 30.07.2018, from https://sunnylandmills.com/2016/05/history-of-bulgur-wheat/

AOAC. (1990). Official methods of analysis (15th Edn) Association of Official Analytical Chemists. Arlington, VA, USA.

Augenstein, D. A. and Hogg, R. (1978). An experimental study of the flow of dry powders over inclined surfaces. *Powder Technology,* **19(2)**, 205-215.

Bafklow, K., Simmonds, H. and Vesk, M. (1973). The nature of the starch-protein interface in wheat endosperm. *Cereal Chemistry,* **50**, 443-454.

Balcı, F. and Bayram, M. (2015). Improving the color of bulgur: new industrial applications of tempering and UV/sun-light treatments. *Journal of Food Science and Technology-Mysore,* **52(9)**, 5579-5589.

Balcı, F. and Bayram, M. (2017). Modification of mechanical polishing operation using preheating systems to improve the bulgur color. *Journal of Cereal Science,* **75**, 108-115.

Barbosa-C´anovas, G.V. , Ortega-Rivas, E., Juliano, P. and Yan, H. (2006). *Food powders: Physical Properties, Processing, and Functionality*: Springer Science & Business Media.

Bayram, M. (1997). *Search for improving of bulgur production techniques.* (Master Thesis), Gaziantep University.

Bayram, M. (2000). Bulgur around the world. *Cereal Foods World,* **45(2)**, 80-82.

Bayram, M. (2003). *Production of bulgur-like foods from soybean and rye.* (Ph. D. Thesis), University of Gaziantep.

Bayram, M. (2005a). Determination of the sphericity of granular food materials. *Journal of Food Engineering,* **68(3)**, 385-390.

Bayram, M. (2005b). Modelling of cooking of wheat to produce bulgur. *Journal of Food Engineering,* **71(2)**, 179-186.

Bayram, M. (2006). Determination of the cooking degree for bulgur production using amylose/iodine, centre cutting and light scattering methods. *Food Control,* **17(5)**, 331-335.

Bayram, M. (2007a). Application of bulgur technology to food aid programs. *Cereal Foods World,* **52(5)**, 249-256.

Bayram, M. (2007b). Bulguration: Combined Cooking and Drying Operation. In V. N. Pletney (Ed.), *Focus on Food Engineering Research and Developments*: Nova Publishers.

Bayram, M. (2011). Comparison of unsplit inshell and shelled kernel of the pistachio nuts. *Journal of food engineering,* **107(3-4)**, 374-378.

Bayram, M. and Balcı, F. (2011). Storage of Flour. In Derya Gülsoy (Ed.), *The Miller's Handbook Wheat & Flour* (pp. 199-227). Parantez Cong. and Tour. Org. and Publication Co., İstanbul.

Bayram, M. and Bozkurt, H. (2007). The use of bulgur as a meat replacement: bulgur-sucuk (a vegetarian dry-fermented sausage). *Journal of the Science of Food and Agriculture,* **87(3)**, 411-419.

Bayram, M., Kaya, A. and Öner, M. D. (2004a). Water absorption, leaching and color changes during the soaking for production of soy-bulgur. *Journal of Food Process Engineering,* **27(2)**, 119-141.

Bayram, M. and Öner, M. D. (2005). Stone, disc and hammer milling of bulgur. *Journal of Cereal Science,* **41(3)**, 291-296.

Bayram, M. and Öner, M. D. (2006). Determination of applicability and effects of colour sorting system in bulgur production line. *Journal of Food Engineering,* **74(2)**, 232-239.

Bayram, M. and Öner, M. D. (2007). Bulgur milling using roller, double disc and vertical disc mills. *Journal of Food Engineering,* **79(1)**, 181-187.

Bayram, M., Öner, M. D. and Eren, S. (2004b). Effect of cooking time and temperature on the dimensions and crease of the wheat kernel during bulgur production. *Journal of Food Engineering,* **64(1)**, 43-51.

Bayram, M., Öner, M. D. and Kaya, A. (2004c). Influence of soaking on the dimensions and colour of soybean for bulgur production. *Journal of Food Engineering,* **61(3)**, 331-339.

Bayram, M. and Öner, M.D. (1996). *Bulgur üretiminin bugünkü durumu ve sorunları. II.* Paper presented at the Un-Bulgur-Bisküvi Sempozyumu (Symposium book), Karaman-Turkey.

Bayram, M. and Öner, M.D. (2002). The new old wheat: convenience and nutrition driving demand for bulgur. *World Grain* **(November)**, 51-53.

Bhise, S.R., Kaur, A. and Manikantan, M.R. (2014). Mositure Dependent Physical Properties of Wheat Grain (PBW 621). *International Journal of Engineering Practical Research.*

Bizzarri, O. and Morelli, A. (1980). *Durum Wheat Chemistry and Technology: Milling of durum wheat.* Milan, Italy: Buhler Miag sp A.

Burubai, W. and Amber, B. (2014). Some physical properties and proximate composition of Ipoli fruits. *Journal of Food Processing and Technology,* **5(7)**.

Caba, Z. T., Boyacioglu, M. H. and Boyacioglu, D. (2012). Bioactive healthy components of bulgur. *International Journal of Food Sciences and Nutrition,* **63(2)**, 250-256.

Chakraverty, A. and De, D. S. (1981). Post harvest technology of cereals and pulses.

Chen, H., Liu, Y.L., Zhao, X.Q., Xiao, Y.G. and Liu, Y. (2015). Numerical investigation on angle of repose and force network from granular pile in variable gravitational environments. *Powder Technology,* **283**, 607-617.

Cheng, N. and Zhao, K. (2017). Difference between static and dynamic angle of repose of uniform sediment grains. *International Journal of Sediment Research,* **32(2)**, 149-154.

Çarman, K. (1996). Some physical properties of lentil seeds. *Journal of Agricultural Engineering Research,* **63(2)**, 87-92.

Çömden, M. (1986). Sürekli bulgur üretim tekniği ve bulgur kurutulması. *Gıda Sanayi Araştırma ve Geliştirme,* **86**, 85-91.

Dceda, S., Yabuzoe, T., Takaya, T. and Nishinari, K. (2001). Effects of sugars on gelatinisation and retrogradation of corn starch. *Starch: Advances in structure and function,* **271**, 67.

Dick, J.W. and Matsuo, R.R. (1988). Durum wheat and pasta products. *Wheat: Chemistry and technology,* **2**, 507-547.

Dreher, M. L. (2001). Dietary fiber overview *Handbook of dietary fiber* (pp. 20-35): CRC Press.

Ercan, R. (1986). Bulgur işleme tekniği ve kimyasal bileşimi. *Gıda,* **11(6)**.

Ertaş, N. (2017). A Comparison of Industrial and Homemade Bulgur in Turkey in Terms of Physical, Chemical and Nutritional Properties. *Chemical Industry & Chemical Engineering Quarterly,* **23(3)**, 341-348.

Ertaş, N. and Türker, S. (2012). The Role of Soaking Process on Mineral HCl-Extractabilities, Phytic Acid Content and Trypsin Inhibitor Activity of Common Bean Bulgur. *Food Science and Technology Research,* **18(3)**, 445-453.

Frączek, J., Złobecki, A. and Zemanek, J. (2007). Assessment of angle of repose of granular plant material using computer image analysis. *Journal of food engineering,* **83(1)**, 17-22.

Geankoplis, C. J. (2003). *Transport processes and separation process principles:(includes unit operations)* (Fourth ed.): Prentice Hall Professional Technical Reference.

Geankoplis, Christie J. (1983). Transport processes: Momentum, Heat and mass.

Geldart, D., Abdullah, E.C., Hassanpour, A., Nwoke, L.C. and Wouters, I. (2006). Characterization of powder flowability using measurement of angle of repose. *China Particuology,* **4(03n04)**, 104-107.

Grossel, S. S., Zalosh, R. G. and Safety, A. (2005). *Guidelines for safe handling of powders and bulk solids*: Center for Chemical Process Safety of the American Institute of Chemical Engineers.

Gürsoy, S. and Güzel, E. (2010). Determination of physical properties of some agricultural grains. *Research journal of applied sciences, engineering and technology,* **2(5)**, 492-498.

Hayta, M. (2002). Bulgur quality as affected by drying methods. *Journal of Food Science,* **67(6)**, 2241-2244.

Hayta, M., Alpaslan, M. and Çakmaklı, U. (2003). Physicochemical and sensory properties of soymilk-incorporated bulgur. *Journal of Food Science,* **68(9)**, 2800-2803.

Hoseney, R.C. (1994). *Principles of cereal science and technology*: American Association of Cereal Chemists (AACC).

Hoyle, W. (2001). *Powders and Solids: Developments in Handling and Processing Technologies*: Royal Society of Chemistry.

Igathinathane, C., Chattopadhyay, P.K. and Pordesimo, L.O. (2005). Combination soaking procedure for rough rice parboiling. *Transactions of the ASAE,* **48(2)**, 665-671.

Ileleji, K.E. and Zhou, B. (2008). The angle of repose of bulk corn stover particles. *Powder Technology,* **187(2)**, 110-118.

Işık, E. (2007). Some engineering properties of soybean grains. *American Journal of Food Technology,* **2(3)**, 115-125.

Jones, J. M. (2010). Regulatory Aspects of Whole Grain and Whole Grain Foods: Definitions and Labeling. *Cereal Chemistry,* **87(2)**, 150-154.

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

Kahyaoğlu, L. N. (2009). *Usage of spouted bed and microwave assisted spouted bed dryers in bulgur production.* (Master Thesis), Middle East Technical University.

Kahyaoğlu, L. N., Şahin, S. and Sumnu, G. (2012). Spouted bed and microwave-assisted spouted bed drying of parboiled wheat. *Food and Bioproducts Processing,* **90(C2)**, 301-308.

Kanawade, L.R., Bhosale, B.W. and Kadam, M.S. (1990). Effects of moisture content on certain selected physical properties of pulse seeds. *Journal of Maharashtra Agricultural Universities,* **15(1)**, 60-62.

Kemahlıoğlu, K. and Demirağ, K. (2010). İzmir Piyasasında Tüketime Sunulan Bazı Bulgurların Türk Gıda Kodeksi Bulgur Tebliği ile Türk Standartları Enstitüsü Bulgur Standardı'na Uyumlarının Karşılaştırılması. *Akademik Gıda,* **8(4)**, 29-34.

Koca, A. F. and Anıl, M. (1996). Farklı buğday çeşitleri ve pişirme yöntemlerinin bulgur kalitesine etkisi. *Gıda Dergisi,* **21(5)**.

Köksel, H., Edney, M. J. and Özkaya, B. (1999). Barley bulgur: Effect of processing and cooking on chemical composition. *Journal of Cereal Science,* **29(2)**, 185-190.

Kweon, M., Martin, R. and Souza, E. (2009). Effect of tempering conditions on milling performance and flour functionality. *Cereal chemistry,* **86(1)**, 12-17.

Lam, P.S., Sokhansanj, S., Bi, X., J. Lim, C., J. Naimi, L., Hoque, M., P. Ye, X. (2008). Bulk Density of Wet and Dry Wheat Straw and Switchgrass Particles. *Applied Engineering in Agriculture,* **24(3)**, 351-358.

Lawton, P.J. (1980). Coefficients of friction between cereal grain and various silo wall materials. *Journal of Agricultural Engineering Research,* **25(1)**, 75-86.

Liu, S.D., Zhou, Z.Y., Zou, R.P., Pinson, D. and Yu, A.B. (2014a). Flow characteristics and discharge rate of ellipsoidal particles in a flat bottom hopper. *Powder Technology,* **253**, 70-79.

Liu, SD, Zhou, ZY, Zou, RP, Pinson, D and Yu, AB. (2014b). Flow characteristics and discharge rate of ellipsoidal particles in a flat bottom hopper. *Powder Technology,* **253**, 70-79.

Madrid, M.A., Darias, J. R. and Pugnaloni, L. A. (2017). *A differential equation for the flow rate during silo discharge: Beyond the Beverloo rule.* Paper presented at the EPJ Web of Conferences.

Magallanes-López, A.M., Ammar, K., Morales-Dorantes, A., González-Santoyo, H., Crossa, J. and Guzmán, C. (2017). Grain quality traits of commercial durum wheat varieties and their relationships with drought stress and glutenins composition. *Journal of Cereal Science,* **75**, 1-9.

Mathew, B. K., Adebowale, A. O. and Oladayo, B. O. (2018). Effect of traditional and modified grain-soaking methods on physicochemical characteristics and consumers acceptability of sorghum ogi. *African Journal of Food Science,* **12(3)**, 28-37.

McCabe, W. L., Smith, J. C. and Harriott, P. (1985). *Unit operations of chemical engineering* (Vol. 4): McGraw-Hill New York.

McGlinchey, D. (2008). *Bulk solids handling*: Wiley-Blackwell.

Mohapatra, D. and Rao, P. S. (2005). A thin layer drying model of parboiled wheat. *Journal of food engineering,* **66(4)**, 513-518.

Molina, M.R., De La Fuente, G. and Bressani, R. (1975). Interrelationships between storage, soaking time, cooking time, nutritive value and other characteristics of the black bean (Phaseolus vulgaris). *Journal of Food Science,* **40(3)**, 587-591.

Mousia, Z., Edherly, S., Pandiella, S. S. and Webb, C. (2004). Effect of wheat pearling on flour quality. *Food Research International,* **37(5)**, 449-459.

Njoku, B.A., Banigo, E.O.I. and Ubbaonu, C.N. (2007). Physical and chemical characteristics of some Nigerian wheat (Triticum aestivum L) bulgurs.

Orth, R. A. and Shellenberger, J. A. . (1988). Origin, Production And Utilization of Wheat. In Y. Pomeranz (Ed.), *Wheat: Chemistry and Technology* (Third ed., Vol. I, pp. 1-14). St. Paul, Minnesota, USA: American Association of Cereal Chemists, Inc.

Özboy, O. and Köksel, H. (2002). An application of linear regression technique for predicting bulgur yield and quality of wheat cultivars. *Nahrung-Food,* **46(1)**, 21-24.

Özkaya, H. and Kahveci, B. (1989). Muhtelif buğday çeşitlerinin bulgura işlenmesi sırasında kimyasal bileşiminde meydana gelen değişmeler. *Tübitak, Doğa,* **13**, 644-653.

Pence, J.W., Robertson, J.A. and Ferrel, R.E. (1964). Effects of Processing on B-Vitamin+ Mineral Contents of Bulgur. *Food Technology,* **18(5)**, 765.

Polat, C. (2010). AB Uyum Sürecinde Şanlıurfa ili Bulgur Sanayinin Mevcut Durumu ve Geleceğe Yönelik Beklentileri Üzerine Bir Araştırma. (Master Tezi), Harran Üniversitesi, Türkiye.

Ravi, P. and Venkatachalam, T. (2015). Important engineering properties of paddy.

Raymus, G.J. (1985). Handling of Bulk solids. Chemical engineer's handbook. New York: McGraw Hill.

Riley, G.S. and Mann, G.R. (1972). Effects of particle shape on angles of repose and bulk densities of a granular solid. *Materials Research Bulletin,* **7(2)**, 163-169.

Saulnier, L., Sado, P., Branlard, G., Charmet, G. and Guillon, F. (2007). Wheat arabinoxylans: exploiting variation in amount and composition to develop enhanced varieties. *Journal of Cereal Science,* **46(3)**, 261-281.

Savaş, K. and Basman, A. (2016). Infrared drying: A promising technique for bulgur production. *Journal of Cereal Science,* **68**, 31-37.

Sayaslan, A., Seib, P. A. and Chung, O. K. (2006). Wet-milling properties of waxy wheat flours by two laboratory methods. *Journal of Food Engineering,* **72(2)**, 167-178.

Schulze, D. (2008). Powders and bulk solids *Behaviour, Characterization, Storage and Flow* (pp. 35-74). Springer.

Seçkin, R. (1968). Bulgurun terkip ve yapılışı üzerinde araştırma. *Ankara Üniversitesi Ziraat Fakültesi Yayınları* **(320)**.

Severa, L. (2010). Different Approaches for Coffee Bean Shape and Contour Determination. *Journal of Food Physics*, 33.

Sharma, A. (2003). Wheat grain structure, quality and milling. *Directorate of distance education Guru Jambheshwar University of Science and Technology, Hisar–125,* **1**.

Shewry, P.R. and Hey, S. J. (2015). The contribution of wheat to human diet and health. *Food and Energy Security,* **4(3)**, 178-202. doi: 10.1002/fes3.64

Simons, D.B. and Şentürk, F. (1992). *Sediment transport technology: water and sediment dynamics*: Water Resources Publication.

Singh, B. and Dodda, LM. (1979). Studies on the preparation and nutrient composition of bulgur from triticale. *Journal of Food Science,* **44(2)**, 449-452.

Singh, S., Sharma, N. S., Dar, B. N. and Sharma, S. (2014). Quality of Bulgur Wheat in Relation to Storage. *American Journal of Food Technology,* **9**, 63-68.

Singh, S. and Singh, N. (2010). Effect of debranning on the physico-chemical, cooking, pasting and textural properties of common and durum wheat varieties. *Food Research International,* **43(9)**, 2277-2283.

Smith, G. S., Barta, E.J. and Lazar, M.E. (1964). Bulgur production by continuous atmospheric-pressure process. *Food Technology,* **18(1)**, 89.

Šramková, Z., Gregová, E. and Šturdík, E. (2009). Chemical composition and nutritional quality of wheat grain. *Acta Chimica Slovaca,* **2(1)**, 115-138.

Stoenescu, G., Ionescu, V., Vasilean, I., Aprodu, I. and Banu, I. (2010). Technological effects of the wheat cleaning equipment of an industrial mill. *The Annals of the University of Dunarea de Jos of Galati. Fascicle VI. Food Technology,* **34(2)**, 54.

Tacer, Z. (2008). *Bulgurun fonksiyonel özelliklerinin belirlenmesi.* (Yüksek Lisans Tezi), İstanbul Teknik Üniversitesi.

Teunou, E., Vasseur, J. and Krawczyk, M. (1995). Measurement and interpretation of bulk solids angle of repose for industrial process design. *Powder Handling and Processing,* **7(3)**, 219-228.

Tipples, KH. (1969). The relation of starch damage to the baking performance of flour. *Bakers' Dig.,* **43**, 28.

TSE. (2017). *Bulgur Standardı TS EN, 29960*.

Turhan, M., Oymael, B. and Ekiz, H. I. (2003). Water vapor adsorption of ready-to-cook wheat. *Journal of Food Engineering,* **57(3)**, 269-276.

Ünal, H. G. and Saçılık, K. (2008). Bulgur milling quality with stone mills. *Tarım Makinaları Bilimi Dergisi,* **4(4)**.

Ünal, H. G. and Saçılık, K. (2011). Milling Quality of Hulled Wheat Bulgur with Stone Mill. *Journal of Food Process Engineering,* **34(3)**, 893-904.

Ünüvar, A.D. (2009). *Soyma İşlemi ve Granülasyon Dağılışının Bulgurun Kalitatif ve Besinsel Özelliklerine Etkisi* (Yüksek Lisans), Selçuk Üniversitesi.

Wen, C. Y. (1966). *Mechanics of fluidization.* Paper presented at the Chemical Enginering Progress Symposium Series.

Wills, B. A. and Finch, J. (2015). Particle Size Analysis. *Wills' mineral processing technology: an introduction to the practical aspects of ore treatment and mineral recovery*: Butterworth-Heinemann.

Wójcik, A., Klapa, P., Mitka, B. and Sładek, J. (2018). The use of the photogrammetric method for measurement of the repose angle of granular materials. *Measurement,* **115**, 19-26.

Woodcock, C.R. and Mason, J.S. (2012). *Bulk solids handling: an introduction to the practice and technology*: Springer Science & Business Media.

Yıldırım, A. (2004). *Effect of different millling systems on selected quality parameters of bulgur.* (Master Thesis), University of Gaziantep, Turkey.

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

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

Yılmaz, V.A. (2012). *Siyez (Triticum monococcum L.) ve Durum (Triticum durum) Buğdayların Bulgura İşlenmesinde Bulgur Kalitesi, Biyoaktif Bileşenler ve Antioksidan Aktivideki Değişmeler.* (Yüksek Lisans Tezi), Ondokuz Mayıs Üniversitesi.

Yousif, S. I., Bayram, M. and Kesen, S. (2018). Characterization of Volatile Compounds of Bulgur (Antep Type) Produced from Durum Wheat. *Journal of Food Quality*.

Yüksel, A. N., Öner, M. D. and Bayram, M. (2017a). Development and characterization of couscous-like product using bulgur flour as by-product. *Journal of Food Science and Technology-Mysore,* **54(13)**, 4452-4463.

Yüksel, A. N., Öner, M. D. and Bayram, M. (2017b). Usage of undersize bulgur flour in production of short-cut pasta-like couscous. *Journal of Cereal Science,* **77**, 102-109.

APPENDIX

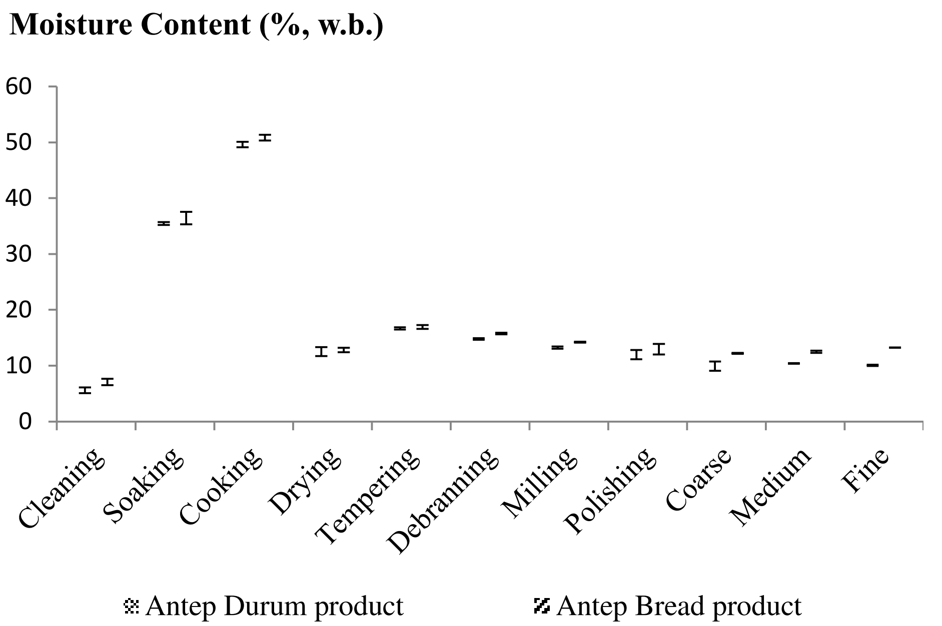


Figure A.1 Moisture content of Antep type bulgur production

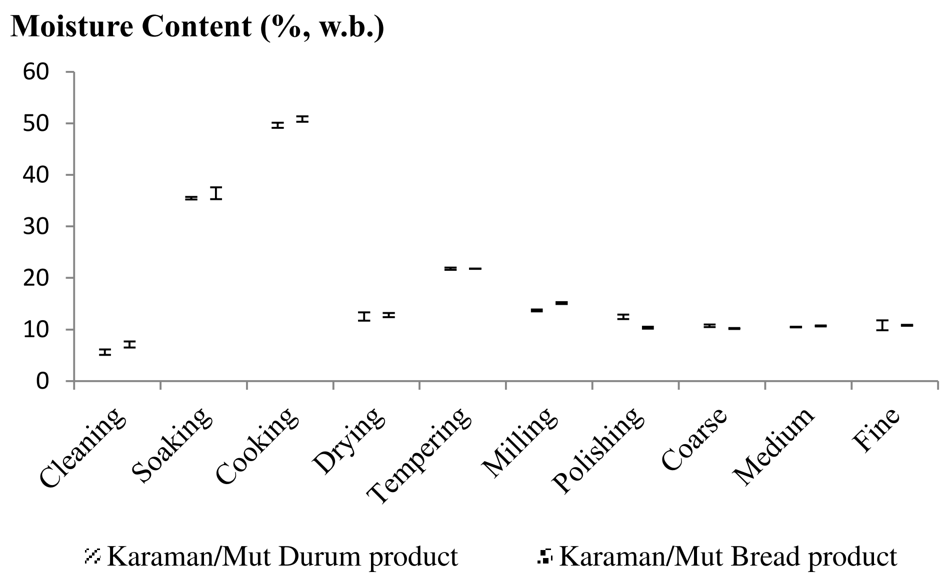


Figure A.2 Moisture content of Karaman/Mut type bulgur production

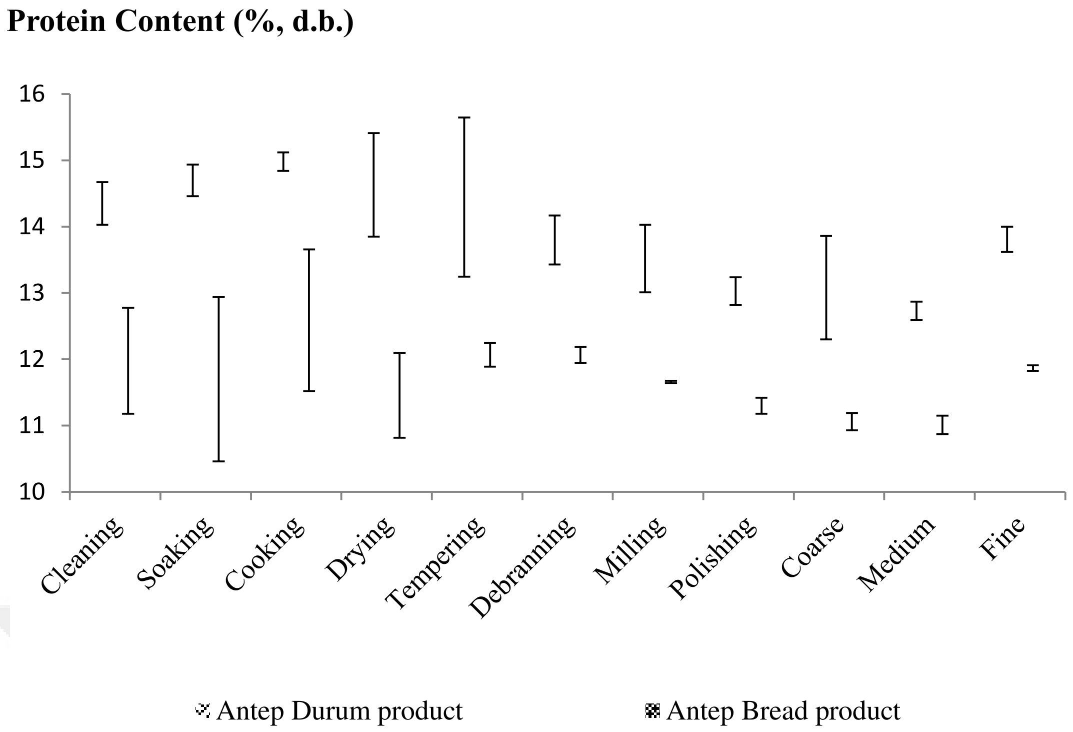


Figure A.3 Protein content of Antep type bulgur production

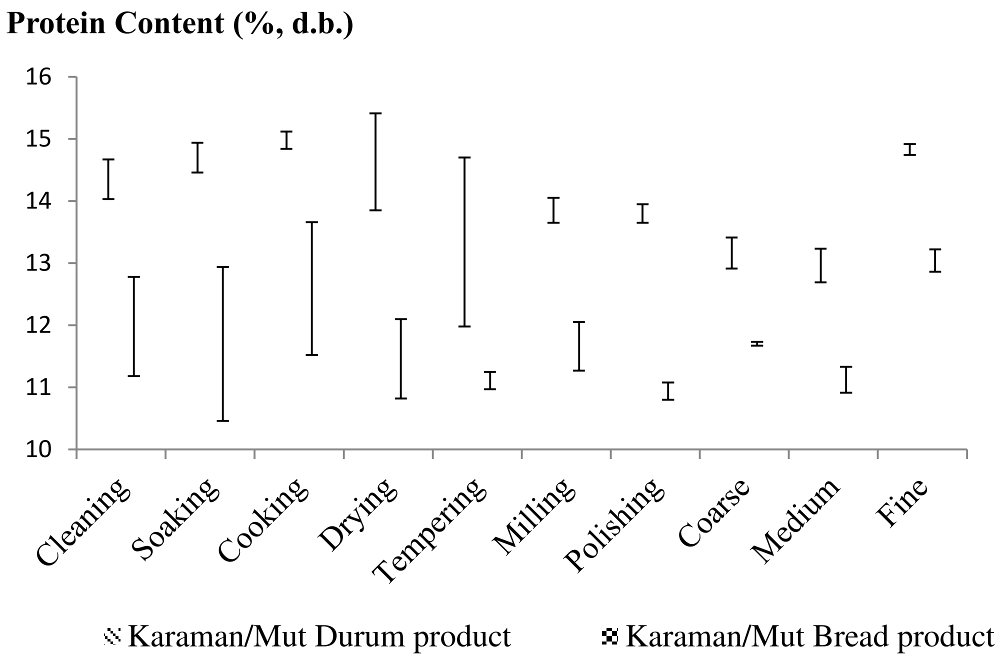


Figure A.4 Protein content of Karaman/Mut type bulgur production

Particle Size (mm)

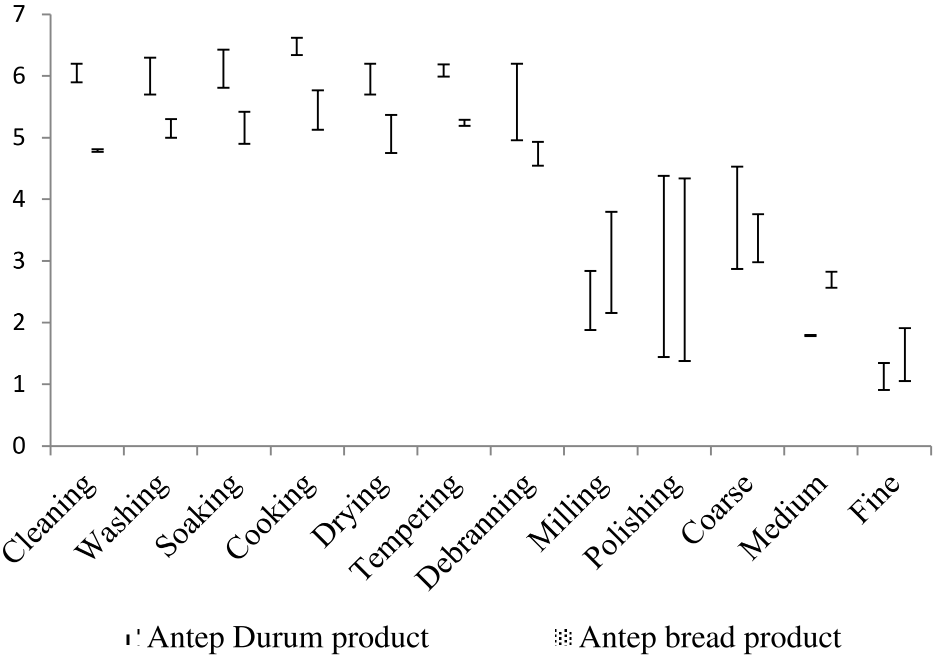


Figure A.5 Particle size of Antep type bulgur production

Particle Size (mm)

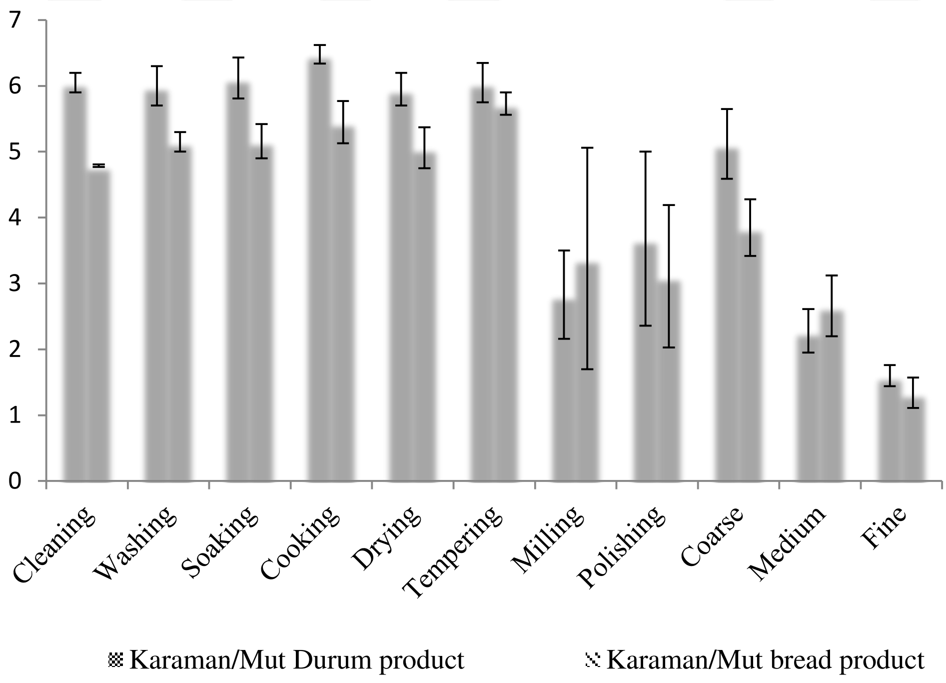


Figure A.6 Particle size of Karaman/Mut type bulgur production

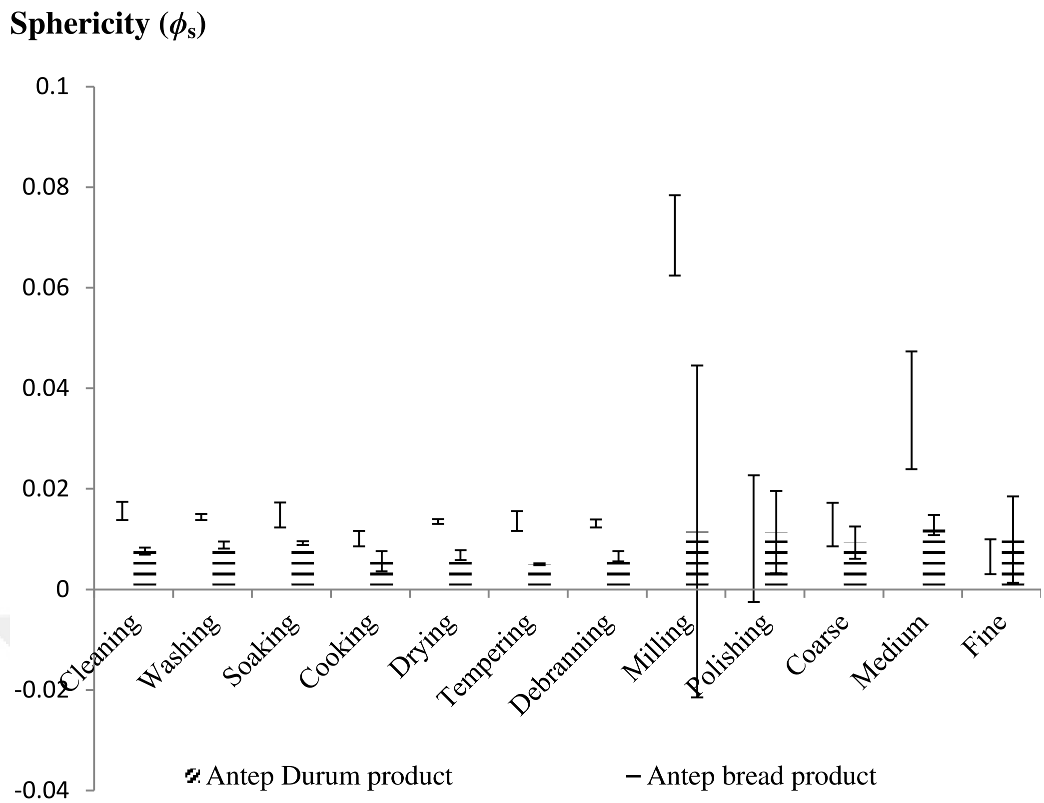


Figure A.7 Sphericity of Antep type bulgur production

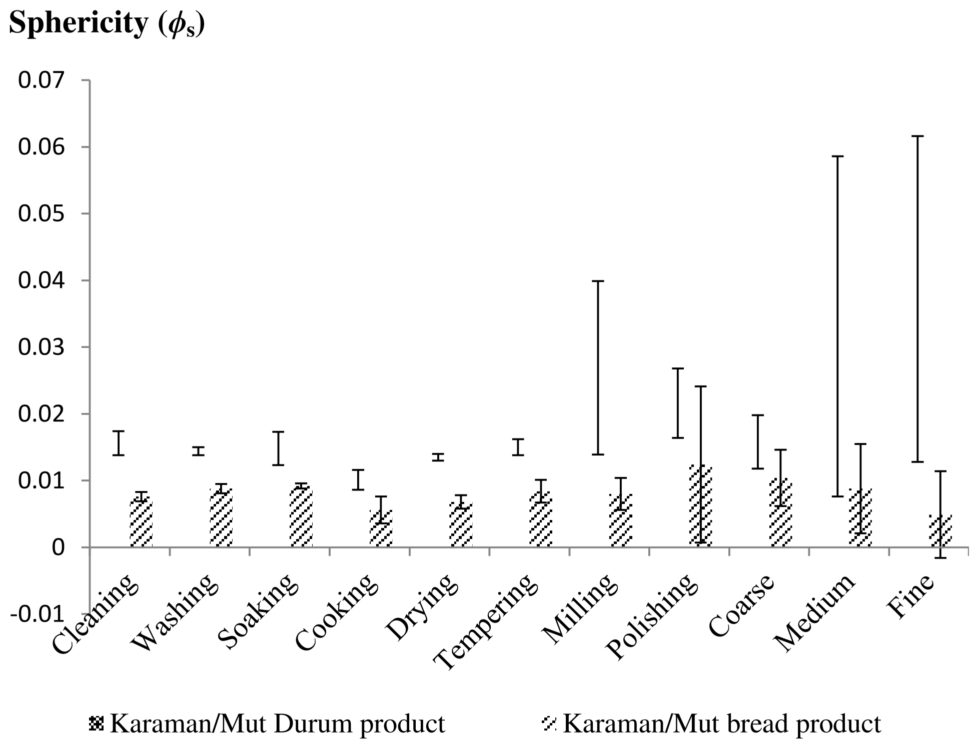


Figure A.8 Sphericity of Karaman/Mut type bulgur production

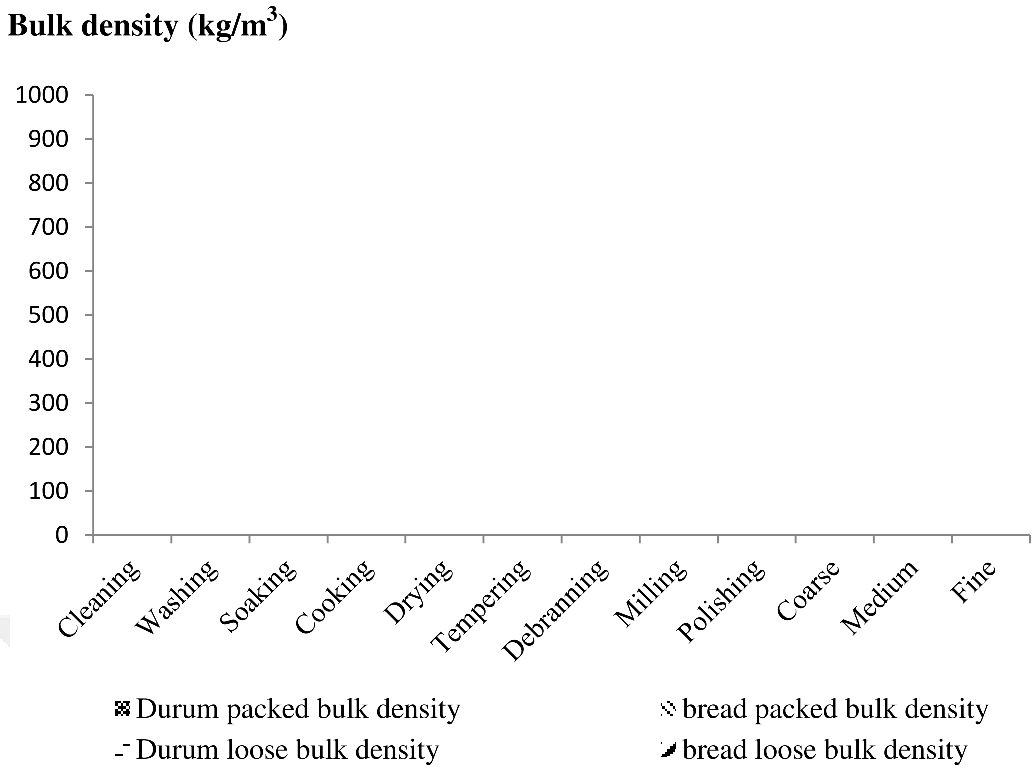


Figure A.9 Bulk density of Antep type bulgur production

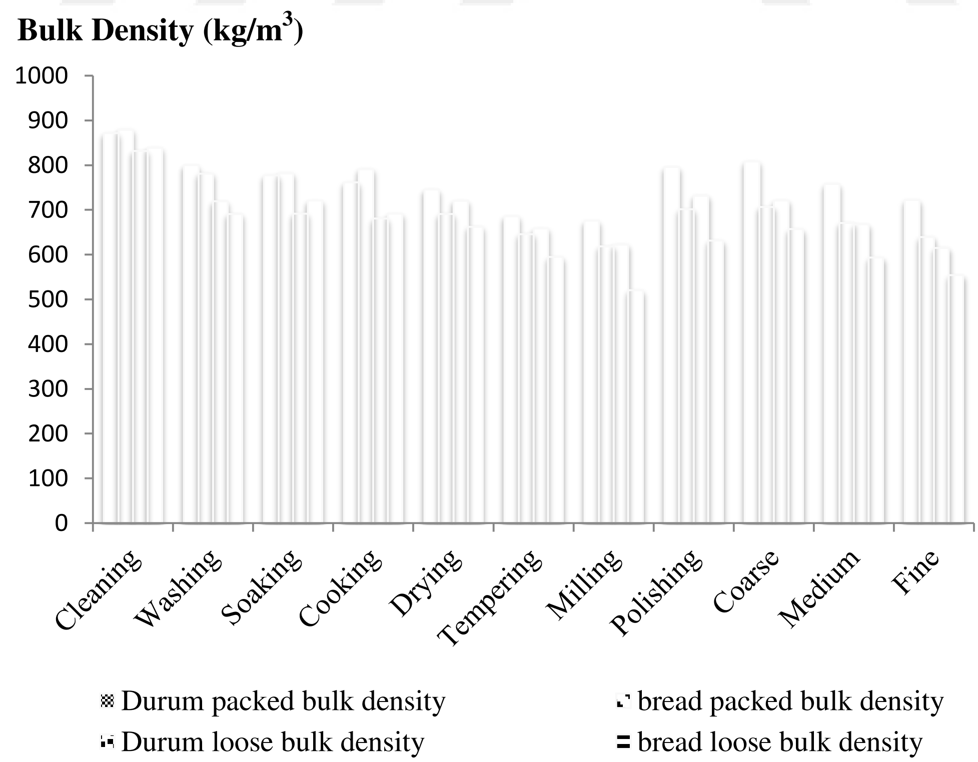


Figure A.10 Bulk density of Karaman/Mut type bulgur production

Angle of Repose (^{o})

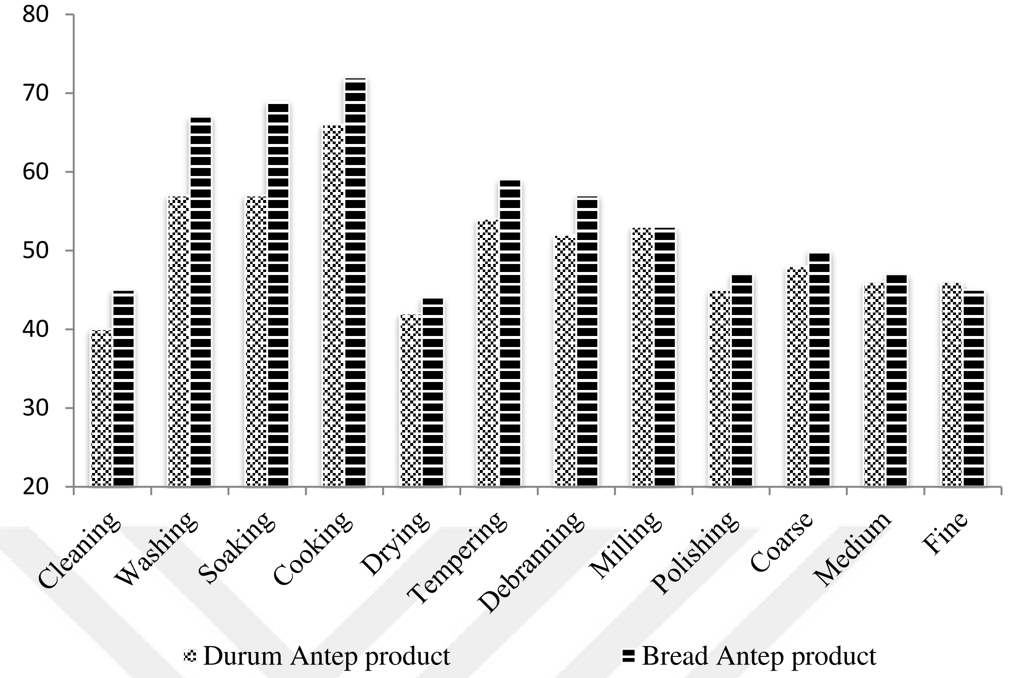


Figure A.11 Angle of repose of Antep type bulgur production

Angle of Repose (^{o})

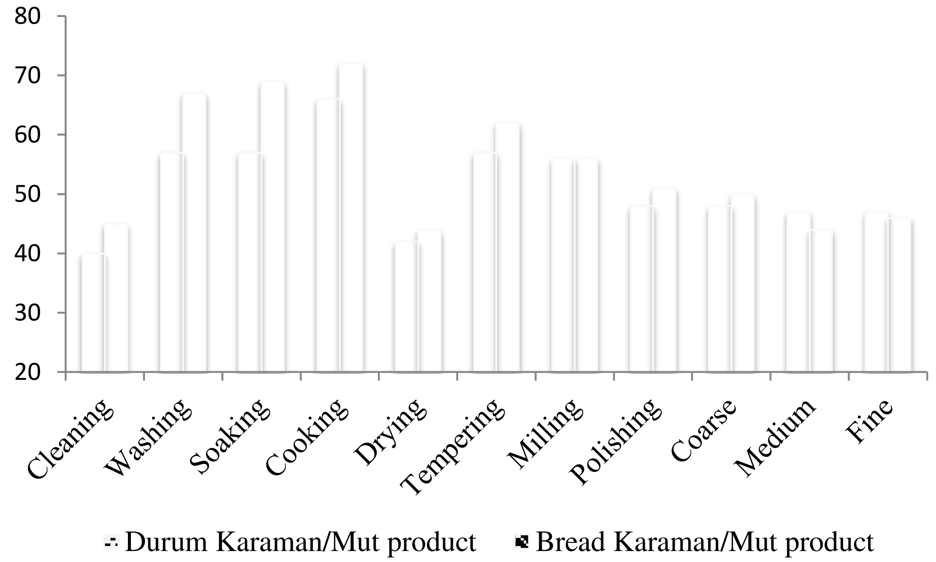


Figure A.12 Angle of repose of Karaman/Mut type bulgur production

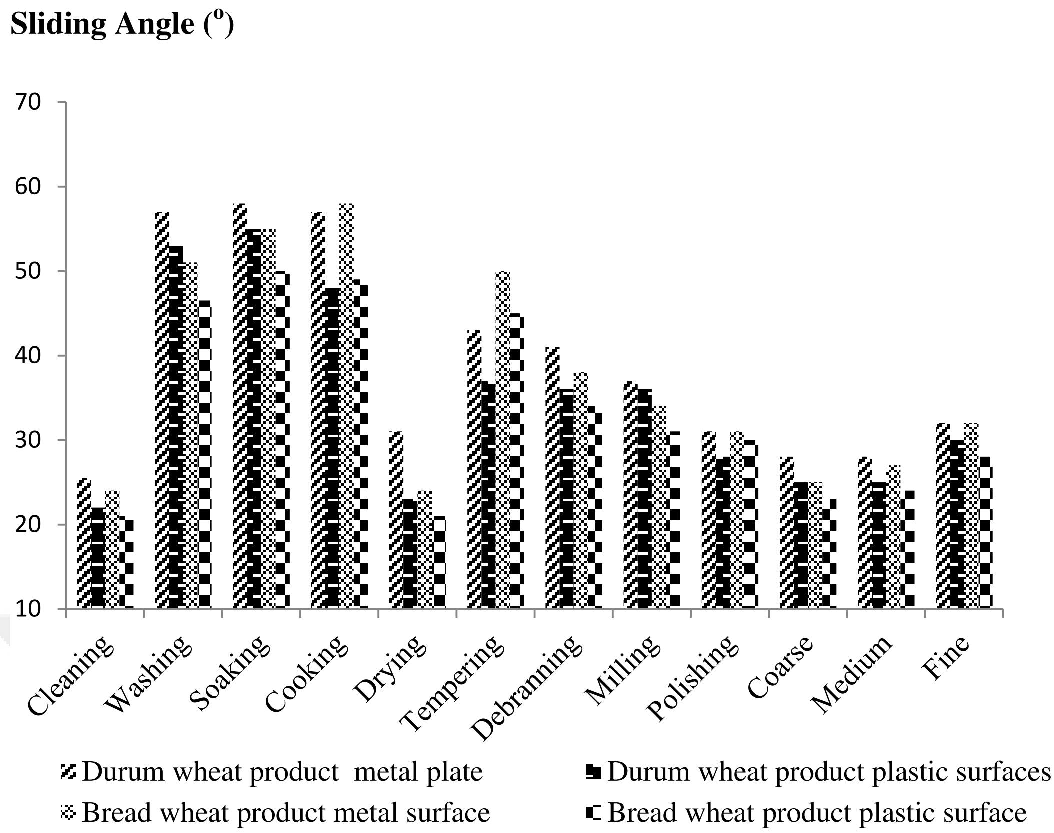


Figure A.13 Sliding angle of Antep type bulgur production

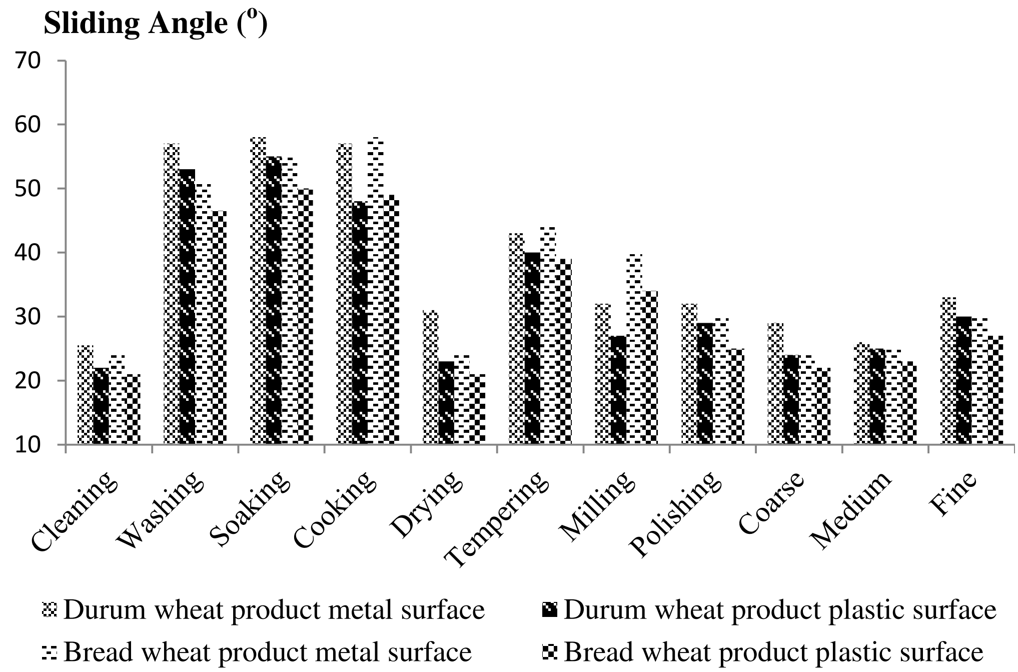


Figure A.14 Sliding angle of Karaman/Mut type bulgur production