MARCH 2018

Ph.D. in Food Engineering

AYŞE NUR YÜKSEL

UNIVERSITY OF GAZİANTEP

GRADUATE SCHOOL OF

NATURAL & APPLIED SCIENCES

USE OF UNDERSIZE BULGUR IN COUSCOUS PRODUCTION

Ph.D. THESIS

IN

FOOD ENGINEERING

BY

AYŞE NUR YÜKSEL

MARCH 2018

Use of Undersize Bulgur in Couscous Production

Ph.D. Thesis

in

Food Engineering

University of Gaziantep

Supervisor(s)

Prof. Dr. Mehmet Durdu ÖNER

Prof. Dr. Mustafa BAYRAM

by

Ayşe Nur YÜKSEL

March 2018

REPUBLIC OF TURKEY
UNIVERSITY OF GAZİANTEP
GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES
DEPARTMENT OF FOOD ENGINEERING

Name of the thesis: Use of Undersize Bulgur in Couscous Production

Name of the student: Ayşe Nur YÜKSEL

Exam date: 09.03.2018

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 Doctor of Philosophy.

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 Doctor of Philosophy.

Prof. Dr. Mustafa BAYRAM Co-Supervisor	Prof. Dr. Mehmet Durdu ÖNER Supervisor

Examining Committee Members:	Signature
Prof. Dr. Mehmet Durdu ÖNER	....
Prof. Dr. İbrahim Halil GÜZELBEY	....
Prof. Dr. Şenol İBANOĞLU	....
Assist. Prof. Dr. Ali YILDIRIM	....
Assist. Prof. Dr. Manolya Eser ÖNER	....

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.

Ayşe Nur YÜKSEL

ABSTRACT

USE OF UNDERSIZE BULGUR IN COUSCOUS PRODUCTION

YÜKSEL, Ayşe Nur
Ph.D. in Food Engineering
Supervisor: Prof. Dr. Mehmet Durdu ÖNER
Co-Supervisor: Prof. Dr. Mustafa BAYRAM
March 2018
151 page

There are three well-known couscous all over the world such as Turkish, African and short-cut pasta-like. Bulgur flour (undersize bulgur) is a by-product of bulgur production, which is a nutritionally valued product have a good potential as a couscous ingredient.

In this thesis, the substitution of *Triticum durum* wheat semolina with undersize bulgur was made at various concentrations to develop nutritious and functional Turkish, African and pasta type couscous. The Influence of the ingredients on quality (protein, ash and cruder fiber contents, bulk density and weight increase), textural (hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness and resilience), functional (total phenol and flavonoid contents and antioxidant activity) and sensory (color, odor, taste, hardness, chewiness and overall acceptability) characteristics of couscous products was determined.

In this study, as a new method, couscous samples were dried by using of packed bed (60 and 80 °C) and microwave dryers (180 and 360 W).

The results revealed that weight increase, total flavonoid content, protein, ash and crude fiber contents, hardness, adhesiveness, cohesiveness, gumminess, chewiness and resilience were significantly ($p \leq 0.05$) affected by bulgur flour substitution in contrast to springiness, bulk density, total phenol content and DPPH scavenging activity.

It was found that the nutritional quality and properties of couscous can be improved by using bulgur flour and new drying techniques.

Key Words: couscous, bulgur flour, packed bed drying, microwave drying

ÖZET

KUSKUS ÜRETİMİNDE ELEK ALTI BULGURUN KULLANILMASI

YÜKSEL, Ayşe Nur
Doktora Tezi, Gıda Mühendisliği Bölümü
Tez Yöneticisi: Prof. Dr. Mehmet Durdu ÖNER
Yardımcı Danışman: Prof. Dr. Mustafa BAYRAM
Mart 2018
151 sayfa

Dünya genelinde iyi bilinen üç çeşit kuskus tipi vardır: Türk, Afrika ve kısa kesim makarna. Bulgur unu (elek altı bulgur) bulgur üretiminin yan ürünüdür ve besinsel anlamda değerli olan bulgur ununun kuskus içerik maddesi olarak kullanılmasında iyi bir potansiyeli vardır.

Bu tezde, besleyici ve fonksiyonel Türk, Afrika ve kısa kesim makarna tipi kuskus geliştirmek için *Triticum durum* buğdayı irmiği ile bulgur unu (elek altı bulgur) çeşitli konsantrasyonlarda ikame edilmiştir. İçerik maddelerinin kuskus ürünlerinin kalite (renk, verim, protein, kül ve ham lif miktarı, yığın yoğunluğu ve ağırlık artışı), tekstürel (dokusal) (sertlik, yapışkanlık, esneklik, yapıştırıcılık, zamklılık, çiğnenebilirlik ve elastikiyet), fonksiyonel (toplam fenolik ve flavonoid miktarı ve antioksidan aktivitesi) ve duyusal (renk, koku, tat, sertlik, çiğnenebilirlik ve kabul edilebilirlik) karakteristikleri üzerindeki etkileri belirlenmiştir.

Bu çalışmada, yeni bir metod olarak, kuskus örnekleri katı yatak (60 ve 80 °C) ve mikrodalga (180 ve 360 W) kurutucu kullanılarak kurutulmuşlardır.

Sonuçlar göstermiştir ki ağırlık artışı, toplam flavonoid miktarı, protein, kül ve ham lif miktarları, sertlik, yapışkanlık, yapıştırıcılık, zamklılık, çiğnenebilirlik ve elastikiyet değerlerinin bulgur unu ikamesinden anlamlı olarak ($p \leq 0.05$) etkilenmesine rağmen esneklik, kütle yoğunluğu, toplam fenolik miktarı ve DPPH yakalama aktivitesi değerleri etkilenmemektedir.

Kuskusun besinsel kalitesini ve özelliklerini geliştirmek için bulgur unu ve yeni kurutma tekniklerinin kullanılabileceği bulunmuştur.

Anahtar Kelimeler: kuskus, bulgur unu, katı yatak kurutma, mikrodalga kurutma

To My Beloved Family

ACKNOWLEDGEMENTS

I wish to express my deepest gratitude to my supervisors Prof. Dr. Mehmet Durdu ÖNER and Prof. Dr. Mustafa BAYRAM for their guidance, advice, criticism, encouragements and insight throughout the research.

I would like to acknowledge the financial and technical support of 1002 - Short Term R&D Funding Program of The Scientific and Technological Research Council of Turkey (TUBITAK) (Project No: 115O117) and University of Gaziantep Scientific Research Project Governing (BAP, Project number: MF.DT.16.10).

I also express my gratitude to TUBITAK for the scholarship from 2211-D Doctoral Scholarship Program for Domestic Industrialization (Sanayiye Yönelik Yurt İçi Doktora Burs Programı).

Thanks to my friends for their deep conversations about life and helps to my problems. You always listen and support and I am always trying to be there for you. Many thanks to my colleagues: R.A. Songül ŞAHİN ERCAN and R.A. Eda ADAL for their help and discussions about studies and life.

I would like to thank to my family: my parents, my brother, my sister and her husband for their endless love, encouragement and trust during my whole life. You are always there for me.

Last but not least, very special thanks to my husband for his love, moral and support. He makes me laugh even when bad days. He always believes in me. In addition, I would also like to express my deepest gratitude to our cat Ponçik. He gives his unconditioned love by massaging with his little paws.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Cereal products are considered as main food for humans and have an important role in human diets due to their nutritional value. Common cereal products are; breads, breakfast cereals, pasta, noodles, couscous, bulgur, biscuits, cookies and cakes, etc.

1.1 Wheat

Wheat ranks third after maize and rice in terms of worldwide production quantity. Wheat is a crop that can grow in a wide range of environmental conditions and that permits large-scale cultivation and long-term storage, making it key to the emergence of urban societies for millennia. Currently, about 65 percent of the wheat crop is used for food, 17 percent for animal feed and 12 percent in industrial utilization, including bio-fuels (Anonymous, 2013).

Wheat is considered of to be the greatest importance among cereals because of its processing characteristics. It is basically classified as soft, hard and durum wheat (Hruskova and Svec, 2009). Soft wheat issued for biscuits, cakes and pastries; durum wheat is preferred for pasta and hard grained wheat issued for noodles, flat breads, pan bread and other products (Orth and Shellenberger, 1988). Wheat quality cannot be simply defined since it changes depending on the workers (from the farmer to those in the processing industry) and end-use (from flour to bread, pasta or cookies). Physical properties of the endosperm, such as hardness, are closely related to the milling process affecting the starch damage, particle size, particle distribution of semolina and flour and total milling yield (Hruskova and Svec, 2009).

Durum wheat (*Triticum turgidum ssp durum*) is the second-most widely cultivated wheat species after hard wheat (*Triticum aestivum L.*). Due to its extra-hard, translucent, light-color properties, it is mainly ground to make semolina for pasta and couscous (Gazza et al., 2011). Durum wheat is the most suitable as a raw material to manufacture such food products as pasta and couscous (gelatinized, dried particles of dough). These products commonly referred as "paste" products because they are made into dough of wheat endosperm and water. Paste is defined as "any shaped and dried dough prepared from semolina, farina or wheat flour, or a mixture of these with water, milk or egg" (Dick and Matsuo, 1988).

A wheat kernel is about 8 mm in length and weighs about 35 mg. The size of the kernels varies depending upon the cultivar and their location in the wheat head or spike. A kernel consists of three main fractions: bran, endosperm and germ (Figure 1.1.) (Hoseney, 1994).

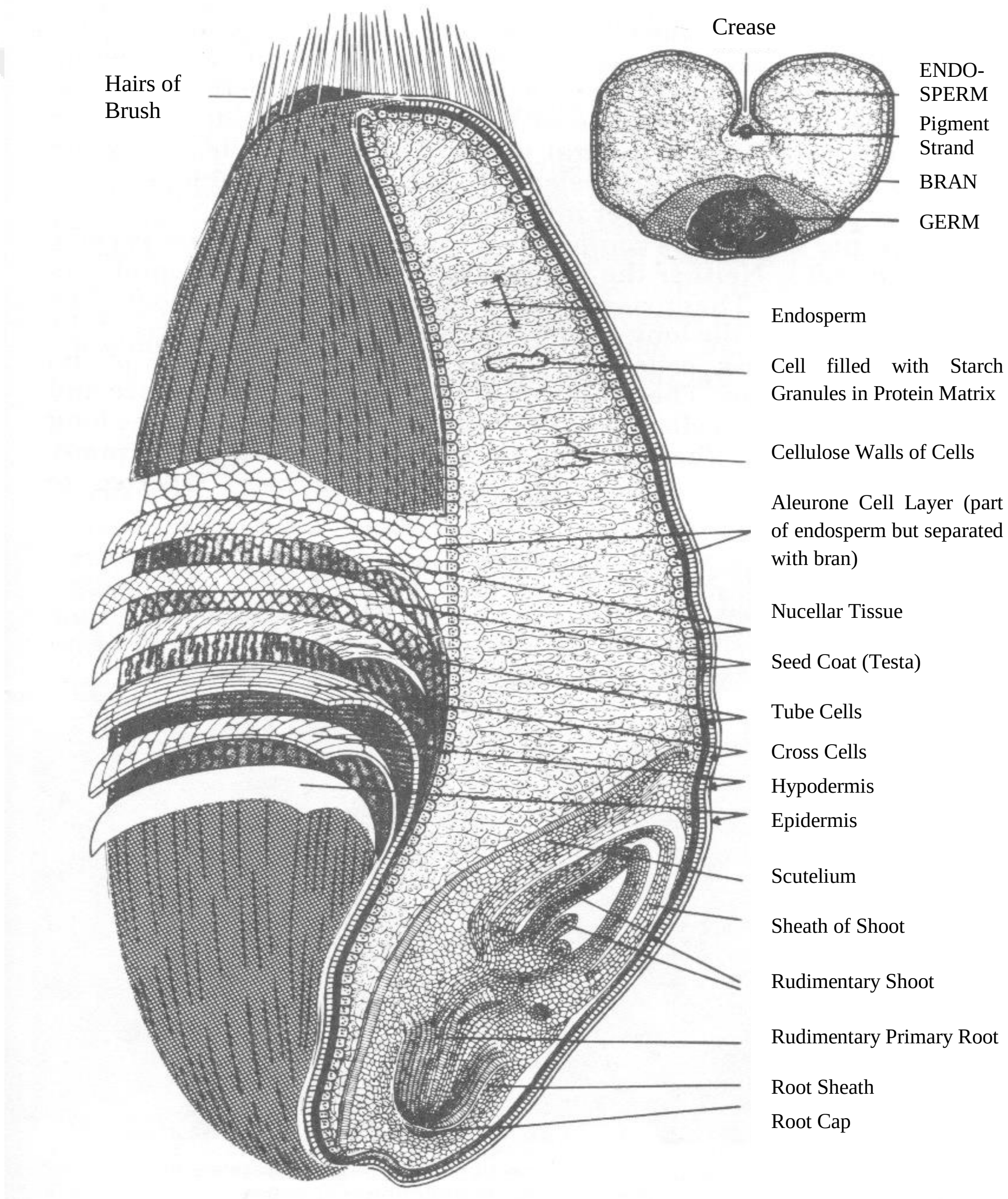

Figure 1.1 Longitudinal and cross sections of a wheat kernel (Hoseney, 1994)

Bran, endosperm and germ fractions are composed approximately 15, 83 and 3 % of wheat kernel, respectively (Orth and Shellenberger, 1988). The main inner volume of the grain is occupied by the starchy endosperm, which becomes the white flour when it is released and crushed to fine particles by the flour miller. The miller has to remove the embryo and the bran layers cleanly from the starchy endosperm to produce a high yield of “white” flour. The aim is thus to remove all the endosperm from the bran particles, whilst keeping the bran and germ tissues as intact as possible, so that the non-endosperm fragments are large and thus easier to remove by sieving (Uthayakumaran, 2010).

Wheat and its products are rich with essential nutrients such as; carbohydrates, proteins, calcium, iron, zinc, potassium, phosphorus, magnesium, dietary fiber and B vitamins (niacin, thiamine, pantothenic acid and riboflavin) (Orth and Shellenberger, 1988). Germ or embryo and aleurone cells surrounding the starchy endosperm are containing the highest concentrations of nutrients. Minerals, many of the B vitamins and protein are found in the aleurone cells. Significant quantities of these components are lost when whole wheat is milled to produce white, endosperm flour because the outer layers of bran is removed with aleurone cells and germ (Betschart, 1988).

1.2 Semolina

A quality pasta product begins with a high quality raw material. Durum wheat (*Triticum durum)* is ideally suited for pasta because of its unique properties like relatively high yellow pigment content, low lipoxygenase activity and high protein content favorable for good cooking quality (Aalami et al., 2007). Durum wheat pasta is characterized by sensory and cooking properties, which are dramatically different from those of pasta produced from soft wheat (*Triticum aestivum*) (De Noni and Pagani, 2010).

Several common factors are considered when evaluating the quality of semolina such as moisture content, granulation, ash and protein contents and color etc. Moisture content of semolina should be as high as without risking spoilage and deterioration during storage, stickiness and poor flow properties depending on excess moisture. A preferred level is 13.5-14.5 % (w.b.). Granulation or particle size distribution is one of the important factors that affecting absorption properties of pasta dough and moreover it affects the quality of finished product. Traditionally, a yellow color in semolina has been associated with good quality. Xanthophylls and lutein are the predominant carotenoid pigments in semolina responsible for the yellow color in pasta. Ash content of durum semolina or flour indicates the bran content. The ash in commercial durum semolina is normally ranges from 0.55-0.75 %. The protein content of semolina is important because it influences the functional quality of pasta. Suitable amounts of gluten protein are necessary to provide desirable attributes of mechanical strength and cooking quality of pasta. Preferred protein level is between 11.0-13.0 % (Dick and Matsuo, 1988).

The dough made from durum wheat semolina has rheological properties ideally suited to the pasta manufacturing process. The content and composition of proteins, gluten strength in particular, are important for the cooking quality of pasta. Semolina is composed of a collection of cells from the starchy endosperm of the wheat plant. These cells are composed of cell wall (bran), starch (endosperm), proteins, and enzymes (Fuad and Prabhasankar, 2010).

1.3 Bulgur

Bulgur (in North America) or burghul (in the Middle East and North Africa) are names given to one of the oldest cereal-based foods (Dick and Matsuo, 1988). It is a whole grain product, which is generally produced from *Triticum durum* wheat by cleaning, cooking, drying, tempering, debraning, milling, polishing (optional) and size classification. Annually in Turkey, about over one million metric ton of bulgur is produced. This production is 2.5, (Bayram and Öner, 2007; Bayram and Öner, 2005; Hayta et al., 2003; Yıldırım et al., 2008a, 2008b) and ~1.2 times greater than pasta and rice productions, respectively. The annual consumption of bulgur is 2.3 and 1.2 times greater than pasta and rice, respectively (Bayram and Öner, 2007; Yıldırım et al., 2008b). Particle size of bulgur changes between 3.5 – 0.5 mm. 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 (bulgur flour) (0.5 mm<) (Yıldırım et al., 2008a, 2008b). According to industrial survey, the amount of the by-product (undersize bulgur) is about 15 % of total produced bulgur and this nutritionally valued product which usually contains bran and bulgur flour obtained in bulgur production, used as an animal feed. Course bulgur is usually boiled or steamed in the presence of meats or vegetables similar to the manner in rice or couscous are prepared. Its flavor and texture varies depending on wheat and the processing method. Fine and very fine bulgur are used in several traditional dishes, where coarse granulation is not required. Bulgur is a nutritious food that stores well and is relatively simple to prepare (Dick and Matsuo, 1988).

Processing steps of wheat during bulgur production provide some functional characteristics as i) resistance to mold contamination, ii) resist to insect attacks, iii) inactivation of enzymes due to cooking process, iv) inactivation of microorganisms due to the cooking and drying (pasteurized), v) numerous nutritional benefits, original wheat kernel nutrients are absorbed during cooking, vi) low fat, high protein, whole grain food, vii) appealing taste, viii) easy preparation and semi or ready to eat food, ix) long shelf life, because starch in wheat is gelatinized and the kernel is almost cooked, so it is more stable than wheat in hot and humid environments, x) inexpensive and economical, xi)consumable as individually due to its nutritional properties and it is a good source for folic acid, xii) the best processing method to decrease the available phytic acid content in contrast to increasing bran content (Bayram et al., 2004).

Starch in wheat is present in the form of granules and composed of amylose and amylopectin. When starch granules are suspended in excess water and heated, starch granules absorb water and swell to some extent. A loss of X-ray crystallinity and birefringence are observed. Amylose partly separates from amylopectin and leaches out of granules. These phenomena are called as gelatinization (Ikeda et al., 2001).

The amounts of worldwide production and consumption bulgur are increasing due to its low price, long shelf life and its classification as semi-ready-to-eat food. The average annual consumption of bulgur in Turkey is approximately 12 kg per person. This consumption is significantly huge in the eastern and southern parts of Turkey (25 kg per person) and in Syria, Iraq, Iran, Israel, Lebanon, Arabia, i.e., Middle East countries (30–35 kg per person) (Bayram and Öner, 2005).

Bulgur is also an important wheat product due to its high dietary fiber content, having 18.3 g dietary fiber per 100 g. Its dietary fiber content is 3.5, 6.8, 1.8, 2.3, 1.3 and 4.3 times greater than rice, wheat flour, oatmeal, whole wheat bread, soybean and pasta, respectively (Bayram and Öner, 2007; Yıldırım et al., 2008a, 2008b).

1.3.1 History of bulgur

Long times of storage are possible due to the low moisture content and being a pre-cooked product. Therefore, it resists mold contamination and attack of insects. Bulgur making from wheat is an ancient process and is still used in small villages in the eastern Mediterranean: boiling the wheat in huge pots (sometimes for days) to completely cooked, drying in the sun with spreading on flat rooftops, then cracking kernels into coarse particles and sieving them to use in different meals.

Bulgur remained as a traditional food of the Mediterranean region for many years and reached to the United States by migrated people from the Middle East. In the mid-1900s intensive research was conducted on the nutritional and technical aspects of the bulgur process and modern nutritionists discovered what the ancients already knew: the value of bulgur as a “perfect food” in terms of nutrients, palatability and keeping quality (Anonymous, 2017b).

1.3.2 Literature review of bulgur

The effects of stone, disc and hammer milling on quality of bulgur were studied by Bayram and Öner (2005). They examined that the particle size distribution, bulk density, surface structure, appearance, 1000 particles weight and dimensions. They found the appearance and surface characteristics of bulgur were significantly affected by hammer milling. Milling yields were found as 98.3, 97.4 and 96.5 % for hammer, stone and disc mill, respectively. In another study of Bayram and Öner (2007), the effects of roller, double disc and vertical disc mills on the quality of bulgur (size, one-thousand particles weight, bulk density and dimension). They found that the highest milling yield (99.19 %) was obtained with roller mill. Yields of double disc and vertical disc mills were found as 94.84 and 97.60 %, respectively. Double disc milled bulgur had the highest bulk density of 74.12 g/100 ml.

Helical disc mill was used to mill bulgur with different disc gaps (1.9, 1.6, 1.3, 1.2, 1.0, 0.8, 0.6, 0.5 and 0.4 mm). Screen analysis, color, yield, loss, energy consumption, capacity, hectoliter-weight (bulk density), ash and moisture contents of bulgur were investigated in the study of Yıldırım et al. (2008a). The decreasing gap of helical disc mill from 1.90 to 0.40 mm decreased the yield from 95.96 % to 13.13 %, hectoliter-weight from 87.37 kg/hl to 81.68 kg/hl, capacity from 705 kg/h to 322 kg/h, ash content from 1.34 % (d. b.) 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 obtained at 0.5 mm disc gap. Due to the abrasion at narrow disc gap heat generation was observed, which caused the evaporation of water from bulgur and decreasing moisture content.

In the study made by Yıldırım et al. (2008b), the effect of ternary roller mill (four rolls and three gaps) on the selected quality parameters of bulgur was researched. Particle size, color, ash content, hectoliter-weight, yield and loss were evaluated for the roller mill. The yields of the roller mill were obtained between 87.86 % and 99.75 % at different gap adjustments. When the particle size decreased, the percent ash was decreased from 2.28 % to 1.46 % due to increase in abrasion effect. A high production yield and capacity were obtained with low energy consumption. It also supplied uniform particle sizes due to multiple milling stages by preventing the escape of kernels from the gaps.

Comparison of the spouted bed and microwave assisted spouted bed drying on affecting physical properties of parboiled wheat and bulgur was made by Kahyaoglu et al. (2010). Drying was performed at different temperatures (50, 70 and 90 °C) and microwave powers (288 and 624 W). They investigated the bulk and apparent density, bulk and apparent porosity, sphericity, color, microstructure and pore size distribution of parboiled wheat after drying. Yield and water absorption capacity were determined 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 and bulk density 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 of bulgur were observed as compared to spouted bed drying.

Hayta (2002) compared the tray, microwave, sun and solar drying of cooked wheat kernels to produce bulgur. He found that solar and microwave drying methods significantly affected the bulk density of bulgur samples. The pilaf bulgur yield was highest for solar-dried bulgur, followed by microwave, tray and sun dried bulgur samples. The drying method affected protein extractability, bulgur yield and water and oil absorption values of bulgur. The lightness value was found significantly higher for solar, sun and microwave dried pilaf bulgur samples compared with tray dried bulgur. The redness and yellowness values of bulgur were also affected by drying methods. The drying method had no significant effect on flavor, mouthfeel and appearance of bulgur samples.

1.4 Couscous

Couscous is a world-wide known traditional cereal product, which is a staple food of North Africa (Aboubacar and Hamaker, 2000; Rahmani and Muller, 1996) and Middle East cuisines. It can be consumed as salad (tabulleh) and side dish with chicken and meat meals, as an alternative for pilaf. Depending on the formulation, processing technique and usage, there are three couscous such as Turkish, African and short-cut pasta-like. Turkish and African couscouses are produced traditionally by hand, which are different from pasta-like.

Pasta-like couscous is generally produced mechanically by using pressing technology (Çelik et al., 2004). Also, pasta-like couscous is widely produced by pasta/macaroni companies by using same pasta production line by changing die of press. The basic industrial (Figure 1.2) and traditional couscous processing steps are: a) mixing and agglomeration of *Triticum durum* semolina with water, b) steaming to precook and c) drying to preserve (Aboubacar et al., 2006; Debbouz and Donnelly, 1996) d) cooling, e) grading to separate by size and f) storage or packaging (Dick and Matsuo, 1988). Wheat flour, semolina, sorghum, millet, maize (Galiba et al., 1988) and barley (Kaup and Walker, 1986) can be used in the couscous production.

In Turkish couscous, it is generally prepared by coating of bulgur granules with semolina, wheat flour and water or milk (Demir et al., 2010). Sometimes egg and milk mixture is used to produce Turkish couscous. Addition of egg and milk increases its nutritional value of the product when compared to pasta-like and African.

1.4.1 History of couscous

The well-known couscous is a traditional food product made by agglomeration of wheat semolina particles with water, developed by the inhabitants of North Africa. Historians have different opinions about the origin of couscous. Some claim that couscous, like pasta, originated from China; while others trace its origin to East Africa. However the most convincing evidence points to a North African origin. Indeed, archaeological evidence dating back to the 9th Century and consisting of kitchen utensils needed to prepare this dish was found in this part of the world.

In the 11th century, Arab-Islamic conquest helped disseminate couscous to all around the North-African region. Economic growth and the development of wheat farming both accelerated this expansion. Thus couscous was brought to Andalusia and the Mediterranean perimeter. Even the 16th century French writer Francois Rabelais was able to appreciate the taste of "Coscoton à la Moresque" in Provence. South America became acquainted with couscous as well, through the Portuguese community who emigrated from Morocco.

The expansion of couscous continued during the 20th century, driven by large waves of migration from North Africa to various European countries and especially France, where this dish became very popular. In fact, many surveys reveal that couscous is second preferred dish among the French.

Now a dish of international renown, couscous is the ambassador of North African cuisine. Couscous remains one of the most attractive and mysterious dishes in the world with its rich tradition (Anonymous, 2016).

1.5 Literature review of couscous

Couscous commonly produced by using semolina and sorghum in Africa and Asia, however in Turkey, traditional Turkish couscous is generally produced by coating wheat bulgur with the wheat flour, water or milk and/or egg.

In Demir et al. (2010)'s research, new couscous product were produced with the addition of chickpea flour and sensory, nutritional and technological properties were determined. Increasing amount of chickpea flour increased the ash, protein and cellulose contents of couscous samples. Addition of chickpea flour significantly ($p<0.05$) affected the flavor, firmness, stickiness and overall acceptability of couscous sample. Acceptable chickpea flour level was found as 50% in terms of technological, nutritional, sensory and functional properties of couscous.

Çelik et al. (2004) produced traditional Turkish couscous from different flours (soy and oat flour) and eggs. The addition of soy and oat flours increased protein content, Ca, K and Fe levels. However, soy flour containing couscous had the highest scores for chewiness and hardness. The odor of soy flour affected couscous preference negatively. Couscous with oat flour was given the lowest scores of taste and odor. Panelists preferred traditional couscous and couscous with eggs or soy flour over couscous with oat flour.

Debbouz and Donnelly (1996) compared home-made, commercial and extruded couscous samples, which were made with semolina, according to their colors, water absorption indexes, degrees of starch gelatinization, cooking qualities and sensory attributes. They observed uniform size, intense yellow color and high degree of starch gelatinization for twin-screw-extruded couscous.

Process parameters of water absorption, barrel temperature, screw speed, mixing time and water temperature were observed in a study that was made by Debbouz and Doetkott (1996) to determine the effects on pasta quality. They found that water absorption and barrel temperature of extruder had the highest effect on pasta brightness, yellowness, firmness, cooked weight and cooking loss. Mixing time had a significant effect on pasta color and firmness, while water temperature affected only firmness.

Rahmani and Muller (1996) investigated thiamin and riboflavin contents of nine couscous samples (five traditional and four commercial) during preparation. Proximate (moisture, protein, fat and ash) and sieving analysis were made. They observed that during steaming average thiamin and riboflavin losses as 15.4±2.7 % and 36.1±5.7 %, respectively.

In another study, the effects of different textures and types of endosperm on production of couscous were observed by Galiba et al. (1988). Corneous endosperm resulted into an increase in flour yield after decortication. Smaller flour particle size provided more water absorption during agglomeration, which was lead to increased couscous yield and also smoother mouth feel was obtained for couscous with moderately fine flour compared to coarser flours.

The effect of different decortication levels of sorghum kernel on couscous quality was also studied by Aboubacar et al. (2006). Ash and protein contents of flours were decreased with increased decortication levels of kernels. They found that there was a decrease in lightness value of couscous samples in contrast to yellowness values as decortication level increased.

Demir and Demir (2016) investigated the effects of different legume flours (soybean, chickpea, lupine, lentil and common bean), buckwheat and wheat germ on couscous quality. They measured ash, protein, moisture, mineral (Ca, Fe, K, Mg, P and Zn) contents, and cooking loss, weight and volume increase values of couscous. In addition, color measurement and sensory analysis were made. While the highest weight increase value was observed with chickpea flour added couscous, the highest value of cooking loss was observed with soybean flour added couscous. Moreover, it was reported that lupine flour and chickpea flour had the highest scores of overall acceptability.

Sidibe (1981) presented a paper in a conference about comparison of couscous yields of different varieties of sorghum grains. Weight increase of the Keninke and Sanio (millet) varieties were yielded more than the Gadiaba and Nio-Fionto sorghums.

Industrial quality (manufactured in Algeria) three durum wheat semolina were used as a raw materials for the agglomeration of couscous experiments by Lefkir (2017). They observed the relation between couscous yields with hydration rate. They indicated that there was negative correlation between the semolina particle size and the lumps yields and also negative correlation between protein content of semolina and couscous yield. Results revealed that hydration caused a raise in the brownness index and reduced the yellowness index. The best hydration rate was found as 38 % due to its better couscous performance.

Couscous produced with sweet potato was studied by Kpomasse (2014). They compared sensory parameters (colour, taste, texture and flavor) of conventional wheat-based couscous with sweet potato couscous. Results indicated that more than 50 % of panelists considered sweet potato couscous as good to very good for all sensory attributes. It showed the product could be accepted by Benin consumers.

Coskun (2013) focused on couscous production method in Turkey and in the world. It was thought that Turkish couscous was very nutritious due to the addition of milk and eggs.

In the study of Opata (2007), fifteen varieties of water yam were used to produce fries, couscous and flour. After cleaning, slicing, steam boiling and cooling, grating was made, then oven drying, milling and sieving were made to produce couscous samples. According to sensory evaluation of couscous samples produced with water yam, light colored couscous was preferred. Stickiness of the samples was not acceptable by panelists.

Technological feasibility to obtain gluten-free couscous based on rice-leguminous supplementation was studied by Benatallah et al. (2008). Semolina of rice (*Oryza sativa)* was substituted with chickpea (*Cicer arietinum*), proteaginous pea (*Pisum arvense*) and field bean (*Vicia faba*). A traditional procedure was used for the three formulae and comparison was made with a control couscous made with wheat semolina (*Triticum durum vulgare*). *C*omparison on the basis of productivity, granulometry, swelling, disintegration level and structure were made. They concluded that three leguminous formulae were feasible to produce and sensory evaluation revealed that Rice-Field bean Couscous had the best scores after hard wheat couscous.

In the literature, there is no study on the usage of by-product in the couscous production. In addition, there is no study on undersize bulgur (bulgur flour). In this thesis, the by-product of bulgur production (undersize bulgur) was used to produce couscous, which is a value added product for food industry.

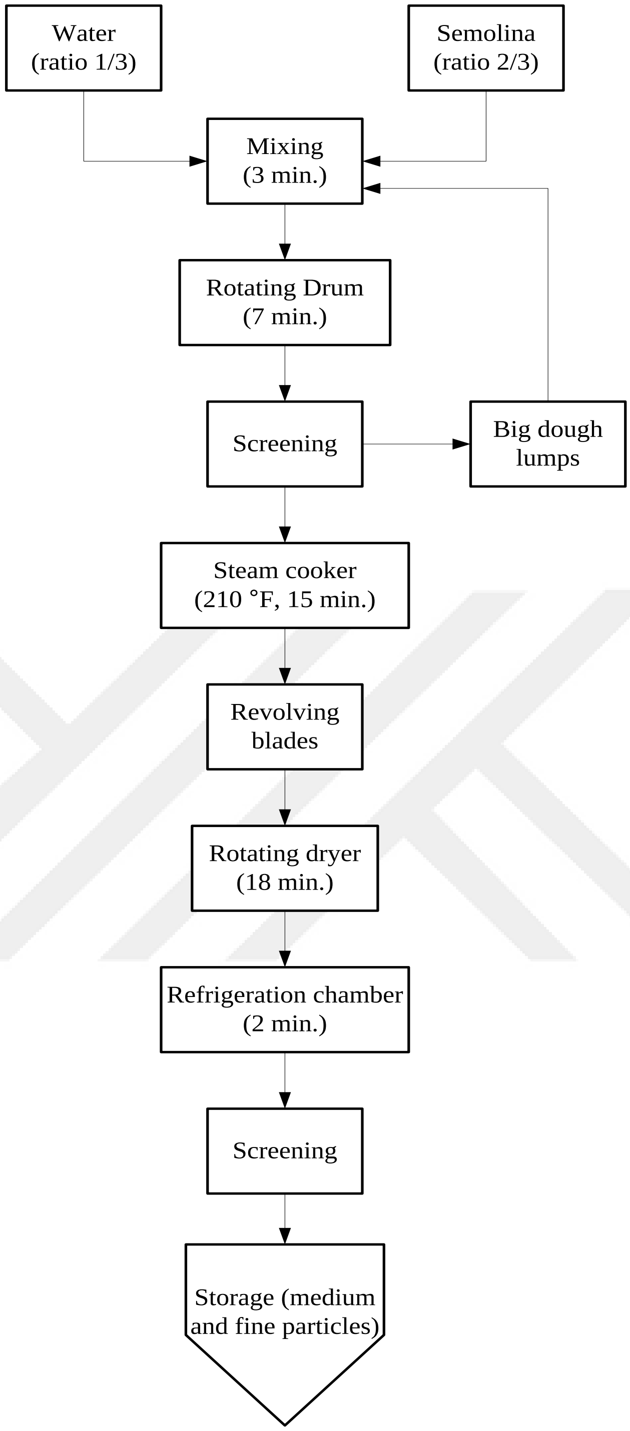

Figure 1.2 Industrial production line of couscous (Anonymous, 2017a)

1.6 Economic value of couscous

Short-cut pasta-like and African couscouses are very popular products in the world, where Turkish couscous is produced and consumed only in Turkey, Georgia, Azerbaijan and Armenia. In Figure 1.3, the distribution of consumption of Turkish and African couscous by countries is given.

About 14.3 million tones pasta (including couscous) is produced worldwide (Anonymous, 2015). In Turkey, the production of pasta quantity has been increased to 1315 thousand tons in 2014 (Anonymous, 2014) and in terms of worldwide production quantity, Turkey ranks third after Italy and United States (Anonymous, 2015). On the contrary, the consumption quantity of pasta in Turkey is lower than other countries (7.5 kg per person per year).

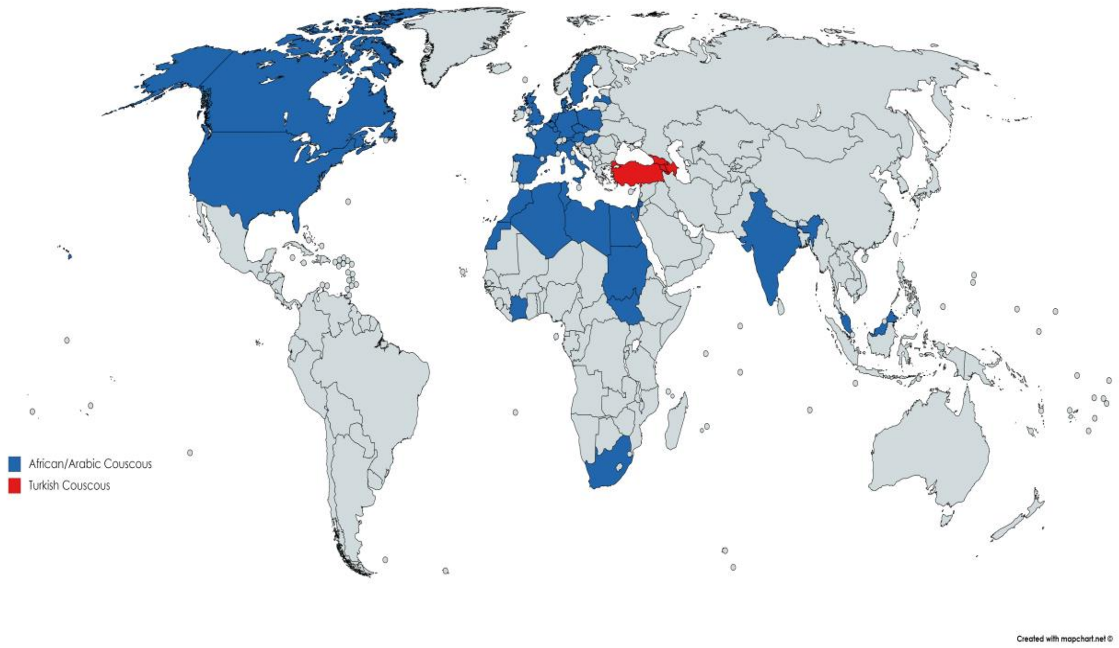

Figure 1.3 The consumption distribution of Turkish and African couscous by countries

In terms of worldwide import quantity of couscous, Turkey ranks one hundred nineteenth between the years of 2012 to 2016. However, Turkey ranks forty-second in the list of exporters. Quantity of exported couscous was decreased from 268 to 231 tons in 2016. Exportation of pasta and couscous is made from Turkey to Iraq, Japan, and United Arab Emirates etc. In Figure 1.4 and Figure 1.5, the importer and exporter of first fifteenth countries in the world are given. Worldwide, total exportation and importation quantity of couscous are 124,481 and 126,799 tons, respectively. Italy, France and Morocco exported couscous in 2016, in terms of quantity 37281, 34809 and 22113 tons, respectively. France ranks first in importers list with 31,436 tons and followed by United Kingdom, Belgium and United States of America with 16763, 8597 and 6870 tons in 2016, respectively. In the first quarter of 2017, Turkey ranks third for exported quantity of couscous after France and United States of America (Anonymous, 2017c).

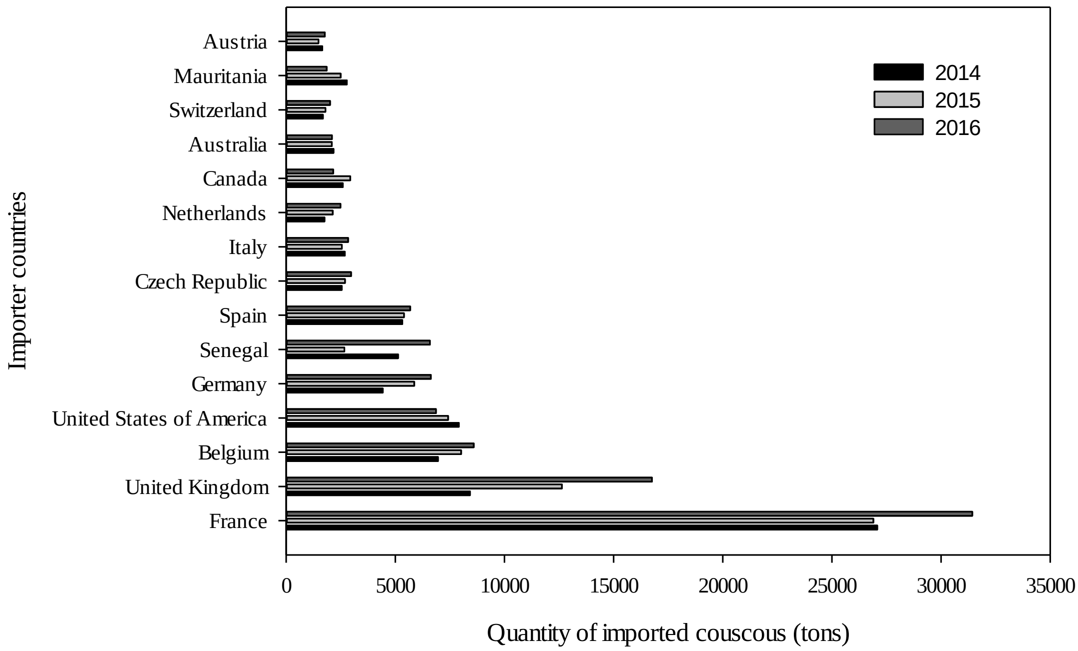

Figure 1.4 Quantity of couscous imported by countries

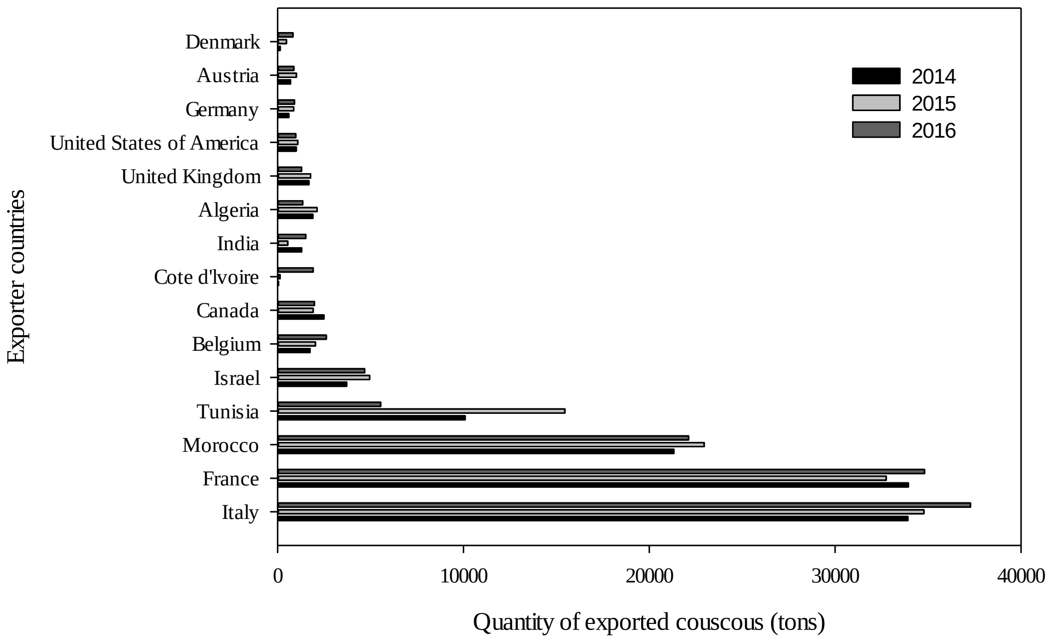

Figure 1.5 Quantity of couscous exported by countries

1.7 Drying methods

Drying of foods is an important and ancient method of preservation process and it is practical to the most of the commercial and agricultural products (De Pilli et al., 2008; Torki-Harchegani et al., 2016). The main objective of drying is the reducing of the moisture content to provide safe storage and preservation. Heat and mass transfer generally happen simultaneously during drying. The quality of the product and the economy of process depends on the knowledge and control of mass transfer (Chayjan and Kaveh, 2014).

Most of the important quality factors are related to the characteristics of the raw material used for the pasta production and to the drying process applied (Zweifel et al., 2000). In pasta production, drying is perhaps the most critical stage because of its impact on texture and flavor development and also, the operational conditions may imply thermal and mechanical damage that affect final pasta texture (Colak et al., 2013). Oven drying facilitates the migration of internal water to the pasta exterior. Poor processing conditions during manufacture of the product can generate cracks thus, reducing quality. This may be the result of extreme temperatures and/or prolonged exposure. Lower drying temperatures (e.g., 40 °C) pose their own risks, including the potential for microbial contamination from prolonged exposure to high humidity (West et al., 2013).

1.7.1 Packed bed drying

Fluid bed, flash, rotary, spray, packed bed and conveyor-truck-tunnel dryers are the examples of convective dryers (Mujumdar, 2014). In convectional drying, heated air is brought into contact with the wet material to be dried to facilitate heat and mass transfer; convection is mainly involved. Pasta products are difficult to dry because moisture slowly migrates to the surface. Hot air is, by itself, relatively efficient at removing free water at or near the surface, whereas the internal moisture takes time to move to the surface.

When drying conventionally, with hot air or infrared, the speed of drying is limited by the rate at which water or another solvent diffuses from the interior to the surface from which it is evaporated. The diffusion occurs by capillarity and the longer or more difficult the diffusion path, the slower the drying. Increasing the ambient temperature, thereby evaporating surface water faster, can sometimes speed up drying. However, this is limited by the rate at which the interior water can reach the surface. It is usually not a good idea to try to dry too quickly since the surface may over dry, case harden or crack because the interior water has not reached it quickly enough. Also, as drying progresses, the path for diffusion of the interior water becomes longer and more difficult and the drying rate slows dramatically (Schiffmann, 2001).

Convectional drying is often a continuous process and is mostly used for products that are relatively low in value. Air drying is usually accomplished by passing air at regulated temperature and humidity over or through the food in a dryer. The rate of drying is affected by temperature, humidity, air velocity and distribution pattern, air exchange, product geometry and characteristics and thickness. The sample is usually placed on mesh trays in one layer or in bulk on a bed or hung from a string for better air circulation over the product. Air circulation can be horizontal or vertical to the layer of bed. The structure and composition, such as fat content, of a product affects the drying rate. In general, the hotter is the air temperature, the faster is the drying rate; and similarly, the higher is the velocity, the higher is the drying rate; the lower is the air humidity, the higher is the drying rate. The relative humidity (a measure of dryness) is lower when air temperature is raised. A dryer must expel air to get rid of moisture, thereby allowing new, lower humidity air to enter the system. However, this process causes heat loss from the dryer. In many cases, two or multistage drying with different conditions could be used, for example, initial drying at 90 °C and then the second or final stage at 60 °C (Rahman, 2007).

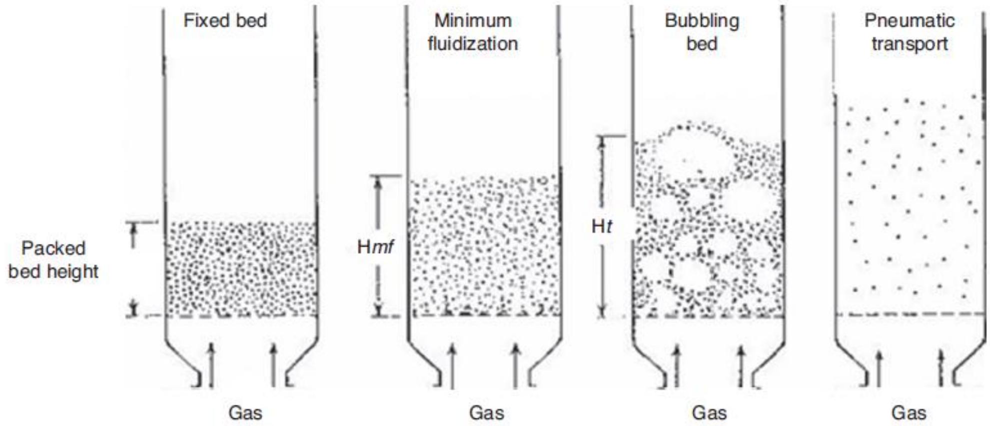

Figure 1.6 Hydrodynamic behavior of fluidized bed (Philippsen et al., 2015)

Fluid bed dryer is one of the conventional drying method, known as uniform method and commonly used in the dehydration of fruits, vegetables and agricultural products (Chayjan and Kaveh, 2014). In fluidized bed dryer, the product pieces are suspended in the heated air throughout the time required for drying (Singh and Heldman, 2009). Using fluidized bed dryer has several advantages, such as; i) uniform moisture distribution in the product, ii) lowering the initial costs if smaller drying chamber used, iii) higher drying capacity with higher heat and mass transfer (Hashemi et al., 2009). In contrast, as a disadvantage, fluidization causes breaking of fragile particles. Therefore, packed bed dryer is more efficient than fluidized bed dryer for the drying of fragile food products. As mentioned previously, couscous particles are very fragile. Therefore, drying mechanism is very critical. The use of packed-bed dryer (Figure 1.6) instead of fluidized bed dryer will be suitable to prevent the breaking of couscous particles during fluidization. In the packed bed drying operation, hot air inlets at the bottom of column-bed, then pass through bed between particles voids. Especially it is an effective drying operation.

1.7.2 Microwave drying

Thermal damage on quality attributes such as color, flavor, nutrients and reduction in bulk density and rehydration capacity of the dried product due to higher temperature and longer drying time occurs in hot-air drying. To overcome these problems, increasing interest in microwave drying took place to achieve fast and effective drying with preserving high quality of products (Vadivambal and Jayas, 2007).

Microwaves are electromagnetic waves in the frequency range of 300 MHz to 300 GHz (equivalent to a wavelength of 1±0.01 m), generated by a magnetron type vacuum tube. Electromagnetic energy at 915 and 2450 MHz can be absorbed by water containing materials or other “lossy” substances, such as carbon and some organics, and converted to heat (Khraisheh et al., 1997; Maskan, 2000). Microwaves can transmit energy in a different way. They travel through the food and provide volumetric heating. The usual temperature gradient in the particle can be reversed so that the center is warmer than the surroundings. This effect accelerates the mass transfer (Erle, 2010).

Major disadvantages of hot air drying of foods are low energy efficiency and longer drying time during the falling rate period. Because of the low thermal conductivity of food materials in this period, heat transfer to the inner sections of foods during conventional heating is limited. The desire to eliminate this problem, prevent significant quality loss and achieve fast and effective thermal processing has resulted in the increasing use of microwaves for food drying. Microwave drying is rapid, more uniform and energy efficient compared to conventional hot air drying (Maskan, 2000).

Microwave heating is based on the formation of electromagnetic energy into thermal energy. Materials can absorb the microwave energy and convert it into heat internally (Vadivambal and Jayas, 2007). Moisture from the food product is removed without shrinkage problem in the microwave drying operation (Prabhanjan et al., 1995). Several advantages in microwave drying are; i) reduction in drying time, ii) better rehydration characteristics and iii) high thermal efficiency when compared to hot-air drying. In this study, microwave was used due to no damaging risk to fragile couscous particles.

The effects of microwave and conventional drying (hot air) on the quality characteristics of cooked pasta were compared. Experiments were carried out on pasta type spaghetti. A huge difference was noticed between times necessary to dry samples by hot air and by microwaves, in fact in the first case, the drying time was on the average 204.5 min vs. 61.7 s of microwave treatment (average) (De Pilli et al., 2009).

Berteli and Marsaioli (2005) studied the hot-air drying of short-cut pasta with the assistance of microwave. Moisture of product decreased from 23 to 12 % (w.b.). They observed more than ten times shorter drying time (18-19 min) compared with conventional drying (6.5 h) without fissures in end product.

Microwave technology is also successfully used to dry macaroni and other small pasta shapes (Kulp, 2000). The drying time for these shapes is less than 2 hours and the advantages are; besides reduced drying times, improved product color and cooking quality as well as reduced microbiological growth and operating costs.

Comparison of the quality characteristics of short-cut macaroni dried by (i) conventional hot air, (ii) microwave energy alone using various microwave power intensities and (iii) hot air followed by microwave energy had been made by Altan and Maskan (2004). Color, firmness, cooking loss, weight increase after cooking and protein solubility were determined. Combination of hot air/microwave resulted better cooking properties. Drying time was also shortened by the combined drying system with resulting improved physical, textural and cooking properties of macaroni samples.

1.8 Thin-layer drying models

Thin-layer drying models used in the study are shown in Table 1.1. These models take into account the external resistance to moisture transport process between the material and atmospheric air, provide a greater extend of accurate results, give a better prediction of drying process behaviors and make fewer assumptions due to their reliance on experimental data. Thus, these models have proved to be the most useful for dryer engineers and designers (Onwude et al., 2016).

Modified Page II model was derived from Newton's law of cooling. As reported in Erbay and Icier (2010), this modified Page model was used to describe the drying of soybeans.

Modified Henderson and Pabis model is a third term general solution of the Fick's second law of diffusion for shortcomings of the Henderson and Pabis model. First term explains the last part of the drying process of food and agricultural products, which occurs largely in the falling rate period, the second term describes the midway part and the third term explains the initial moisture loss of the drying process.

Table 1.1 Thin-layer drying models

Model Name	Model	Reference
Modified Page II	$MR = \exp(-(kt)^n)$	Togrul and Pehlivan, 2003; Vega-Galvez et al., 2010
Modified Henderson and Pabis	$MR = a\exp(-kt) + b\exp(-gt) + c\exp(-ht)$	Akpinar et al., 2003; Zenoozian et al., 2008
Hii and others	$MR = a\exp(-kt^n) + b\exp(-gt^n)$	Hii et al., 2009
Midilli and others	$MR = a\exp(-kt^n) + bt$	Midilli et al., 2002
Weibull	$MR = \exp(-(t/b))^a$	Vega-Galvez et al., 2010
Logarithmic	$MR = a\exp(-kt) + b$	Ertekin and Yaldiz, 2004
Wang and Singh	$MR = 1 + at + bt^2$	Omolola et al., 2014; Vega-Galvez et al., 2010
Silva and others	$MR = \exp(-at - b\sqrt{t})$	Onwude et al., 2016
Peleg	$MR = 1 - t/(a + bt)$	da Silva et al., 2015

k is the drying constant, a, b, c, g, h and n are the parameters.

The Hii and others model involves a combination of the Page and the two-term model with the inclusion of a dimensionless empirical constant “n” (Onwude et al., 2016). Hii et al. (2009) proposed the model for the drying of cocoa beans, however the model has been found appropriate for the drying kinetics of some fruits (Onwude et al., 2016).

Midilli et al. (2002) proposed a new model with the addition of an extra empirical term that includes *t* to the Henderson and Pabis model (Erbay and Icier, 2010).

Logarithmic model is also a modified from of the Henderson and Pabis model. Wang and Singh model gives a good fit to the experimental data of drying of fruits (Onwude et al., 2016).

An empirical model for the kinetic modeling of chickpea was proposed by da Silva et al. (2013). For Peleg model there is no physical and theoretical interpretation, however it has been applied successfully only in describing the drying behavior of banana (Onwude et al., 2016).

1.9 Estimation of the effective moisture diffusivity during drying

The effective moisture diffusivity, which is a function of temperature and the moisture content of a material, is an important transport property in the modeling of the drying process of foods. According to Crank (1975), Fick’s second law of diffusion (Eq. 1.1) is used to interpret the drying process when moisture diffusion is one of the main mass transfer mechanisms (López et al., 2016). Effective moisture diffusivity is affected by composition, moisture content, temperature and porosity of the material (Demirhan and Ozbek, 2010a).

$$\frac{\partial x}{\partial t} = D_{eff}\,\frac{\partial^2 x}{\partial L^2} \qquad (1.1)$$

In Eq. 1.2, n equals to 1 for long drying periods. Eq. 1.1 can be written for sphere, slab and cylinder as Eqs. 1.3, 1.4 and 1.5, respectively.

$$MR = \frac{6}{\pi^2}\sum_{n=1}^{\infty}\exp\left(\frac{-n^2 D_{eff}\pi^2 t}{L^2}\right) \qquad (1.2)$$

$$MR = \frac{6}{\pi^2} \exp\left(\frac{-D_{eff} \pi^2 t}{R^2} \right) \tag{1.3}$$

where D_{eff} is the diffusion coefficient ($m^2\ s^{-1}$); t is the drying time (s); R is the radius of a sphere (m).

$$MR = \frac{8}{\pi^2} \exp\left(\frac{-D_{eff} \pi^2 t}{L^2} \right) \tag{1.4}$$

where L is the thickness of a slab (m).

$$MR = \frac{4}{R^2} \frac{1}{\beta_n^2} \exp\left(-D_{eff} \beta_n^2 t \right) \tag{1.5}$$

where R is the radius of a cylinder (m); β_n is Bessel function.

As reported by Onwude et al. (2016) and Erbay and Icier (2010), the boundary conditions for thin-layer drying models are

i. the product is homogenous and isotropic
ii. the material properties are constant and the shrinkage is neglected
iii. the pressure variations are neglected
iv. evaporation is occurring only at surface
v. the mass transfer is symmetrical with uniform moisture distribution during process
vi. surface diffusion is ended, so the moisture equilibrium arises on the surface
vii. temperature distribution is uniform and equals to the ambient drying air temperature during the drying process
viii. the heat transfer occurs by conduction within the product and by convection outside of the product
ix. effective moisture diffusivity is constant versus moisture content during drying.

1.10 The aims of this study

As mentioned before, the amount of the by-product (undersize bulgur) is available at high level during bulgur production according to industrial survey and this nutritionally valued product, which usually contains the bran, used as an animal feed.

In this study, it is aimed;

- to use of bulgur flour (undersize bulgur) and develop nutritious and functional Turkish, African and short-cut pasta-like couscous by substituting *Triticum durum* wheat semolina with undersize bulgur at various concentrations;
- to find out the optimum level of substitution;
- to study the influence of the ingredients on quality (color, yield, protein and ash contents, cooking loss, weight and volume increases, bulk density etc.);
- to study the effects of the ingredients on functional (total phenolic and flavonoids contents, antioxidant activity) property;
- to study the influence of the ingredients on textural (adhesiveness, cohesiveness, hardness, chewiness, gumminess, springiness and resilience) and sensory (chewiness, hardness, odor, taste, color and general acceptability) characteristics of developed couscous samples;
- to investigate crude fiber contents of couscous samples;
- to evaluate drying rate curves of packed bed and microwave drying;
- to make mathematical modeling of packed bed and microwave drying of couscous samples.

CHAPTER 2

MATERIALS AND METHODS

2.1 Materials

Undersize bulgur (bulgur flour, <0.8 mm) produced from *Triticum durum* wheat was obtained from a local factory in Gaziantep, Turkey. Semolina produced from *Triticum durum* wheat (the particle size of between 0.5 and 1.00 mm), milk and eggs were obtained from a local market. Distilled water was used in all experiments and formulations. All chemicals and standards used in proximate and phytochemical analysis were obtained from Sigma-Aldrich Chemie GmbH (Germany).

2.2 Couscous preparation

The quantities were given based on the ratio of total semolina and bulgur flour weight (w/w). The quantity of water, milk and eggs to prepare dough was obtained by trial and error based on suitable dough stickiness, texture and consistency. As a control (semolina-couscous), the couscous sample was produced using the quantity of 100 % durum semolina (0 % of bulgur flour).

In this study, three different couscous were studied such as pasta-like, African and Turkish.

2.2.1 Pasta-like couscous

Experimental set-up is shown in Figure 2.1. Short cut pasta type couscous was produced by using a small scale pasta machine (Dolly, La Monferrina, Italy) by substituting *Triticum durum* semolina with undersize bulgur (bulgur flour, <0.8 mm) at different quantities (25, 50, 75 and 100 %). Yields (%, w/w) were calculated by weighing total mix and produced uncooked couscous. The formulations are given in Table 2.1.

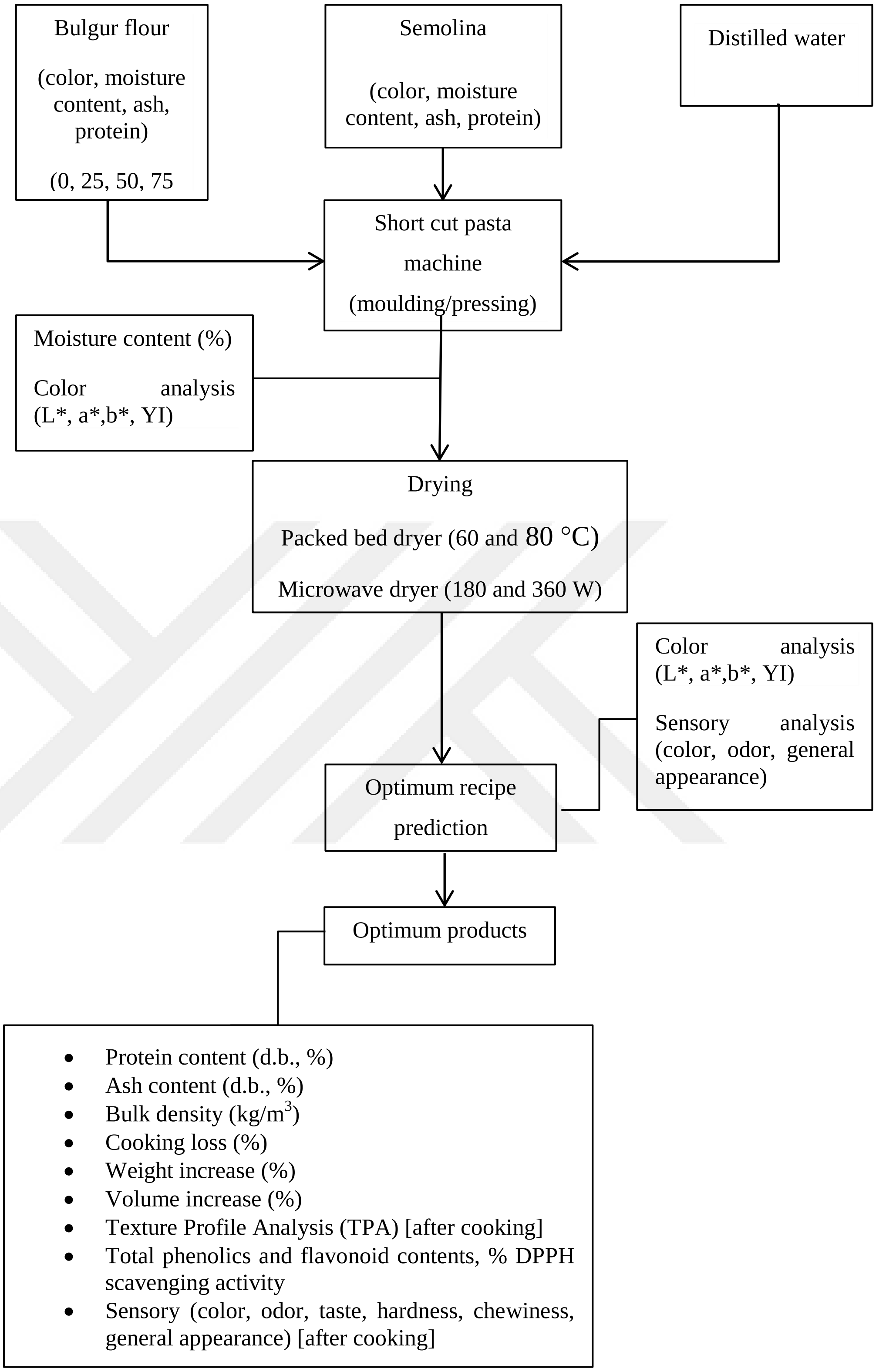

Figure 2.1 Experimental setup of pasta-like couscous

Table 2.1 Compositions of short-cut pasta-like couscous

Compositions	Bulgur flour (%, w/w)	Semolina (%, w/w)	Water (%, w/w)
1	0	100	33.25
2	25	75	33.25
3	50	50	33.25
4	75	25	33.25
5	100	0	33.25

The quantities of water were calculated according to total semolina and bulgur flour weight.

2.2.2 African couscous

As a second type African/Arabic type couscous was studied. Experimental set-up is shown in Figure 2.2. African/Arabic type couscous was produced manually by substituting *Triticum durum* semolina with undersize bulgur (<0.8 mm) at different quantities (25, 50, 75 and 100 %). However, the yields of products with 75 and 100 % of bulgur flour were lower than 50 %, which was the target yield to produce enough couscous for further processes. For that reason, only samples with 25 and 50 % of bulgur flour were only used. The quantities were given in total semolina and bulgur flour weight (w/w). The formulations are given in Table 2.2.

Table 2.2 Compositions of African couscous

Compositions	Bulgur flour (%, w/w)	Semolina (%, w/w)	Water (%, w/w)
1	0	100	30
2	25	75	46.75
3	50	50	50

The quantities of water were calculated according to total semolina and bulgur flour weight.

2.2.3 Turkish couscous

Experimental set-up is shown in Figure 2.3. Turkish type couscous was produced manually by substituting *Triticum durum* semolina with undersize bulgur (<0.8 mm) at different quantities (25, 50, 75 and 100 %). However, yields of products with 75 and 100 % of bulgur flour were lower than 50 %, which was the target yield to produce enough couscous for further processes. For that reason, only samples with 25 and 50 % of bulgur flour were only used. The quantities were in total semolina and bulgur flour weight (%, w/w). The formulations are given in Table 2.3.

Table 2.3 Compositions of Turkish couscous

Compositions	**Bulgur flour (%, w/w)**	**Semolina (%, w/w)**	**Milk (%, w/w)**	**Egg (%, w/w)**
1	0	100	26.25	3.75
2	25	75	30.63	4.38
3	50	50	35	5

The quantities of milk and eggs were calculated according to total semolina and bulgur flour weight.

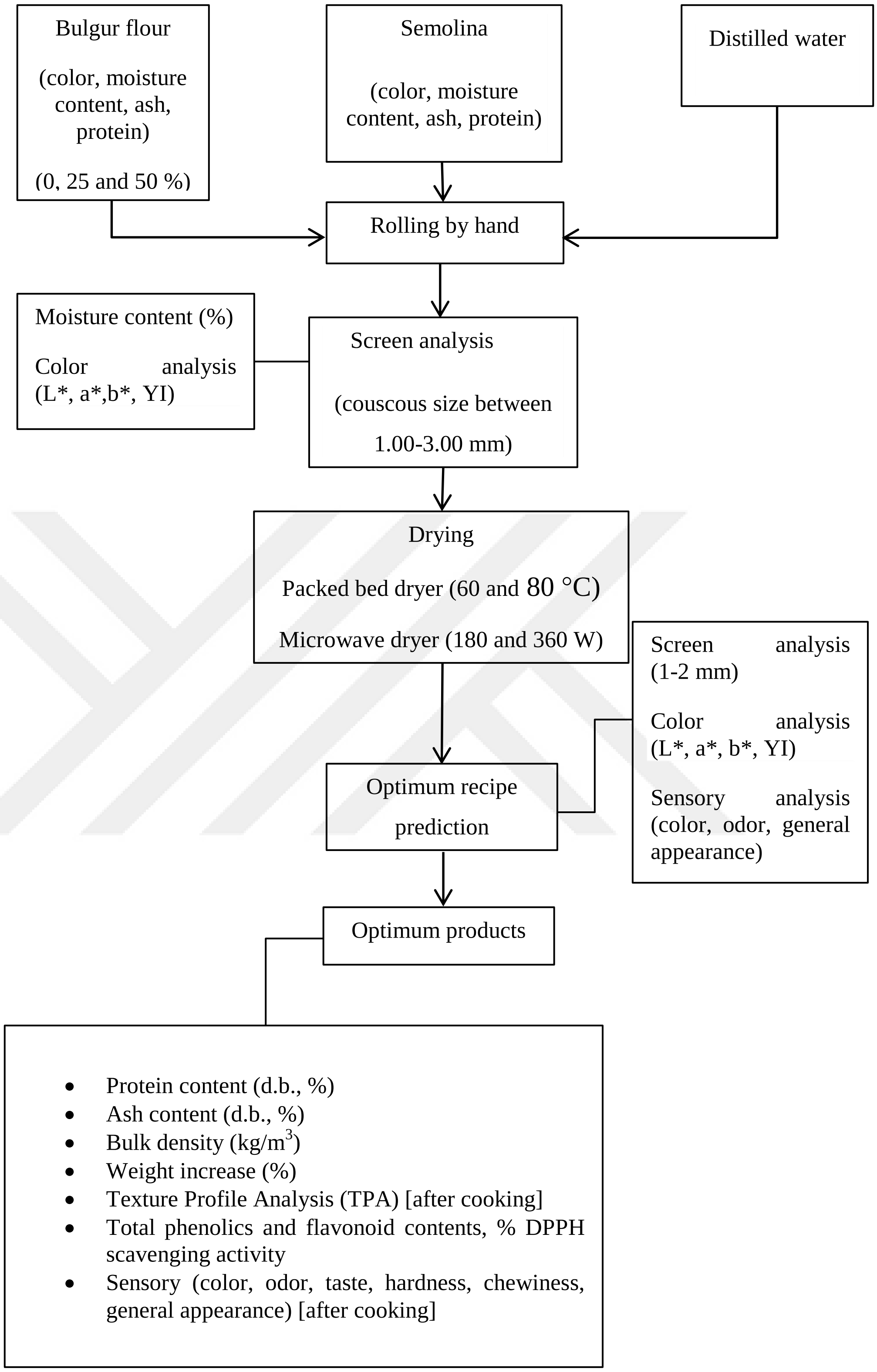

Figure 2.2 Experimental setup of African couscous

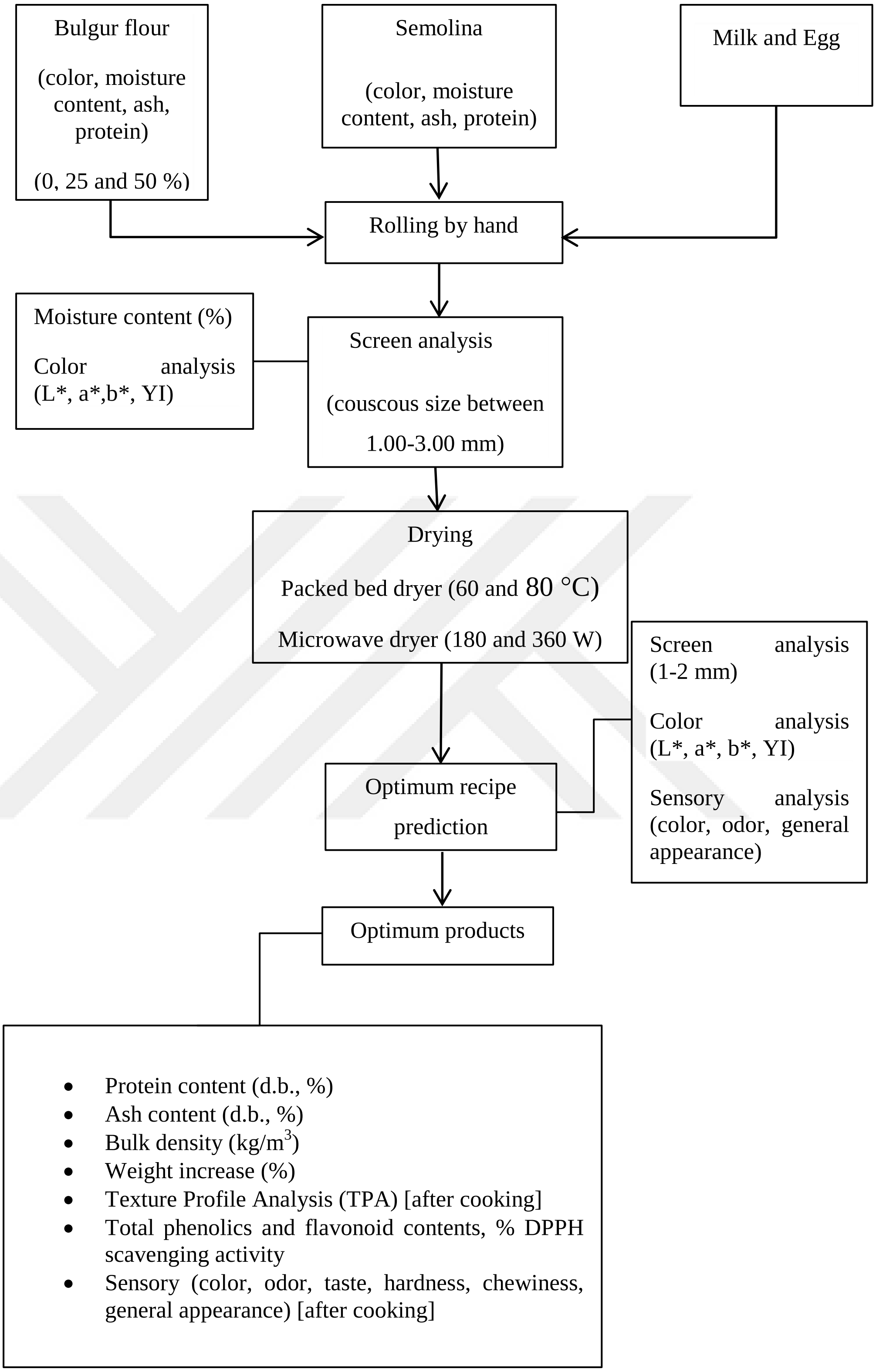

Figure 2.3 Experimental setup of Turkish couscous

2.3 Drying

Produced couscous from three methods e.g. short-cut pasta-like, African/Arabic, Turkish, were dried by using packed bed and microwave drying. The samples were dried to 12 % (w.b.) of moisture content using artificial dryers e.g. packed bed (MR II, Sherwood Scientific, Cambridge, England) and microwave (HMT84G421, Bosch, Germany) dryers. Drying was made at two different temperatures such as 60 and 80°C (for pasta-like couscous: air velocity: 0.35 m/s, volumetric flow rate: 6.19×10^{-3} m^3/s; for Arabic/African and Turkish couscous: air velocity: 0.05 m/s, volumetric flow rate: 8.84×10^{-4} m^3/s) for packed bed dryer. Also, microwave drying was made at two different intensities such as 180 and 360 W. Six hundred grams of sample was placed into the dryers. The weight of sample was recorded at the beginning of the drying operations. Weighing was made until the sample reaches to 12 % (w/w, w.b.) of moisture content within 4 minutes intervals.

2.3.1 Preparation of drying curve

Drying curve was prepared for each drying system individually. Weight of dry solid was calculated by using Equation 2.1 and the moisture content was calculated by using Equation 2.2.

$$W_s = W_0 * (1 - X_w) \qquad (2.1)$$

where W_s is the weight of dry solid (kg); W_0 is the initial weight of sample (kg); X_w is the moisture fraction of sample.

$$X_t = \frac{W_t - W_s}{W_s} \qquad (2.2)$$

where X_t is the moisture content (kg kg^{-1} dry solid); W_t is the weight of sample (kg); W_s is the weight of dry solid (kg).

Free moisture content was calculated with Equation 2.3 and the drying rate graph was drawn as drying rate versus free moisture content, where free moisture content versus time graph was also drawn.

$$X_f = X_t - X_e \tag{2.3}$$

where X_f is free moisture content (kg kg^{-1} dry solid); X_t is moisture content of sample at any time (kg kg^{-1} dry solid); X_e is the final moisture content (kg kg^{-1} dry solid)

2.3.2 Mathematical modeling of drying data

The experimental moisture ratio (Eq. 2.4) of bulgur-couscous was calculated using the following equation:

$$MR = \frac{X_t - X_e}{X_i - X_e} \tag{2.4}$$

where MR is the moisture ratio; X_t is the moisture content at time *t* (kg kg^{-1} dry solid); X_i and X_e are the initial and final moisture content (kg kg^{-1} dry solid), respectively.

Drying rate was calculated using Equation 2.5:

$$R = -\frac{W_s}{A} x \frac{(X_{t+1} - X_t)}{(t_{t+1} - t_t)} \tag{2.5}$$

where R is the drying rate (kg m^{-2} $hour^{-1}$); W_s is the weight of dry solid (kg); A is the drying area (m^2); X_t is the moisture content at certain time (kg kg^{-1} dry solid), t is time (hour).

Drying area (A) was calculated by multiplying surface area of sphere with number of couscous particles (Eqs. 2.6 and 2.7).

n = (total weight of couscous x number of certain particles)/weight of certain particles (2.6)

$$A = n(4\pi r^2) \tag{2.7}$$

where n is the total number of couscous particles; r is the radius of spherical couscous sample (m).

2.3.3 Effective moisture diffusivity

According to the study of Crank (1975), the effective moisture diffusivities were calculated with Fick's second law for long drying times and sphere geometry in one dimension (Eq. 2.8). Assumptions were made as: 1) mass transfer occurred in diffusion mode; 2) volume change was negligible; 3) temperature and diffusion coefficients were constant at the drying process (Chayjan and Kaveh, 2014).

$$MR = \frac{6}{\pi^2} \exp\left(\frac{-D_{eff} \pi^2 t}{r^2} \right) \tag{2.8}$$

where D_{eff} is the diffusion coefficient ($m^2\ s^{-1}$); t is the drying time (s); r is the radius of sample (m). D_{eff} was obtained by plotting the experimental data of ln(MR) versus time (sec) which gives a straight line (Doymaz and Ismail, 2011).

In this study, mathematical drying models were fitted to the drying data and the equation parameters were determined using non-linear least squares regression analysis by using Sigma Plot software (Erkrath, Germany). Four criteria were adopted to evaluate the goodness of fit of each model, correlation coefficient (R^2), the reduced chi-square (χ^2), root mean square error (RMSE) and residual sum of squares (RSS). These parameters were calculated using Eqs. 2.9, 2.10 and 2.11 (McMinn, 2006).

$$\chi^2 = \frac{\sum_{i=1}^{N} (MR_{\exp,i} - MR_{pred,i})^2}{N - n_p} \tag{2.9}$$

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (MR_{\exp,i} - MR_{pred,i})^2} \tag{2.10}$$

$$RSS = \sum_{i=1}^{N} (MR_{\exp,i} - MR_{pred,i})^2 \tag{2.11}$$

where $MR_{exp,i}$ is the experimental moisture ratio obtained from Eq.2.4; $MR_{pred,i}$ is the predicted moisture ratio obtained from the models; N is the number of experimental data points and n_p is the number of parameters in the model.

2.4 Determination of optimum processing parameters and recipes

In order to determine the optimum processing parameters and recipes; yields (for African and Turkish type couscous), sensory attributes and color values (L*, a*, b*, YI and sensory color results) were used. The optimum recipes were used for further analysis in order to determine the properties of couscous.

2.5 Moisture content measurement

Association of Official Analytical Chemists (AOAC) method was used for the determination of moisture content using 3-4 g of sample in an oven (JS Research Inc., Korea) at 130°C until constant weight reached (AOAC, 1990).

2.6 Ash content measurement

AOAC (1990) method was used to measure ash content of couscous samples (%, d.b.).

2.7 Protein content measurement

AOAC (1990) Kjeldahl method was used to measure protein content of couscous samples (%, d.b.).

2.8 Crude fiber analysis

Determination of crude fiber contents of couscous samples was made in Mersin Food Control Laboratory (Laboratory of Ministry of Food, Agriculture and Livestock) by using ISO (1981) 5498 method.

2.9 Color measurements

Color of the dry samples before the cooking operation was determined by measuring the *L** (100 = white; 0 = black), *a** (+, red; -, green) and *b** (+, yellow; -, blue) and *YI* (Yellowness Index) values using QUEST II Minolta CR-400 (Minolta Camera, Co., Ltd, Osaka, Japan) with illuminate D65/10 as reference. The color results were the average of four measurements.

2.10 Screen analysis

Bulgur flour under the sieve with 0.80 mm of aperture opening was used. After size enlargement and each drying operations, the samples were sifted with 3.00/2.00/1.00 mm screens and each fraction was calculated by weighing the remaining couscous-like product on each sieve. Yields were determined for dried samples as weighing products between 2.00 and 1.00 mm screens, where weighing products between 3.00 and 1.00 mm screens was made for non-dried ones.

2.11 Analysis of percent changes in cooking loss (% CL), volume (% VI) and weight (% WI) of pasta-like couscous

Percent changes in cooking loss (%, w/w, CL), volume increase (%, v/v, VI) and weight increase (%, w/w, WI) were determined by modification of the method presented by Demir et al. (2010) for short cut pasta type couscous samples. In this method, 10 g of couscous were cooked in 100 ml distilled water for 5 minutes. After cooking, the samples were washed with distilled water, and then drained for 2 min. The drained cooking water was dried in an oven (JS Research Inc., Korea) until constant weight is reached. Then, % CL was calculated by using Eq. 2.12.

CL (%) = 100x(weight of residue in cooking water)/(weight of dry sample) (2.12)

WI was determined by differences between dry (uncooked, before cooking) and cooked (after draining) couscous weights (Eq. 2.13).

WI (%) = 100x(weight of cooked sample-weight of dry sample)/weight of dry sample (2.13)

% VI’s of dry (uncooked) and cooked couscous samples were determined, individually. In order to determine % VI, 10 g of sample was placed in a 250 mL graduated cylinder, then 50 mL of distilled water was added to measure water level increase. % VI was calculated by using Eq. 2.14.

VI (%) = 100x(volume of cooked sample - volume of dry sample)/volume of dry sample (2.14)

2.12 Analysis of percent change in weight (% WI) of African and Turkish couscous

Percent change in weight increase (% WI) was determined by modification of the method presented by Demir et al. (2010) for African and Turkish couscous samples. In this method, 6 ml of boiling distilled water was poured on 10 g of couscous and waited for 5 minutes. WI was determined by differences between dry (uncooked, before cooking) and cooked couscous weights (Eq. 2.13).

2.13 Bulk density analysis

For bulk density measurement, 10 g of sample was poured into 50 mL graduated cylinder, the sample was packed well by hitting the cylinder on a cloth, such that the sample packs well, afterwards the volume of sample was measured. Bulk density was determined by the ratio of weight to volume of sample as kg/m^3.

2.14 Sensory analysis

Color, odor and general appearance of dry couscous samples were evaluated by 30 panelists. Scores were given between 1 (dislike extremely) and 10 (like extremely). Depending on yields, instrumental color (L*, a*, b* and YI) values and sensory analysis, the optimization of recipe was made and this recipe was used for further analysis.

In sensory analysis of pasta-like couscous, 250 g couscous samples were cooked in 500 ml water for 10 min and drained for 20 seconds In sensory analysis of Turkish and African couscous samples, 120 ml of boiling distilled water was poured on 200 g of couscous samples and kept for 10 min. The couscous samples were evaluated by acceptance test using a hedonic scale and 30 panelists, who are working/studying in Department of Food Engineering, Gaziantep University. Panelists evaluated each sample in duplicate. The panelists had access to water to help cleanse their palates prior to proceeding to the next sample. Sensory evaluation was performed in a special sensory analysis room at the controlled temperature of 25 °C in open sitting. All samples were served at the same time on the same day. Panelists gave scores on a ten-point scale from 1 (dislike extremely) to 10 (like extremely) for chewiness, hardness, odor, taste, color and overall acceptability of couscous samples (Table A.18).

2.15 Texture profile analysis (TPA)

TPA values of cooked couscous samples were measured by using TA.XT2i Texture Analyzer (Stable Micro System Ltd., Surrey, UK) according to the method published by Altan and Maskan (2004). During test, compression rig apparatus was used. Compression was applied two times on the couscous samples. Testing conditions were as follows: 2 mm/s of pre-test speed, 0.5 mm/s of test and post-test speed. Hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness and resilience were measured as the parameters of TPA.

2.16 Analysis of total phenol content, total flavonoids content and DPPH (1,1diphenyl-2-picrylhydrazyl) scavenging activity (%)

According to the procedure of Caba et al. (2012), the phenolic compounds were extracted with 1ml of 80 % methanol containing 1 % HCl using 100 mg sample. The extraction solvent and the ground sample were mixed in an orbital shaker at 200 rpm for 2 h at ambient temperature. The mixture was then centrifuged at 4000 rpm for 15 min. The aqueous phase was separated and collected in another tube. The extraction procedure was repeated on the precipitate. Collected extracts were used for further analysis.

Total amount of phenolic compounds in couscous samples was determined by using the modification of Folin–Ciocalteu method, using Gallic acid as a standard. Water (0.5 ml), 125 µl of sample extract and 125 µl of Folin–Ciocalteu reagent (diluted with distilled water, 1:10) were added in a test tube. After standing for 6 min, 1.25 ml of sodium carbonate solution (7.5 %) and another 1 ml of water were added into the mixture solution. The solution was left in the dark place for 1.5 h. Absorbance was measured at 760 nm by using a spectrophotometer (Thermo Scientific Multiskan GO, USA) (Caba et al., 2012).

Total amount of flavonoids in the couscous samples was determined by using the modified method of Zhishen et al. (1999), using catechin as a standard. Water (1.25 ml distilled water) was added on 0.25 ml of sample extract. Then, 0.75 ml of $NaNO_2$ (5 %) and 0.15 ml of $AlCl_3.6H_2O$ (10 %) were added to the mixture. After 6 min, 0.5 ml of 1 M of NaOH was added and homogenized using a vortex for 10 sec.

Absorbance was measured at 510 nm by using a spectrophotometer (Thermo Scientific Multiskan GO, USA).

Total antioxidant capacity of couscous samples was measured using DPPH radical scavenging activity percent method. According to the modified DPPH (1,1diphenyl-2-picrylhydrazyl) method, 1 ml of sample extract was added into a test tube containing 4 ml of methanol (80 %) and 1 ml (containing 1mM of DPPH) of freshly prepared DPPH solution. Then, the final concentration of DPPH solution was adjusted to 167 µmol. After that, tubes were left in the dark for 30 min and sample absorbance was measured by using the spectrophotometer at 517 nm. Results were given as "DPPH Scavenging Activity, %" (Caba et al., 2012).

2.17 Statistical analysis

One-way analysis of variance (ANOVA) was performed for all data to determine significant differences at the significance level of $\alpha = 0.05$ by using SPSS software (version 22.0) (IBM Software, NY, USA). Duncan's multiple range tests were carried out to determine the effect of parameters on all responses. All experiments were replicated twice and the analyses were duplicated.

Mathematical drying models were fitted to the drying data and the equation parameters were determined using non-linear least squares regression analysis by using Sigma Plot software (Erkrath, Germany).

CHAPTER 3

RESULTS AND DISCUSSION

The couscous samples were produced by substitution of *Triticum durum* semolina with undersize bulgur (bulgur flour) at various quantities to increase the economic value of bulgur flour, which is a by-product. The most important attributes (L*, a*, b*, YI, protein and ash contents) of bulgur and semolina used as raw material in the experiments are given in Table 3.1. Due to the high bran content in bulgur flour, the values of lightness (L*) and yellowness (b*) were lower than that of semolina. However, the values of redness (a*) and cloudiness-opaqueness (YI, yellowness index) of bulgur flour were higher than semolina. Bulk densities of bulgur flour and semolina were 590±0.00 and 790±0.02 kg/m^3, respectively (Table 3.1). The difference between the bulk densities of bulgur flour and semolina was due to difference in their particle sizes. Theoretically, when the particle size decreases, surface area and void between particles increase, therefore bulk density decreases.

For pasta and pasta-like products, texture or firmness of the cooked product and the quantity of cooking loss are the most important quality parameters besides color and overall appearance to affect consumer's acceptance.

The experimental results are given in Tables A.1-A.17.

3.1 Pasta-like couscous

Pasta like couscous was produced by substitution of *Triticum durum* semolina with undersize bulgur (bulgur flour) at various quantities (25, 50, 75 and 100 %). The quantities were given in total flour weight (w/w). Yields were calculated by weighing total mix and produced uncooked couscous. It was found that yields of couscous with 0, 25, 50, 75 and 100 % of bulgur flour were determined before drying as 91.65, 93.11, 93.93, 93.63 and 93.59 %, respectively.

Table 3.1 Color values and protein (%, d.b.), ash (%, d.b.) and crude fiber (%, d.b.) contents, total phenol content and total flavonoid content, DPPH scavenging activity and bulk density of bulgur flour and semolina

	L*	**a***	**b***	**YI**	**Protein content [d.b., %]**	**Ash content [d.b., %]**	**Crude fiber content [d.b., %, w/w]**	**Bulk density [kg/m^3]**	**Total phenol content [mg gallic acid/100 g sample]**	**Total flavonoid content [mg catechin/100 g sample]**	**% DPPH scavenging activity**
Bulgur flour	64.86±0.18	5.52±0.04	25.01±0.10	59.98±0.13	12.32±0.44	2.92+0.07	6.20±0.44	590±0.00	73.83±1.62	105.88±6.56	70.58±0.60
Semolina	79.91±0.37	3.33±0.12	28.37±1.27	54.84±2.11	10.78±0.47	0.76±0.05	0.75±0.05	790±0.02	83.53±5.06	63.92±5.92	68.67±1.46

Color values are the averages of four replicates.

3.1.1 Determination of optimum processing parameters and formulations for pasta-like couscous

In order to determine the optimum processing parameters and recipes; 0, 25, 50, 75 and 100 % of bulgur containing couscous samples were prepared (Figure 3.1). The prepared couscous samples were dried by using packed bed (60 and 80 °C) and microwave (180 and 360 W) dryers. After all products were obtained from the drying operations, the sensory analysis and the color measurements (L*, a*, b*and YI) were made to determine the optimum processing parameters and formulations.

Figure 3.1 Non-dried 25 (up) and 75 % (down) of bulgur flour containing short-cut pasta type couscous

3.1.1.1 Optimization based on color values and sensory analysis for pasta-like couscous

The changes in L*, a*, b* and YI values based on the quantity of bulgur flour of samples are shown in Figures 3.2-3.5. For all non-dried and dried couscous, the quantity of bulgur flour was significantly effective ($p \leq 0.05$) on lightness and yellowness. However, the quantity of bulgur flour was not significantly ($p>0.05$) effective on redness (a*) for the microwave dried samples at 180 and 360 W, while being significantly ($p \leq 0.05$) effective for packed bed dried samples at 60 and 80 °C. The quantity of bulgur flour for the packed bed dried samples at 60 and 80 °C has not significant ($p>0.05$) effect on the cloudiness-opaqueness (Yellowness index, YI value).

According to Duncan's multiple range tests, there were no significant difference ($p>0.05$) between lightness values of microwave dried couscous at 180 W that consist of 75 and 100 % bulgur flour. On the other hand, there were significant differences ($p \leq 0.05$) between lightness values of non-dried, packed bed dried at 60 and 80 °C and microwave dried couscous at 360 W. Increasing quantity of bulgur flour caused to decrease in lightness values of microwave dried couscous samples compared to non-dried ones. On the contrary, the lightness values of packed bed dried samples increased by increasing quantity of bulgur flour, which were higher than non-dried couscous. In Tables A.1-A.5, color values of pasta-like couscous were given.

For redness values of non-dried and packed bed dried couscous samples consist of 0 % bulgur flour (control sample) were significantly ($p \leq 0.05$) different than the others (consisting 25, 50, 75 and 100 % of bulgur flour). Redness values of microwave dried samples were higher than non-dried and packed bed dried ones. Adversely, yellowness values of microwave dried samples were higher than non-dried and packed bed dried ones. However, yellowness values were getting closer with increasing the quantity of bulgur flour. It could be explained as the depending of the retention of yellow pigment on enzyme inactivation (Acquistucci, 1996). Additionally, pasta yellowness is affected by the quality of semolina (natural carotenoid pigments, protein and ash contents and lipoxygenase activity) and processing conditions (Borrelli et al., 1999; Debbouz et al., 1994). Additionally it was found that microwave dried samples were much opaque than non-dried and packed bed dried couscous samples.

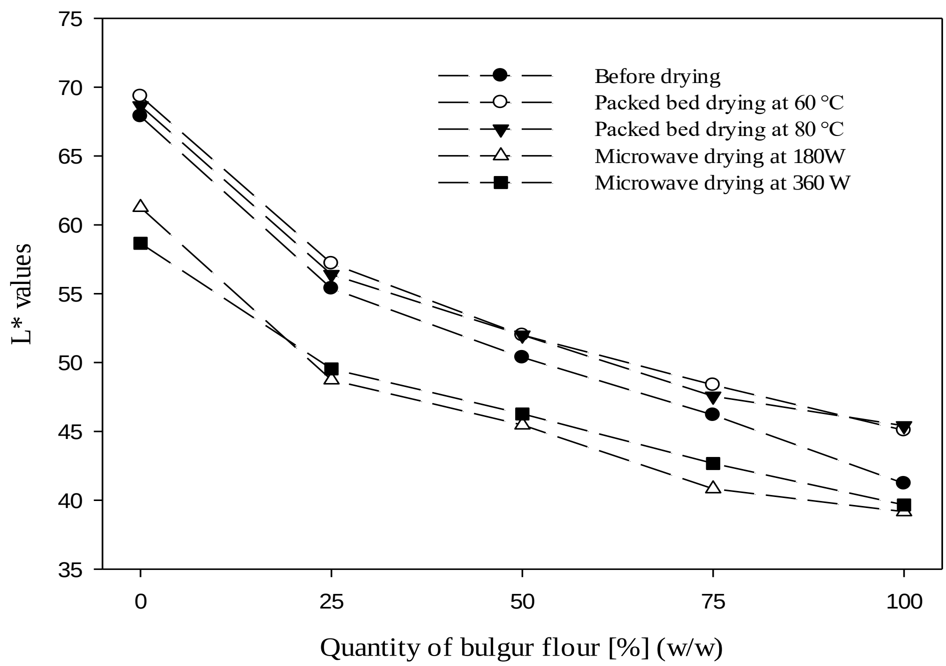

Figure 3.2 L* values of short-cut pasta like uncooked couscous

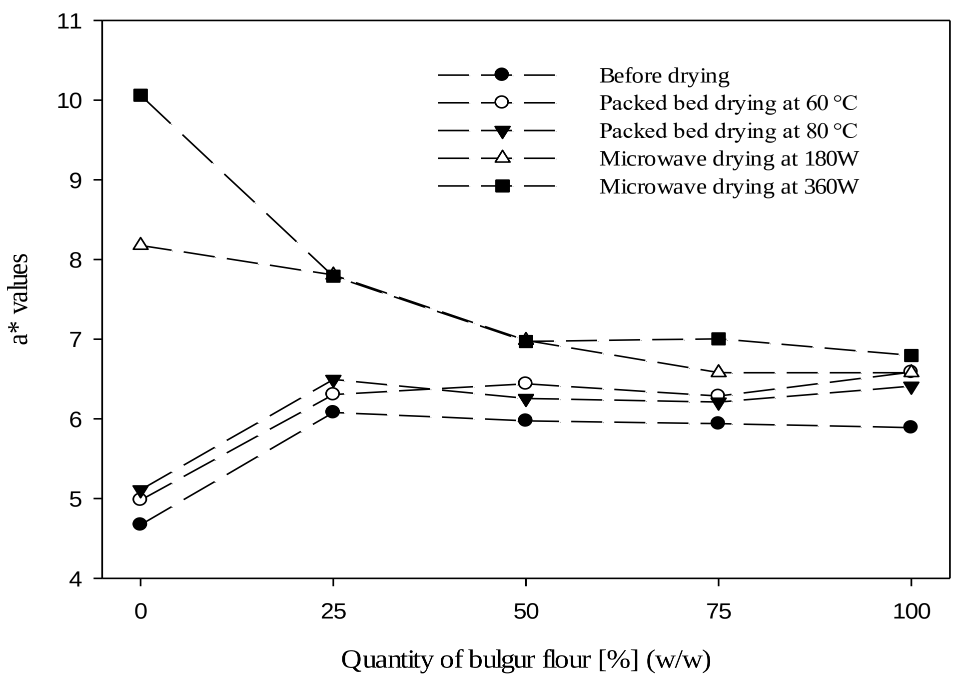

Figure 3.3 a* values of short-cut pasta like uncooked couscous

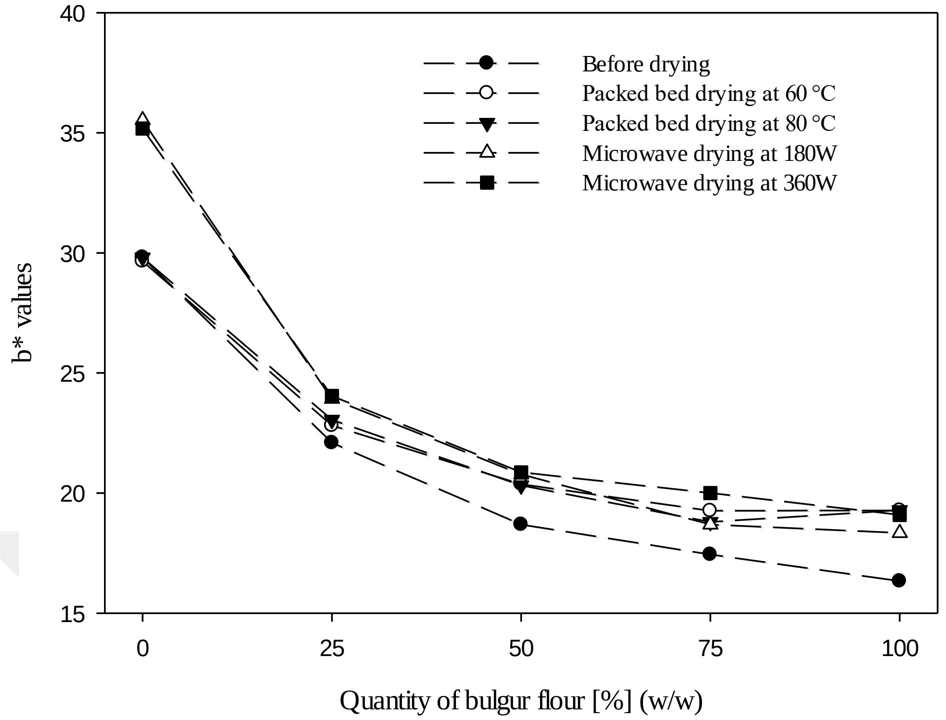

Figure 3.4 b* values of short-cut pasta like uncooked couscous

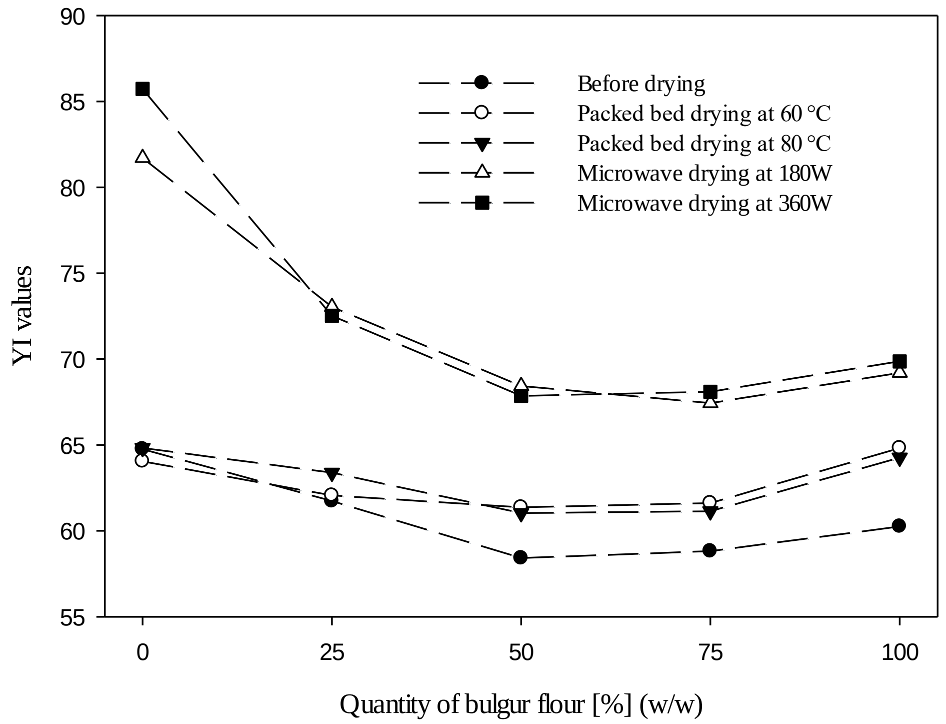

Figure 3.5 YI values of short-cut pasta like uncooked couscous

The sensory analysis after the drying operations were made and the results were given in Table 3.2. It was found that the quantity of bulgur flour (i.e. 0, 25, 50, 75 and 100 %) was not significantly (p>0.05) effective on odor and color in contrast to general appearance.

Table 3.2 Results of sensory analysis of uncooked short-cut pasta like couscous

			Sensory Attributes		
Quantity of bulgur flour [%]	**Drying technique***	**Drying parameters**	**Color**	**Odor**	**General Appearance**
0	PBD	60 °C	6.83±1.65^{abc}	6.56±1.49^{abc}	7.11±1.78^{abcd}
		80 °C	7.11±2.00^{abc}	7.06±2.15^{abc}	7.78±2.10^{cd}
	MW	180 W	8.17±1.92^{c}	6.83±2.01^{abc}	8.28±1.41^{d}
		360 W	7.39±1.79^{bc}	7.00±2.00^{abc}	7.61±1.75^{bcd}
25	PBD	60 °C	6.50±1.62^{ab}	7.11±1.60^{abc}	7.17±1.47^{abcd}
		80 °C	6.33±1.57^{ab}	7.61±1.79^{bc}	6.83±1.62^{abc}
	MW	180 W	6.56±1.25^{ab}	6.94±1.39^{abc}	7.11±1.28^{abcd}
		360 W	6.83±1.25^{abc}	6.78±1.48^{abc}	7.00±1.37^{abcd}
50	PBD	60 °C	6.17±1.42^{ab}	6.78±1.59^{abc}	6.61±1.50^{abc}
		80 °C	6.33±1.78^{ab}	7.11±1.64^{abc}	6.44±1.65^{abc}
	MW	180 W	6.50±2.04^{ab}	6.94±1.43^{abc}	6.72±1.90^{abc}
		360 W	6.61±2.12^{ab}	7.56±1.72^{bc}	6.83±2.07^{abc}
75	PBD	60 °C	5.83±2.04^{a}	7.28±1.53^{abc}	6.22±1.99^{ab}
		80 °C	5.89±2.00^{ab}	7.83±1.72^{c}	6.00±1.97^{a}
	MW	180 W	6.06±2.58^{ab}	6.83±1.29^{abc}	6.56±2.09^{abc}
		360 W	6.11±2.19^{ab}	6.78±1.35^{abc}	6.28±1.64^{ab}
100	PBD	60 °C	6.17±1.82^{ab}	6.44±1.58^{ab}	6.56±2.06^{abc}
		80 °C	6.39±2.09^{ab}	6.22±1.63^{a}	6.50±2.12^{abc}
	MW	180 W	6.22±1.86^{ab}	7.11±1.37^{abc}	6.61±1.94^{abc}
		360 W	6.50±2.38^{ab}	7.06±1.39^{abc}	6.78±2.18^{abc}

*PBD: Packed Bed Dryer. MW: Microwave. Each column followed by different superscripts is significantly different (p≤0.05).

3.1.1.2 Optimum results for pasta-like couscous

According to color (L*, a*, b* and YI) and sensory values after the drying operations, the optimum processing parameters and the formulations were determined such as; 1) 33.25 % (w/w) of water for dough preparation, 100 % of bulgur flour, 80 °C drying temperature for packed bed dryer; 2) 33.25 % (w/w) of water for dough preparation, 100 % of bulgur flour, 360 W drying power for microwave dryer. As a note, the quantity of water was calculated according to total semolina and bulgur flour weight to obtain suitable dough stickiness and consistency. According to these optimum conditions, the further analyses were made for the optimum products.

3.1.2 Analysis of the optimum products/formulations produced at optimum parameters for pasta-like couscous

Chemical and physical analyses were made at the optimum products predicted to determine some functional and engineering properties (bulk density, volume and weight increases etc.) of the couscous. In order to compare the results, the control couscous sample results were also used.

3.1.2.1 Bulk density for pasta-like couscous

Bulk density is very important technological attribute of solid bulk products to evaluate product size, particle shape, smoothness, particle surface area and void fraction. Additionally, it can be used to design the processing equipment of couscous. The decrease in bulk density occurs due to the higher temperature and longer drying time in conventional drying (Vadivambal and Jayas, 2007).

It was found that the bulk densities of control samples (semolina-couscous) were significantly ($p \leq 0.05$) higher than pasta-like couscous (bulgur-couscous), which were produced with packed bed (at 80 ºC) and microwave (at 360 W) dryers (Table 3.3). This difference in bulk density can be explained such as i) the same die and cutting speed were used, therefore couscous particle size were same. However, irregular (not smooth surface) particle caused less bulk density for bulgur couscous (high void between particles, high surface area and volume).

3.1.2.2 Volume and weight increases for pasta-like couscous

Volume and weight increases were used to analyze the water absorption ability of couscous. It was found that volume and weight increases in semolina-couscous (control sample) were significantly ($p \leq 0.05$) higher than bulgur-couscous for the packed bed dried products (Table 3.3). Also, there was no significant ($p > 0.05$) difference for the microwave dried semolina and bulgur couscous samples. However, it seems that there was a small difference between both. Weight increase of packed bed dried bulgur containing couscous was decreased by 23.45 % compared to the control couscous sample. Similarly, Jeffers (1979) found 20 % decrease in WI of udon noodle when increasing yellow bean flour addition compared to the control.

Volume and weight increases are deal with the gelatinized starch found in bulgur. Therefore, the water intake decreased in the samples. Bran containing foods are absorbing less water by the starch because bran competes for water with starch (Aravind et al., 2012). Demir et al. (2010) replaced wheat flour with chickpea flour to cover bulgur in couscous production and they explained the decrement of weight increase while increasing chickpea flour content as decrease in starch amount with substitution and the possible decrease in water intake for gelatinization. Sabanis et al. (2006) substituted wheat flour with chickpea flour at various levels and produced lasagna. It was reported that water uptake increases proportionally as the amount of chickpea flour decreases.

Additionally, microwave caused significant decrease in volume and weight increases (%) (Table 3.3). It may be explained due to case hardening during short time heating caused by microwave.

3.1.2.3 Cooking loss for pasta-like couscous

In terms of couscous acceptance, cooking properties have the highest consideration in the couscous properties (Demir and Demir, 2016). Cooking loss is the quality parameter for pasta, pilaf types of products. Therefore, couscous should be analyzed for the loss during cooking (leaching of soluble compound to cooking water).

It was found that bulgur-couscous had high cooking loss value when compared with semolina-couscous in both drying techniques (Table 3.3). Similarly, the loss of solids during cooking increased with the level of substitution of broad bean (*Vicia faba*) with bread wheat flour in production of spaghetti (Gimenez et al., 2012). Increased cooking loss of pasta samples was observed by Krishnan and Prabhasankar (2010) with increasing substitution level of sprouted finger millet (ragi flour) and green banana flour. Moreover, Zhao et al. (2005) also observed similar behavior of cooking loss with increased level of green pea, yellow pea, chickpea and lentil flours.

3.1.2.4 Change in protein and ash contents for pasta-like couscous

Protein and ash contents of bulgur-couscous have significantly ($p \leq 0.05$) higher than semolina-couscous due to the raw materials properties (Table 3.3). Bulgur has higher protein and ash contents than semolina; therefore it caused a good gain to finished product. Ash comes from bran layer of wheat and bran is not removed completely during bulgur production. In addition, phytic acid is very low in bulgur bran due to its production process (i.e. due to the cooking operation) (Bayram et al., 2004). Therefore, bulgur is a good dietary fiber source (Bayram, 2005) for couscous by increasing bran content without phytic acid. Aalami et al. (2007) observed similar protein and ash contents of semolina produced from six different Indian durum wheat varieties, which protein and ash contents were between 9.30 and 13.83 % (d.b.) and between 0.79 and 0.86 % (d.b.), respectively. Rahmani and Muller (1996) measured ash and protein contents of five traditional and four commercial couscous samples and found that protein and ash contents were between 12.2-14.3 g/100 g sample (d.b.) and 1.03-1.49 g/100 g sample (d.b.), respectively.

3.1.2.5 Crude fiber contents for pasta-like couscous

Crude fiber is the residue after treatment of couscous samples with dilute acid and alkali. The residue of crude fiber is primarily composed of cellulose and lignin. Crude fiber contents of bulgur flour and semolina were 6.20±0.44 and 0.75±0.05 % (d.b.) (Table 3.1). Due to the high bran content of bulgur flour, the crude fiber contents of bulgur containing samples were significantly ($p \leq 0.05$) higher than the control samples. According to Duncan’s multiple range tests, bulgur-couscous samples were significantly ($p \leq 0.05$) different than semolina-couscous samples (Table 3.3).

Similar results obtained by Cardenas-Hernandez et al. (2016) whom investigated the effects of dried amaranth leaves and amaranth seed flour on functional properties of pasta. The results showed that the addition of amaranth seed flour and dried amaranth leaves increased crude fiber content of pasta. The crude fiber contents of enriched pasta samples were in between of 1.62 and 4.14 %, which were higher than the control sample (100 % of semolina, 0.72 % of crude fiber).

Table 3.3 Quality properties of predicted formulations of pasta like couscous produced using optimum parameters

			Quality Properties						
Quantity of bulgur flour [%]	**Drying technique***	**Drying parameters**	**Bulk density [kg/m^3]**	**Volume increase [%, w/w]**	**Weight increase [%, w/w]**	**Cooking loss [%, w/w]**	**Protein content [d.b., %]**	**Ash content [d.b., %]**	**Crude fiber content [d.b., %, w/w]**
0	PBD	80 °C	670.00±0.95^a	22.04±2.40^a	137.67±13.92^a	4.63±0.08^a	10.35±0.16^a	0.77±0.06^a	0.84±0.04^a
100			515.20±17.95^b	15.84±1.18^b	105.38±2.83^b	15.89±0.05^b	12.84±0.23^b	2.89±0.01^b	5.00±0.03^b
0	MW	360 W	630.30±56.15^a	14.41±1.19^b	98.96±2.88^b	3.39±0.27^c	10.57±0.11^a	0.73±0.01^a	1.00±0.14^a
100			590.30±1.25^{ab}	13.56±0.00^b	86.90±2.07^b	12.61±0.05^d	12.43±0.18^b	2.80±0.22^b	5.52±0.73^b

*PBD: Packed Bed Dryer. MW: Microwave. Each column followed by different superscripts is significantly different (p≤0.05).

Table 3.4 Texture properties of predicted recipes of pasta like couscous produced using optimum parameters

Quantity of bulgur	Drying technique*	Drying parameters	Hardness (N)	Adhesiveness (N.s)	Springiness	Cohesiveness	Gumminess	Chewiness	Resilience
			Texture Properties						
0	PBD	80 °C	879.79±438.01[a]	-53.36±22.88[a]	0.55±0.10[a]	0.45±0.01[a]	398.41±207.20[a]	230.79±154.37[a]	0.23±0.00[a]
100			200.76±11.52[b]	-34.65±16.25[a]	0.41±0.02[a]	0.28±0.01[b]	55.31±1.46[b]	22.55±0.40[a]	0.09±0.01[b]
0	MW	360 W	475.86±86.74[ab]	-17.86±8.89[a]	0.41±0.01[a]	0.37±0.02[c]	175.93±23.79[ab]	72.73±8.54[a]	0.19±0.02[c]
100			125.13±2.71[b]	-32.25±1.57[a]	0.39±0.22[a]	0.25±0.01[b]	30.83±0.62[b]	12.01±6.46[a]	0.08±0.00[b]

*PBD: Packed Bed Dryer. MW: Microwave. Each column followed by different superscripts is significantly different ($p \leq 0.05$).

Table 3.5 Sensory properties of predicted recipes of pasta like couscous produced using optimum parameters

			Sensory Properties					
Quantity of bulgur flour [%]	**Drying technique***	**Drying parameters**	**Chewiness**	**Hardness**	**Odor**	**Taste**	**Color**	**General acceptability**
0	PBD	80 °C	5.63±1.77[a]	6.13±1.57[b]	6.05±1.64[b]	6.58±1.69[c]	6.13±1.53[b]	6.33±1.43[b]
100			5.52±1.60[a]	4.87±1.59[a]	5.13±1.44[a]	4.37±1.61[a]	4.78±1.61[a]	4.98±2.02[a]
0	MW	360 W	6.88±1.53[b]	7.07±1.95[c]	7.07±2.03[c]	7.37±1.51[d]	7.47±1.72[c]	7.58±1.27[a]
100			5.45±1.73[a]	4.40±1.77[a]	5.43±1.48[a]	5.12±1.97[b]	4.67±1.80[a]	5.18±1.83[c]

*PBD: Packed Bed Dryer. MW: Microwave. Each column followed by different superscripts is significantly different ($p \leq 0.05$).

Table 3.6 Functional properties of predicted recipes of pasta like couscous produced using optimum parameters

			Functional Properties		
Quantity of bulgur flour [%]	**Drying technique***	**Drying Parameters**	**Total phenol content [mg gallic acid/100 g sample]**	**Total flavonoid content [mg catechin/100 g sample]**	**% DPPH scavenging activity**
0	PBD	80 °C	62.40±29.54[a]	39.23±8.67[a]	74.06±1.43[a]
100			41.61±3.97[a]	48.54±9.09[a]	63.55±11.26[a]
0	MW	360 W	22.03±2.89[a]	23.65±8.01[a]	74.01±2.86[a]
100			34.42±12.13[a]	35.55±16.29[a]	70.60±1.81[a]

*PBD: Packed Bed Dryer. MW: Microwave. Each column followed by different superscripts is significantly different (p≤0.05)

3.1.2.6 Total phenol and total flavonoid content and % DPPH scavenging activity for pasta-like couscous

Phenolics provide essential functions in the reproduction and growth of the plants and acting as defense mechanisms. In addition, phenolic substances in the diet may provide health benefits associated with reduced risk of chronic diseases. Phenolic compounds in whole grains contribute to antioxidant activity (Liu, 2007). Total phenol and flavonoid contents of bulgur flour and semolina were determined as 73.83±1.62 and 83.53±5.06 mg gallic acid/100 g sample and 105.88±6.56 and 63.92±5.92 mg catechin/100 g sample, respectively. Their % DPPH scavenging activities were 70.58±0.60 % for bulgur flour and 68.67±1.46 % for semolina (Table 3.1). According to the statistical analysis, total phenol, flavonoid content and % DPPH scavenging activity were not significantly ($p>0.05$) different (Table 3.6).

Negative effect was observed for drying process on total phenols and flavonoid contents. Phenolic substances are found in free and bound form in whole grains. Bound phenols consist 85 % in corn, 76 % in wheat, 75 % in oats and 62 % in rice (Liu, 2007). The reason of lower total phenol content of couscous samples may be due to not enough extraction of bound phenols.

Caba et al. (2012) determined total phenols and DPPH scavenging activity % of five different bulgur brands and they found that the average total phenol content and % DPPH values are 59.5±5.2 mg gallic acid/100 g dry sample and 22.2±2.4 %, respectively. Higher percentage of DPPH activity resulted due to the high quantities of bran in bulgur flour. Similarly, due to the higher pigment content of semolina, antioxidant activities of control sample were high. Where radical scavenging activities of higher pigment content containing red sorghum and black rice were 92 and 87 %, respectively; non-pigmented cereals have DPPH activity of 7 – 67 % (Choi et al., 2007).

3.1.2.7 Texture Profile Analysis (TPA) for pasta-like couscous

Texture profile of cooked pasta-like couscous samples were given in Table 3.4. Hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness and resilience were measured by using texture analyzer. It was found that cohesiveness and resilience were significantly ($p\leq0.05$) different for semolina and bulgur couscous samples, where hardness, adhesiveness, springiness, gumminess and chewiness were not significantly ($p>0.05$) different. The hardness of bulgur-couscous was lower than semolina-couscous for each drying technique.

Adhesiveness is defined as negative force to pull the compression rig from the sample (Altan and Maskan, 2004). Adhesiveness of packed bed dried couscous samples was higher (not preferred) than microwave dried ones. Moreover, couscous samples containing 100 % of bulgur flour had similar adhesiveness value for both drying technique. Springiness refers the height of sample recovers between the end of the first bite and the start of the second where chewiness is the energy needed to masticate couscous samples (Altan and Maskan, 2004). The TPA parameters of adhesiveness, springiness and chewiness have not got significant ($p>0.05$) difference for the samples containing 0 and 100 % of bulgur flour, which were dried by using packed bed and microwave dryers. Semolina-couscous dried with packed bed dryer, which had the highest values for all TPA parameters.

3.1.2.8 Sensory analysis for pasta-like couscous

Sensory analysis showed that there were significant ($p\leq0.05$) differences between all sensory attributes (Table 3.5). It was obtained that bulgur-couscous had lower sensory scores than semolina-couscous generally.

Bulgur-couscous dried with microwave dryer had the lowest scores for chewiness, hardness and color attributes. Bulgur-couscous dried with packed bed dryer had lowest scores for odor, taste and general acceptability. Semolina-couscous and bulgur-couscous were not significantly ($p>0.05$) different from each other according to chewiness, hardness, odor and color scores. Decrease in sensory scores of color, appearance, taste, texture and overall acceptability were observed by Jayasena and Nasar-Abbas (2012) with increasing level of lupin flour during pasta production.

3.1.2.9 Drying curves of pasta-like couscous samples

The drying curves of couscous samples of short-cut pasta like are given in Figures 3.6-3.15.

The drying of bulgur-couscous sample was made until moisture content decreased from 33.91 % to 12 % (w.b.). The drying rate curves of packed bed (60 and 80 °C) and microwave (180 and 360 W) dried semolina-couscous and bulgur-couscous samples are shown in Figure 3.6 and 3.7, respectively. Microwave drying at 360 W had higher drying rates during drying in comparison with 180 W and packed bed drying. In the packed operation, drying time was reduced 30 % with increasing air temperature from 60 to 80 °C. In the microwave drying operation, it was reduced 56.25 % with increasing microwave power from 180 to 360 W. It can be concluded that microwave power increment is more effective on the drying time of bulgur-couscous than the increment of drying air temperature in the packed bed dryer. The free moisture contents of packed bed dried (80 °C) samples containing 0 and 100 % of bulgur flour were between 36-39 %. As seen in Figures 3.8 and 3.10, the free moisture contents decreased with time.

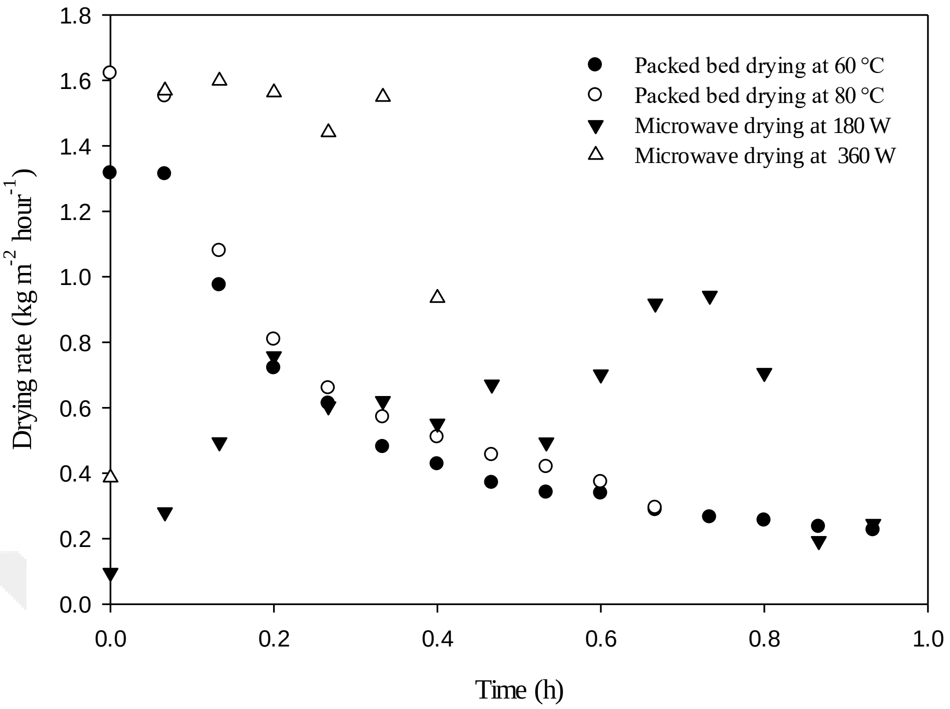

Figure 3.6 Drying rate curves against time of packed bed and microwave dried pasta-like semolina-couscous (0 % of bulgur flour)

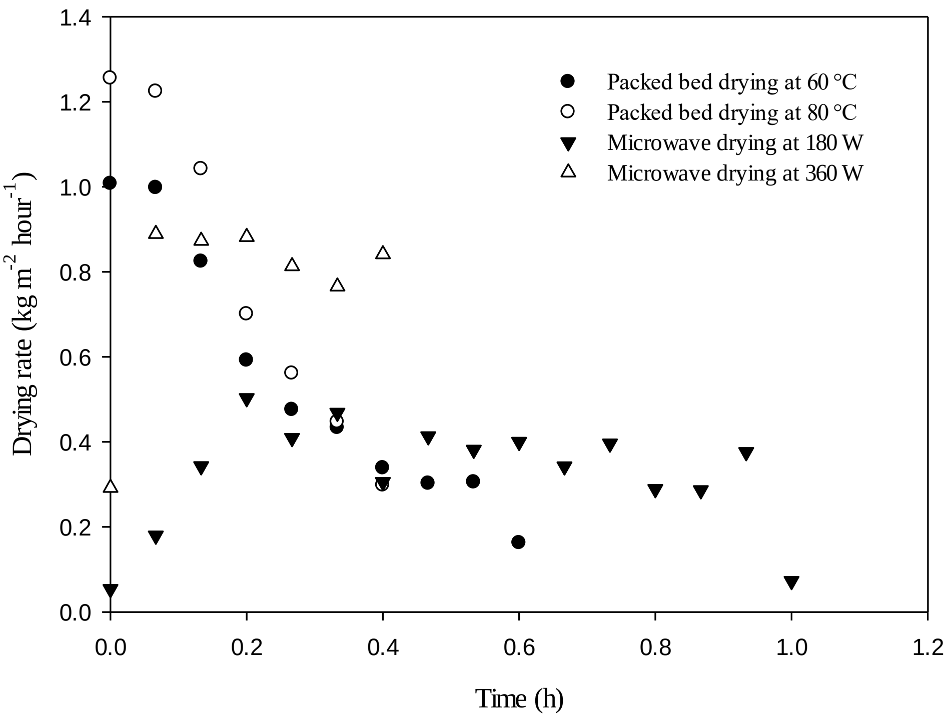

Figure 3.7 Drying rate curves against time of packed bed and microwave dried pasta-like bulgur-couscous (100 % of bulgur flour)

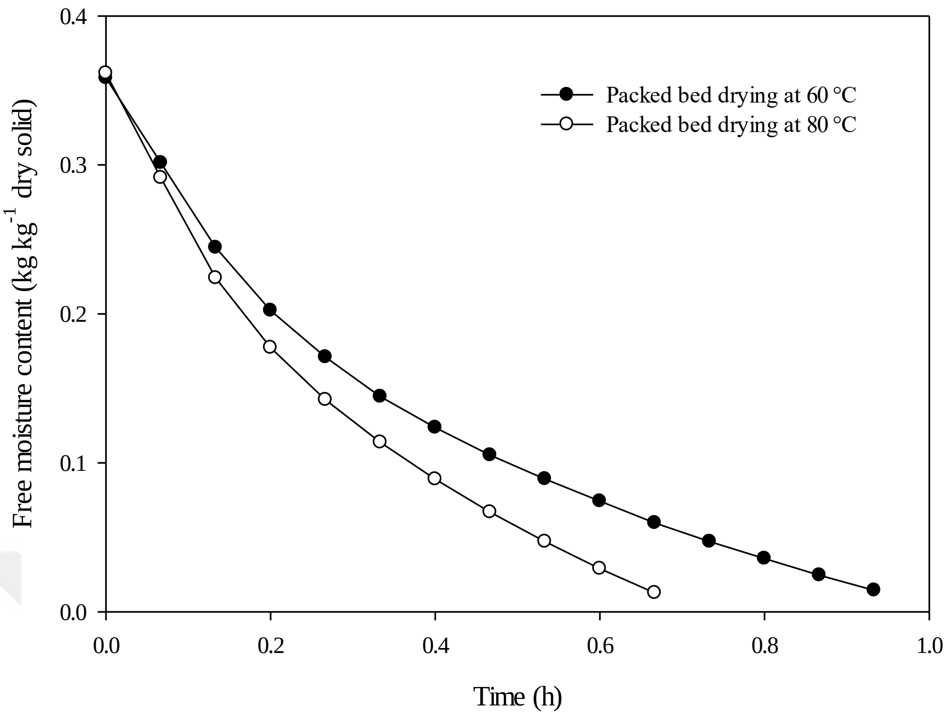

Figure 3.8 Free moisture content versus time graph of packed bed dried pasta-like couscous containing 0 % of bulgur flour

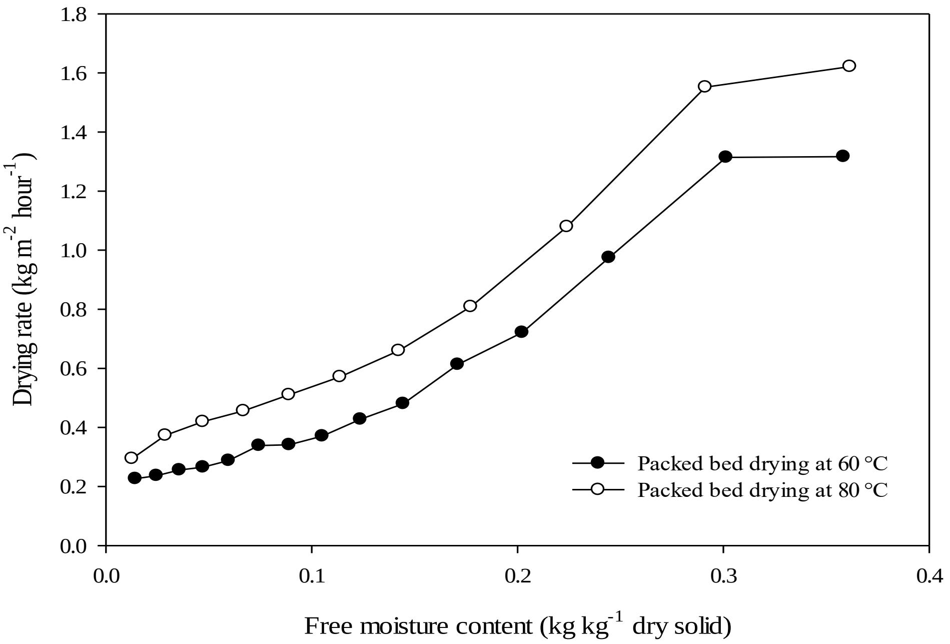

Figure 3.9 Free moisture content versus drying rate graph of packed bed dried pasta-like couscous containing 0 % of bulgur flour

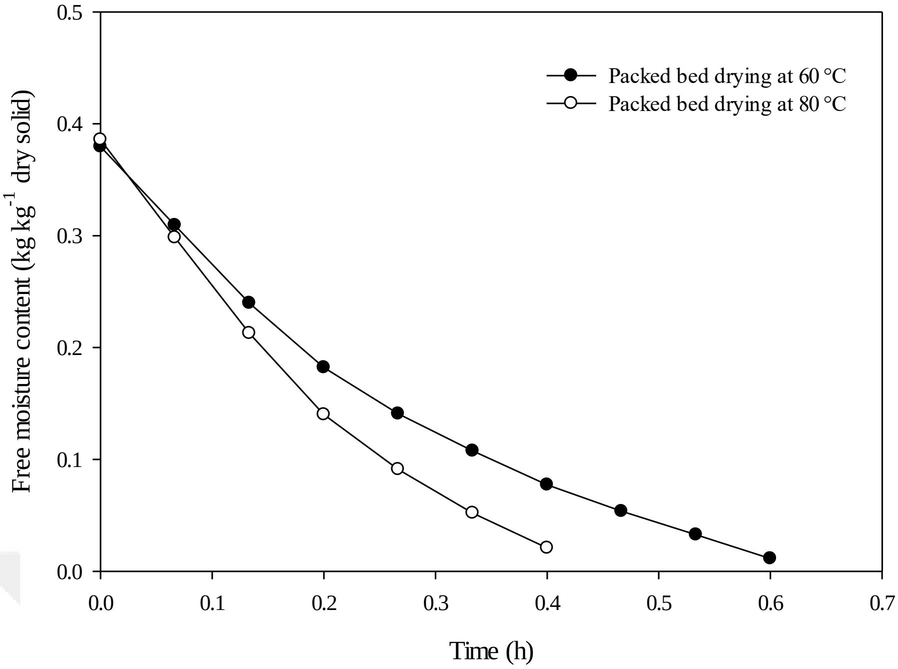

Figure 3.10 Free moisture content versus time graph of packed bed dried pasta-like couscous containing 100 % of bulgur flour

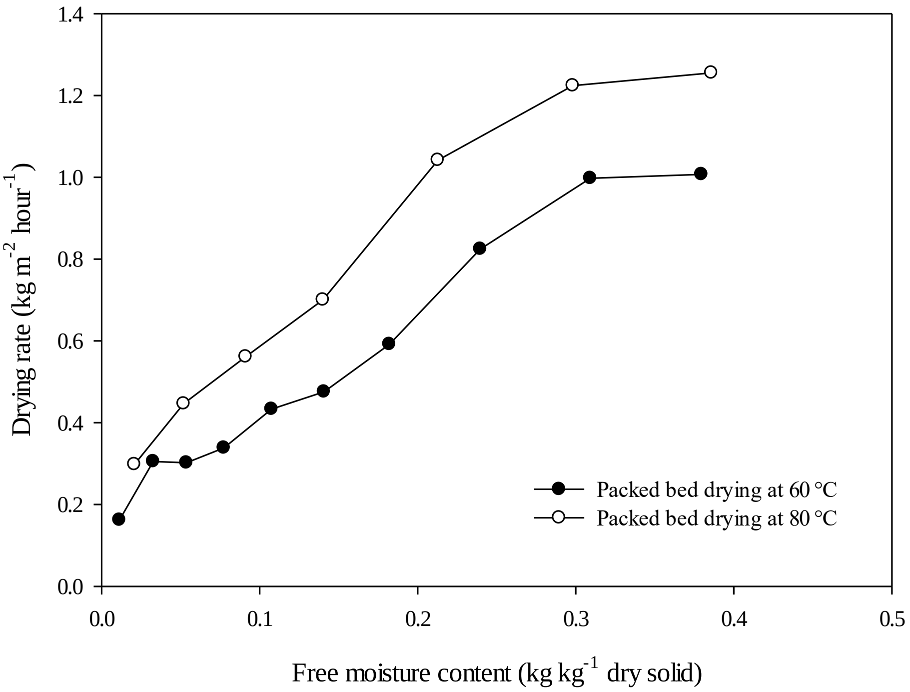

Figure 3.11 Free moisture content versus drying rate graph of packed bed dried pasta-like couscous containing 100 % of bulgur flour

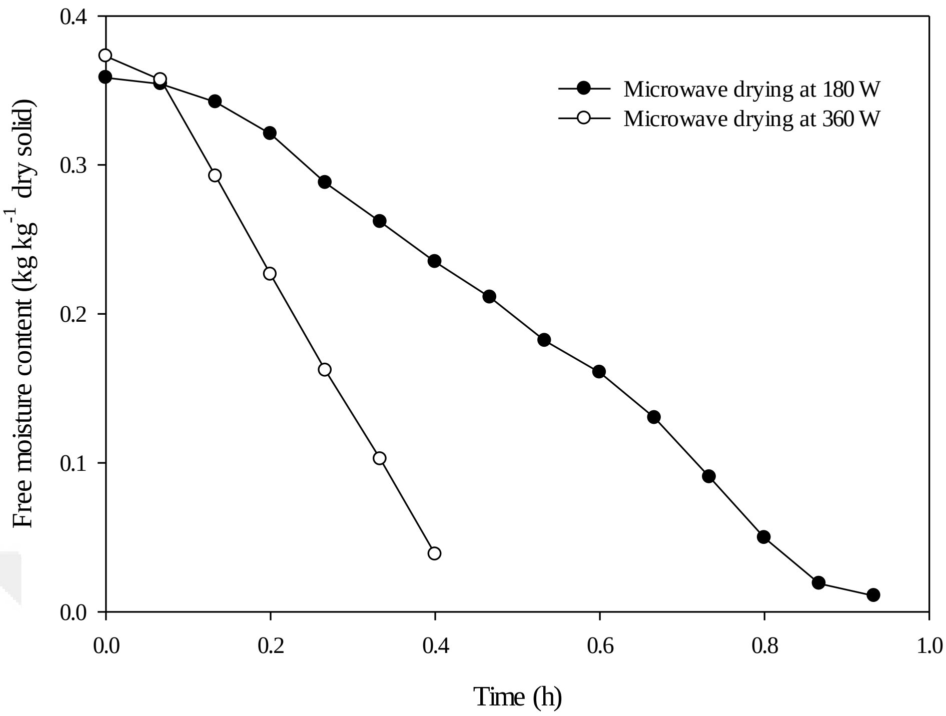

Figure 3.12 Free moisture content versus time graph of microwave dried pasta-like couscous containing 0 % of bulgur flour

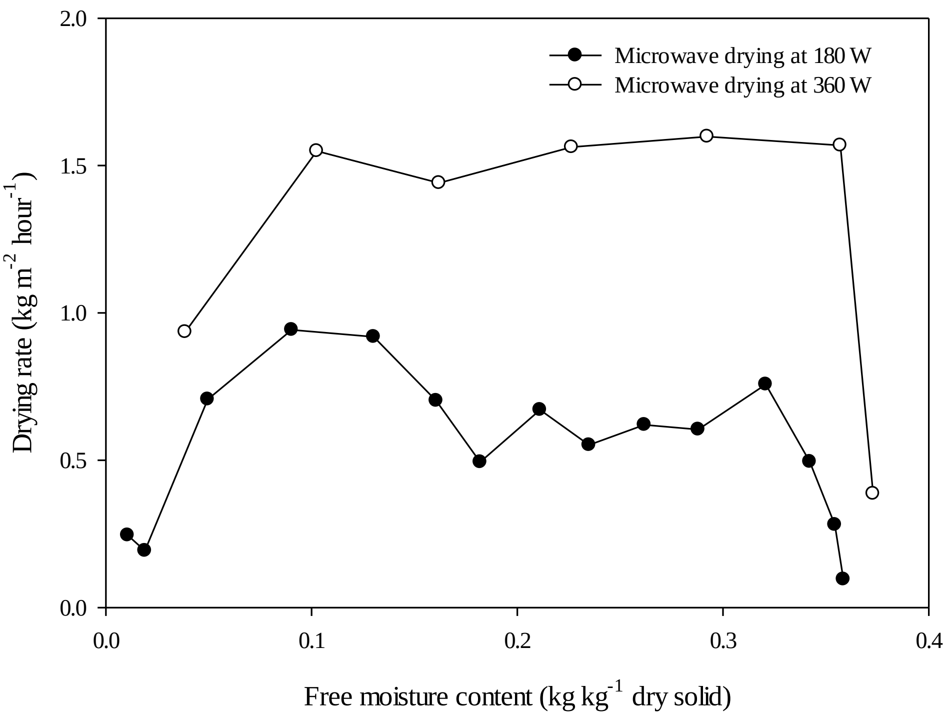

Figure 3.13 Free moisture content versus drying rate graph of microwave dried pasta-like couscous containing 0 % of bulgur flour

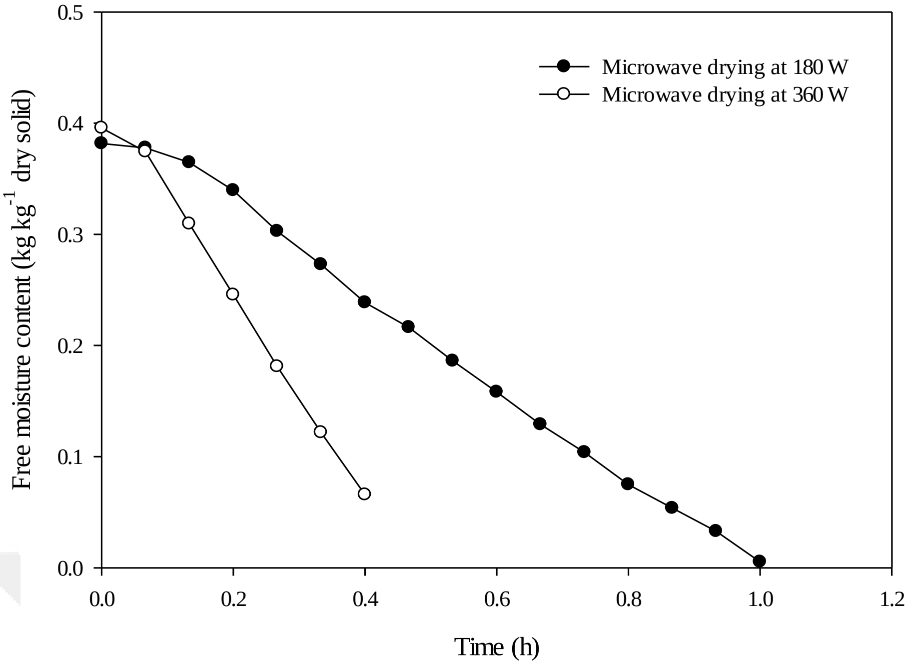

Figure 3.14 Free moisture content versus time graph of microwave dried pasta-like couscous containing 100 % of bulgur flour

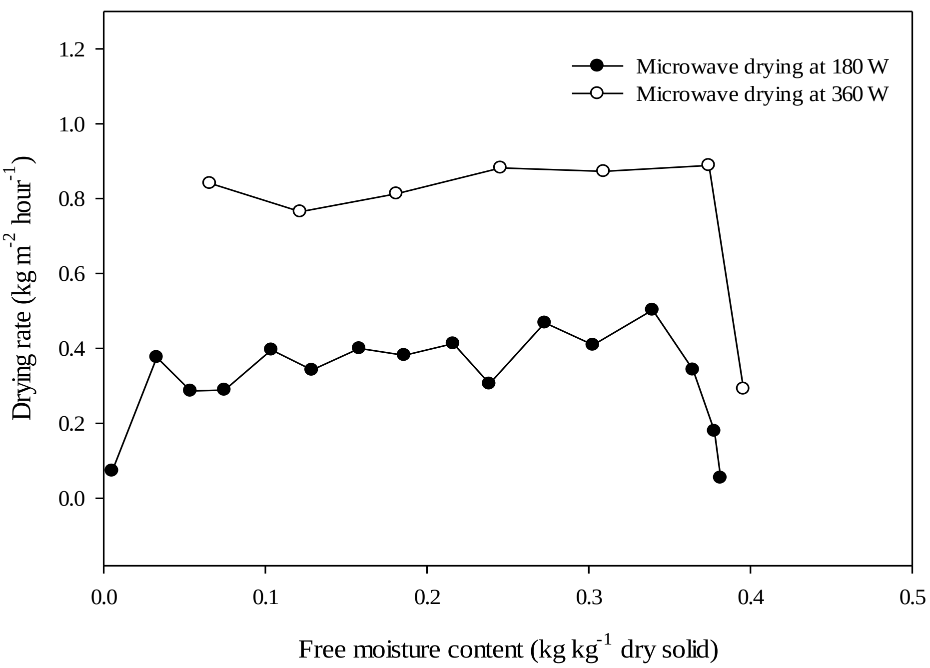

Figure 3.15 Drying rate versus free moisture content graph of packed bed and microwave dried pasta-like couscous containing 100 % of bulgur flour

3.1.2.10 Mathematical modeling of packed bed and microwave dried pasta-like couscous

Six different drying models; Modified Page model (Togrul and Pehlivan, 2003; Vega-Galvez et al., 2010), Modified Henderson and Pabis model (Akpinar et al., 2003; Zenoozian et al., 2008), Hii and others model (Hii et al., 2009), Wang and Singh model (Omolola et al., 2014; Vega-Galvez et al., 2010), Silva and others model (Onwude et al., 2016) and Peleg model (da Silva et al., 2015) were used (Table 1.1) for the modeling of the drying operations (e.g. packed bed and microwave).

During drying, the drying rate decreased continuously with time as moisture content decreasing (Figure 3.7). The whole drying occurred in the falling-rate period; which suggests that the material surface was not saturated with water and the drying rate was controlled by internal diffusion (Chayjan and Kaveh, 2014) and it was the main mechanism of moisture transfer similar to the studies of Dadali et al. (2007), López et al. (2016) and Uribe et al. (2013). According to the drying curves (Figure 3.7), drying periods decreased with increasing drying air temperature and microwave power. It revealed that mass and heat transfers through the samples were faster at higher temperature and microwave power.

Table 3.7 Effective moisture diffusivities of pasta-like couscous

Dryer	Drying Parameter	Effective Diffusivity (D_{eff} x 10^{-8} m^2 s^{-1})
Packed Bed	60 °C	1.48
	80 °C	1.98
Microwave	180 W	0.89
	360 W	1.27

The effective moisture diffusivities of bulgur-couscous were between 0.89 x 10^{-8}-1.98 x 10^{-8} m^2s^{-1} (Table 3.7). D_{eff} values of bulgur-couscous increases with increasing air temperature and power intensity of microwave. Similar behavior of D_{eff} was reported by various authors: working with chickpea 7.13 x 10^{-11}-13.78 x 10^{-11} m^2s^{-1} for 40-60 °C (da Silva et al., 2013); quinoa 3.78 x 10^{-11}-7.67 x 10^{-11} m^2s^{-1} for 40-80 °C (Vega-Galvez et al., 2010); quinoa seeds 0.38 x 10^{-11}-7.19 x 10^{-11} m^2s^{-1} for

30-90 °C (Gely and Santalla, 2007); amaranth grains 0.65 x 10^{-9}-2.15 x 10^{-9} m^2s^{-1} for 40-70 °C (Resio et al., 2004); parboiled Burgos wheat 2.38 x 10^{-11}-14.10 x 10^{-11} m^2s^{-1} for 50-70 °C (Yıldırım, 2018); spinach 1.99 x 10^{-10}-5.24 x 10^{-10} m^2s^{-1} for 180-900 W (Dadali et al., 2007); basil 2.17 x 10^{-10}-7.90 x 10^{-10} m^2s^{-1} for 180-900 W (Demirhan and Ozbek, 2010b).

Table 3.8 Parameters for the drying models for pasta-like couscous

		Packed Bed Drying		Microwave Drying	
Model Name		**60 °C**	**80 °C**	**180 W**	**360 W**
Modified Page II	*k*	0.0011	0.0014	0.0005	0.0001
	n	1.2118	1.3523	1.9680	2.0092
Modified Henderson and Pabis	*a*	0.3468	0.3495	0.3894	0.3736
	b	0.3468	0.3495	0.3894	0.3736
	c	0.3468	0.3495	0.3894	0.3736
	k	0.0011	0.0015	0.0005	0.0011
	g	0.0011	0.0015	0.0005	0.0011
	h	0.0011	0.0015	0.0005	0.0011
Hii and others	*a*	0.4951	0.4958	0.4939	0.4931
	b	0.4951	0.4958	0.4942	0.4931
	k	0.0002	0.0001	1.8026	5.6561×10^{-7}
	g	0.0002	0.0001	1.8026	5.6569×10^{-7}
	n	1.2351	1.3683	2.0141	2.0665
Wang and Singh	*a*	-0.0008	-0.0011	-0.0002	-0.0005
	b	1.6288×10^{-7}	2.8298×10^{-7}	-1.1434×10^{-8}	-8.4167×10^{-8}
Silva and others	*a*	0.0014	0.0022	0.0009	0.0019
	b	-0.0106	-0.0201	-0.0191	-0.0302
Peleg	*a*	996.7010	801.6652	4138.4636	2062.3942
	b	0.5731	0.5027	-0.1462	-0.2429

The dimensionless moisture ratio against drying time for the experimental data at two different drying air temperatures and drying power intensities was fitted to Modified Page II, Modified Henderson and Pabis, Hii and others, Wang and Singh, Silva and others and Peleg models available in the literature (Table 1.1). The results of fittings are displayed in Table 3.8 and 3.9, which show the values of estimated constants with their corresponding R^2, RMSE, χ^2 and RSS values. High values of correlation coefficient, low root mean square errors, low reduced chi-square and low residual sum of squares indicate a good fitting of the model in predicting drying kinetics of the product (Kucuk et al., 2014). The results showed that experimental data fitted adequately to the models used in the study. The correlation coefficients were obtained between 0.9088-0.9994. According to the results, the models that best fitted to the experimental data, considering as the first criterion of selection as the correlation coefficient (R^2>0.990); were Modified Page II, Hii and others, Wang and Singh and Peleg models for all drying conditions. However, when evaluating the fitting quality with other statistical values, Wang and Singh model for packed bed drying and microwave drying was observed to be the most suitable for the experimental data with the highest values of R^2, and the lowest values of RMSE, χ^2 and RSS. Moisture ratio against time for packed bed and microwave drying with comparing experimental data with predicted data were illustrated in Figs 3.16 and 3.17. It was an interesting that the shape of drying curve of packed bed in the falling rate period was exponential (Figure 3.16). However, in Figure 3.17, the shape of drying graph of microwave was linear. This difference in falling rate period between the drying operations can be explained as an increase in microwave power level caused the drying curve become steeper, indicating an increase in drying rate. This similar result was also observed by the study of Bal et al. (2010). Senadeera et al. (2003) investigated the influence of shapes of beans, potato and peas on drying kinetics during fluidized bed drying. They determined effective diffusivity coefficient and activation energy of vegetables which were dried at 30, 40 and 50 °C. Exponential and Page model gave R^2 values greater than 0.90. However, according to mean square error values of two models, the Page model gave a better fit than simple exponential model. Vega-Galvez et al. (2010) for convective drying of quinoa, Togrul and Pehlivan (2003) for convective drying of single apricots and Demirhan and Ozbek (2010b) for microwave drying of basil found the best fitting model as logarithmic model. Akpinar et al. (2003) studied on the drying of red peppers with convective dryer at 55, 60 and 70 °C and found approximation of diffusion model as the best fitting model. da Silva et al. (2015) compared continuous and intermittent drying of whole bananas and observed the Peleg model was giving the best fitting. For convective drying of lemon slices, Midilli and Kucuk model was found the most suitable by Torki-Harchegani et al. (2016) and also for microwave drying of purslane by Demirhan and Ozbek (2010a). Wang and Singh and Page models were found as the best for microwave drying of bamboo shoot slices (Bal et al., 2010) and spinach (Dadali et al., 2007), respectively.

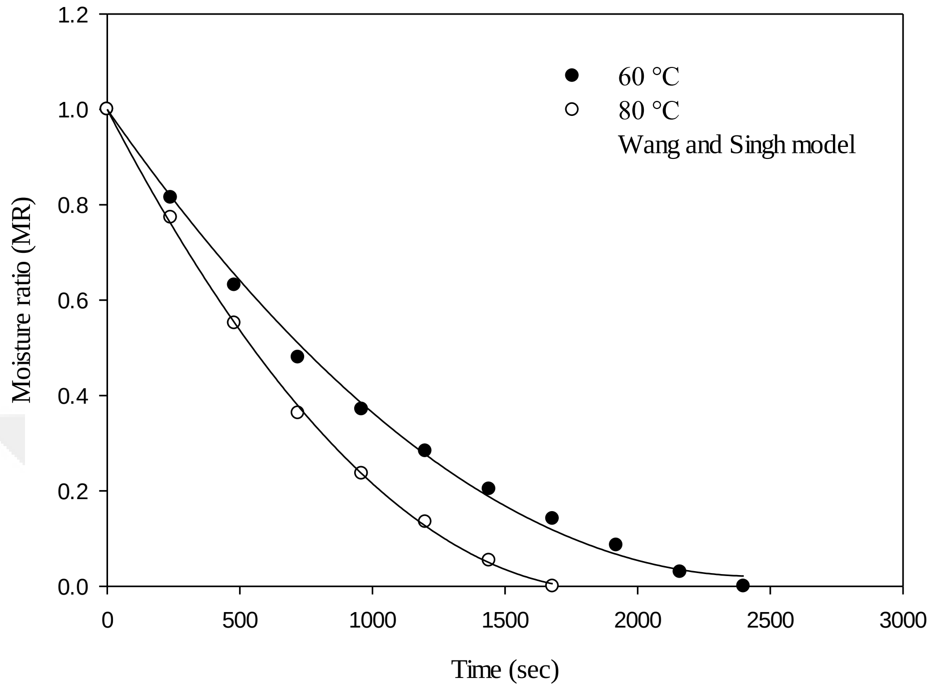

Figure 3.16 Moisture ratio against time for packed bed drying, comparing experimental data with predicted Wang and Singh model for pasta-like couscous

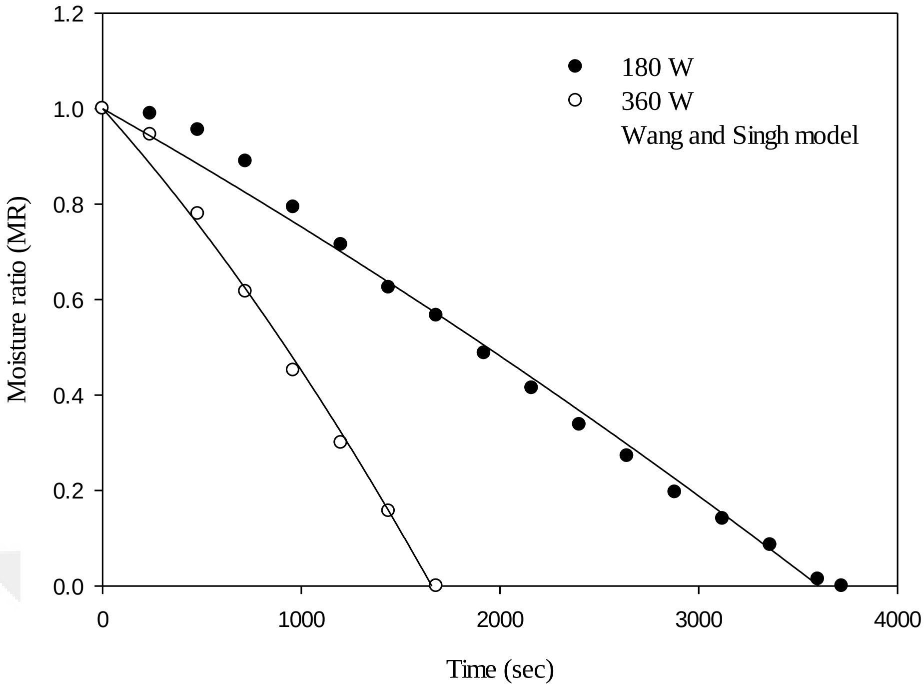

Figure 3.17 Moisture ratio against time for microwave drying, comparing experimental data with predicted Wang and Singh model for pasta-like couscous

Table 3.9 Statistical results for various drying model for pasta-like couscous

Drying Parameters	**Packed Bed Drying**								**Microwave Drying**							
	60 °C				**80 °C**				**180 W**				**360 W**			
Model Name	**R^2**	**RMSE**	**χ^2**	**RSS**	**R^2**	**RMSE**	**χ^2**	**RSS**	**R^2**	**RMSE**	**χ^2**	**RSS**	**R^2**	**RMSE**	**χ^2**	**RSS**
Modified Page II	0.9959	0.0203	0.0005	0.0045	0.9971	0.0181	0.0004	0.0026	0.9934	0.0277	0.0009	0.0131	0.9913	0.0321	0.0014	0.0082
Modified Henderson and Pabis	0.9877	0.0350	0.0027	0.0135	0.9796	0.0479	0.0092	0.0183	0.9222	0.0948	0.0139	0.1529	0.9088	0.1036	0.0429	0.0859
Hii and others	0.9960	0.0200	0.0007	0.0044	0.9972	0.0178	0.0008	0.0025	0.9935	0.0273	0.0011	0.0127	0.9916	0.0315	0.0027	0.0080
Wang and Singh	**0.9970**	0.0173	0.0004	0.0033	**0.9994**	0.0080	0.0001	0.0005	**0.9910**	0.0322	0.0012	0.0177	**0.9939**	0.0267	0.0010	0.0057
Silva and others	0.9938	0.0249	0.0008	0.0068	0.9937	0.0266	0.0009	0.0057	0.9676	0.0612	0.0042	0.0637	0.9687	0.0607	0.0049	0.0295
Peleg	0.9990	0.0102	0.0001	0.0011	0.9974	0.0004	0.0172	0.0024	0.9907	0.0328	0.0012	0.0182	0.9934	0.0279	0.0010	0.0062

3.2 African couscous

3.2.1 Determination of optimum processing parameters and formulations

In order to determine the optimum processing parameters and formulations; 0, 25, 50, 75 and 100 % of bulgur containing samples were prepared (Figure 3.18). However, the yields of non-dried products with 75 and 100 % of bulgur flour were lower than 50 %, which was the target yield to produce enough couscous for further processes. For that reason, the samples with 25 and 50 % of bulgur flour were only used. The prepared samples were dried using packed bed (60 and 80 °C) and microwave (180 and 360 W) dryers. After all products were obtained from the drying operations, screen analysis were made in order to determine the production yield, sensory analysis and color measurements (L*, a*, b*and YI) for determining the optimum processing parameters and formulas.

Figure 3.18 25 % of bulgur flour containing African couscous

3.2.1.1 Optimization based on yield of African couscous

After the preparation of the samples, screen analysis was made before the drying operations. Sieves with 3.00, 2.00 and 1.00 mm of apertures were used. The products, with granule sizes between 3.00 and 1.00 mm were accepted for the drying operations. Aboubacar et al. (2006) produced couscous from flours of different sorghum cultivars and they separated couscous into fine (<1 mm), medium (1-2 mm) and coarse (>2 mm) particles. They defined the couscous yield as the amount of 1-2 mm particles. Yields, before drying operation, were 52.6±2.28, 54.81±2.44 and 50.5±1.33 % for the couscous consisting quantity of 0, 25 and 50 % bulgur flour, respectively. Quantity of bulgur flour was not significantly (p>0.05) effective on the yield of the couscous samples before the drying operations.

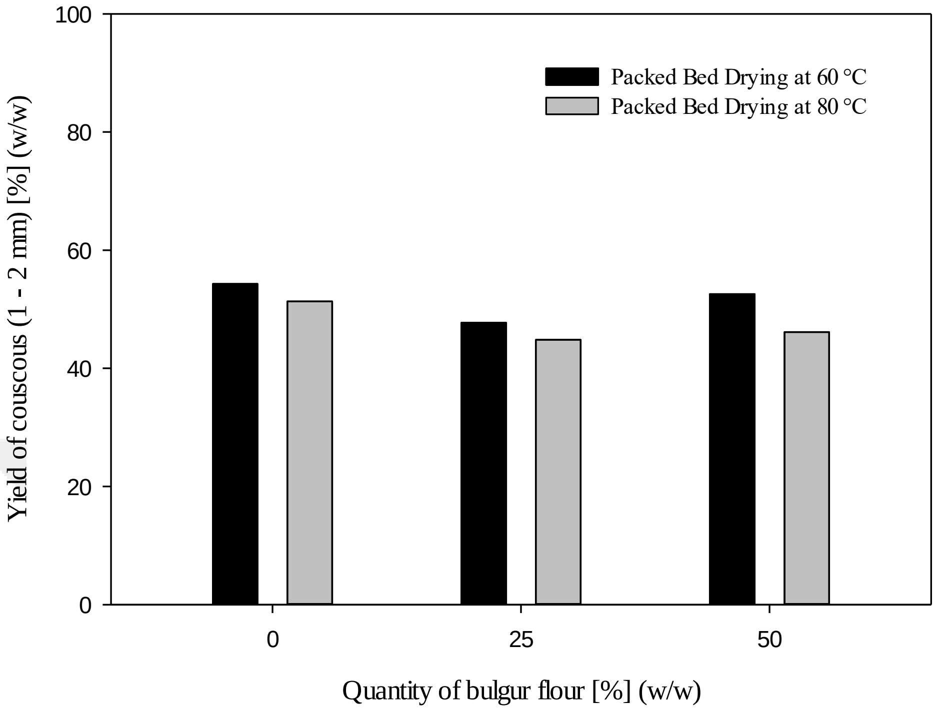

Figure 3.19 Yields of packed bed dried African couscous

For packed bed drying at 60 °C, the yields were 54.28±3.78, 47.70±1.73 and 52.57±7.04 % for the couscous consisting quantity of 0, 25 and 50 % bulgur flour, respectively. Moreover, at 80 °C, the yields were 51.34±0.77, 44.84±1.18 and 46.13±1.28 % for the couscous consisting quantity of 0, 25 and 50 % bulgur flour, respectively (Figure 3.19). Even though quantity of bulgur flour was not significantly (p>0.05) effective on the yield when dried at 60 °C, it was significantly (p≤0.05) effective on the yield when dried at 80 °C. It can be said that increasing temperature caused decreasing yield of couscous for packed bed drying.

The amount of desired particle size couscous differed by the changes of the quantity of bulgur flour even though flour mixture was mixed well before the production. The reason of this variety can be resulted from the production technique. Moreover, the lower fraction of desired size couscous was due to the high amount of bran in bulgur flour competes with starch for water and results in less available water for starch gelatinization (Aboubacar et al., 2006).

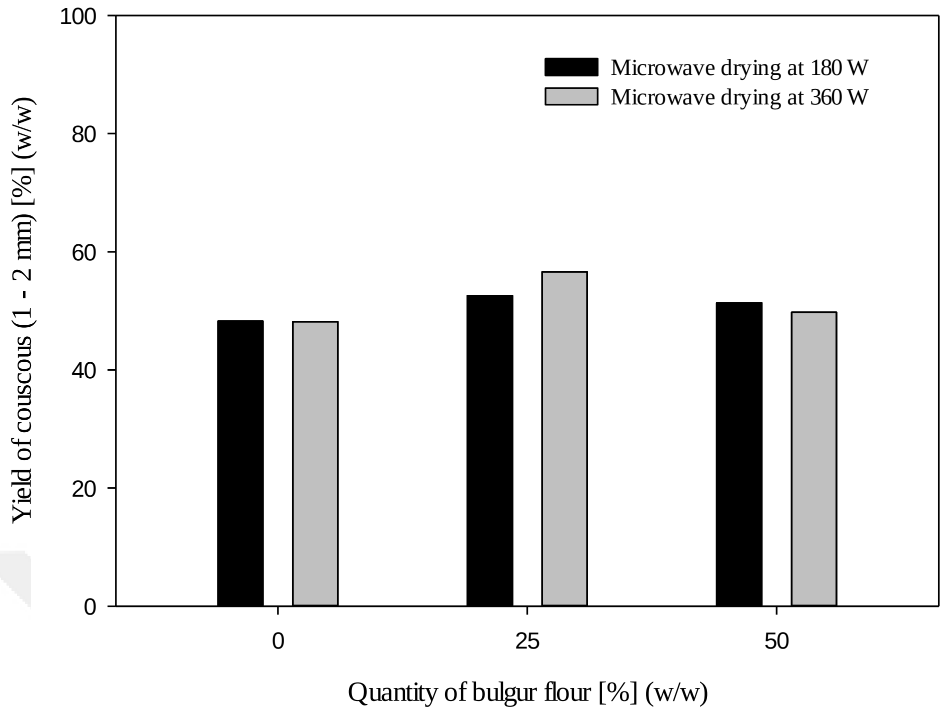

Figure 3.20 Yields of microwave dried African couscous

For microwave drying at power intensities of 180 W, the yields were 48.26±1.92, 52.56±0.96 and 51.36±3.03 % for the couscous consisting quantity of 0, 25 and 50 %, respectively. Additionally, for microwave drying at power intensity of 360 W, the yields were 48.18±0.67, 56.60±1.19 and 49.74±2.06 % for the couscous consisting quantity of 0, 25 and 50 %, respectively (Figure 3.20). Even though quantity of bulgur flour was not significantly ($p>0.05$) effective on the yield of couscous when dried at 180 W, it was also significantly ($p\leq0.05$) effective on the yield of couscous when dried at 360 W. It can be said that increasing power intensity of microwave dryer resulted increase in the yield of desired particle size of couscous.

The yields of couscous were slightly higher for microwave drying compared to packed bed drying. The reason of lower yields can be due to the breakage of couscous particles in the packed bed dryer. Even no fluidization of product occurred in the dryer; the velocity and the temperature of the drying air can cause breaking and separation of semolina/bulgur flour particles during drying. At low moisture content, couscous particles became more fragile.

3.2.1.2 Optimization based on color values and sensory analysis of African couscous

The changes in L*, a*, b* and YI values based on the quantity of bulgur flour of samples are shown in Figures 3.21-3.24. For all dried and non-dried couscous, the quantity of bulgur flour was significantly ($p \leq 0.05$) effective on lightness, yellowness and redness. The quantity of bulgur flour, when packed bed dried samples at 80 °C, has no significant ($p > 0.05$) effect on the cloudiness-opaqueness (Yellowness index, YI value). Lightness (L*) values of couscous samples were decreased with increasing the quantity of bulgur flour after both drying operations. Although lightness values of packed bed dried and non-dried couscous were similar, microwave dried couscous had lower lightness values at different quantity of bulgur flour.

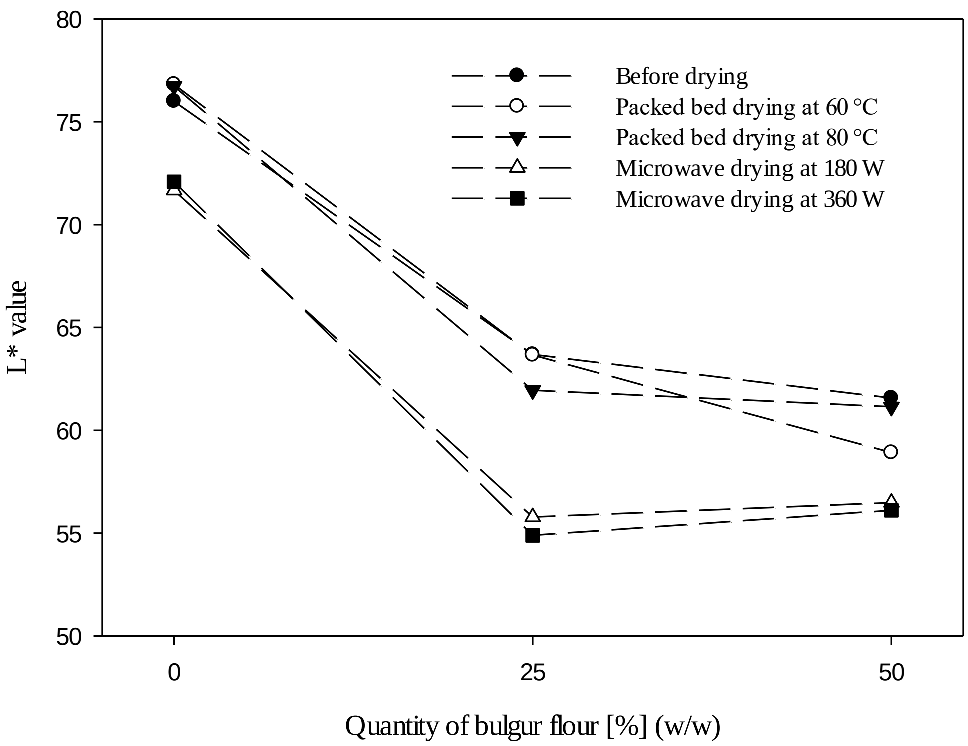

Figure 3.21 L* values of uncooked African couscous

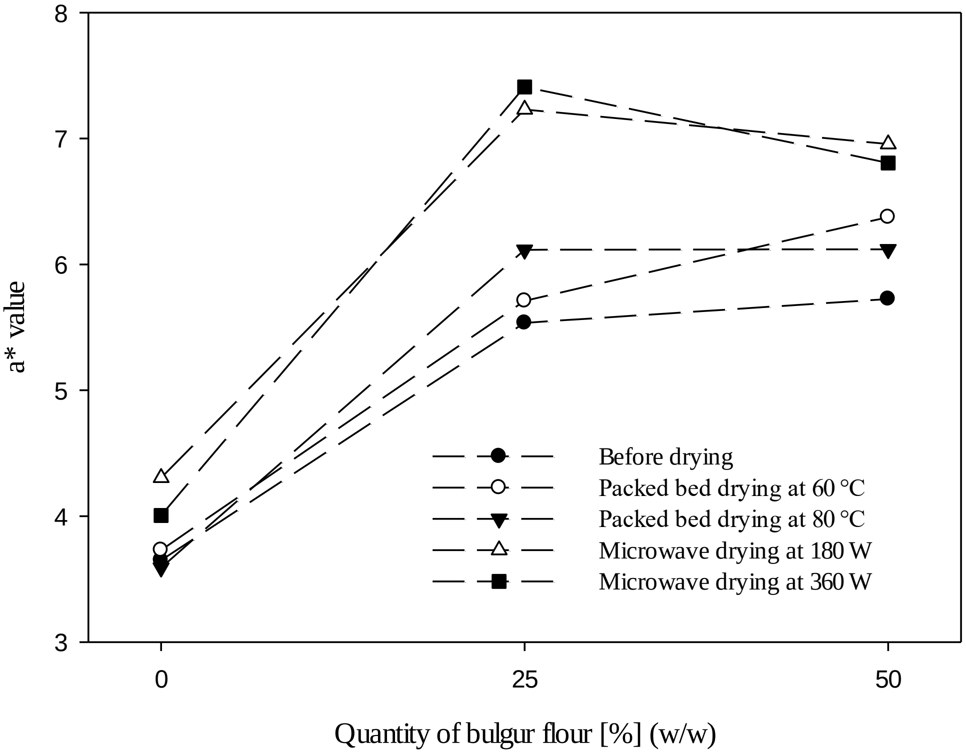

Figure 3.22 a* values of uncooked African couscous

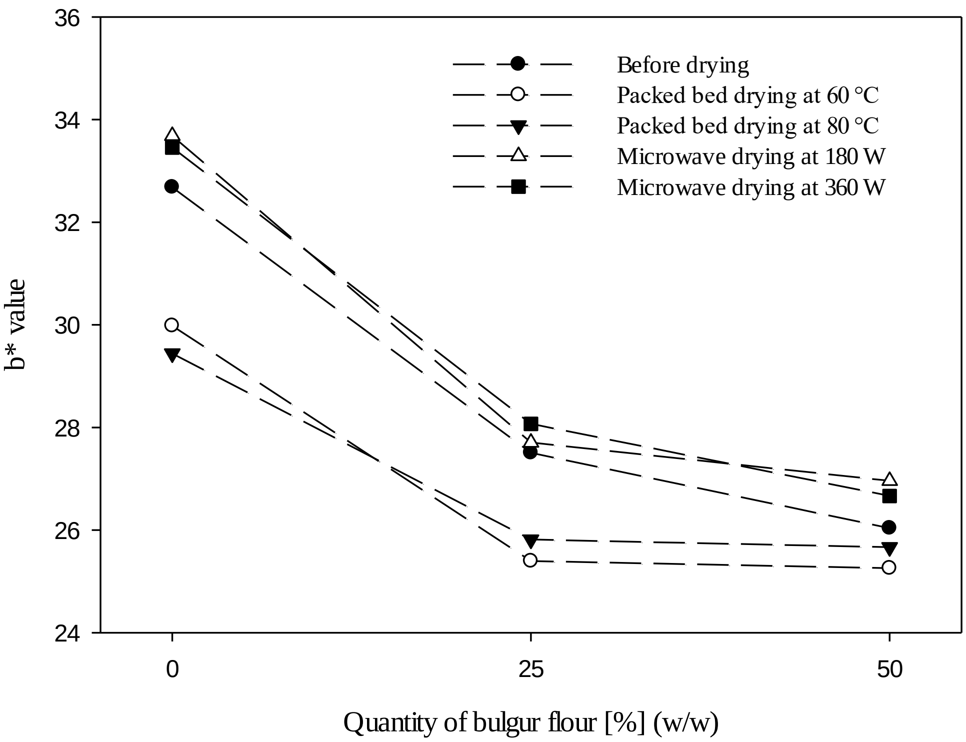

Figure 3.23 b* values of uncooked African couscous

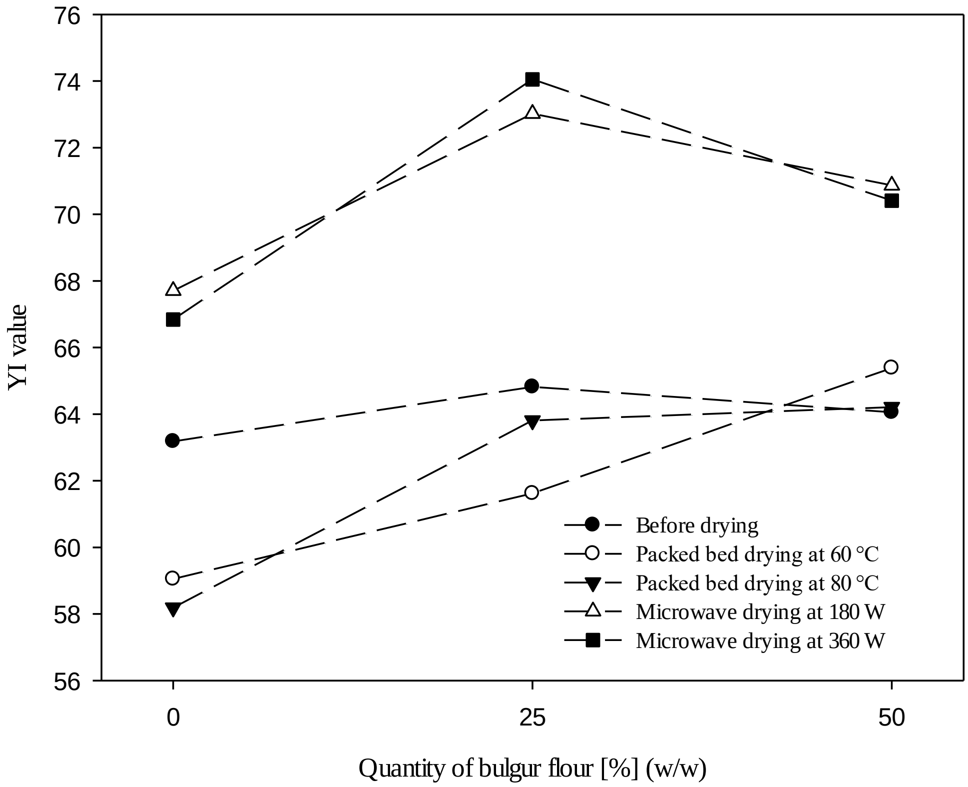

Figure 3.24 YI values of uncooked African couscous

According to Duncan's multiple range tests, L* values of couscous were significantly ($p \leq 0.05$) different for non-dried and microwave dried couscous at 180 and 360 W. L* values of packed bed dried couscous at 60 and 80°C were not significantly ($p > 0.05$) different for quantity of 25 and 50 % bulgur flour. However, both were significantly ($p \leq 0.05$) different than the control (quantity of 0 % bulgur flour) couscous. b* values of couscous before drying, packed bed dried at 60 and 80°C and microwave dried at 360 W were not significantly different for quantity of 25 and 50 % bulgur flour, however both were significantly different than control (quantity of 0 % bulgur flour) couscous. Moreover, when microwave dried at 180 W, b* values of couscous were significantly ($p \leq 0.05$) different. a* values of non-dried, microwave dried (180 and 360 W) and packed bed dried (60 and 80°C) couscous were not significantly ($p > 0.05$) different for quantity of 25 and 50 % bulgur flour. However, both were significantly ($p \leq 0.05$) different than control (semolina-couscous). It is well known that yellow and brown color are correlated both to pigment content and enzymatic reactions, while the red index is strictly related to the development of Maillard reaction products (Oliver et al., 1993).

Yellowness (b*) values of microwave dried at 180 and 360 W were higher than couscous before drying. However, yellowness values of packed bed dried couscous at 60 and 80°C were lower than couscous before drying.

The sensory analysis after the drying operations were made and results are given in Table 3.10. It was found that the quantity of bulgur flour (i.e. 0, 25 and 50 %) was not significantly ($p>0.05$) effective on odor in contrast to color and general appearance.

Table 3.10 Results of sensory analysis of uncooked African couscous products

			Sensory Attributes		
Quantity of bulgur flour [%]	**Drying technique***	**Drying parameters**	**Color**	**Odor**	**General Appearance**
0	PBD	60 °C	6.33 ± 1.88^{abc}	6.47 ± 1.25^{a}	6.87 ± 1.73^{bc}
		80 °C	6.20 ± 1.66^{abc}	6.60 ± 1.30^{a}	7.00 ± 1.46^{bc}
	MW	180 W	6.87 ± 1.41^{bc}	6.33 ± 1.54^{a}	7.13 ± 1.36^{bc}
		360 W	7.33 ± 1.54^{c}	6.53 ± 1.51^{a}	7.40 ± 1.30^{c}
25	PBD	60 °C	5.47 ± 1.96^{ab}	5.87 ± 1.19^{a}	5.93 ± 1.71^{ab}
		80 °C	5.33 ± 1.88^{a}	6.07 ± 1.22^{a}	5.73 ± 1.83^{ab}
	MW	180 W	5.80 ± 1.74^{ab}	6.60 ± 1.18^{a}	6.07 ± 1.87^{abc}
		360 W	5.93 ± 1.87^{abc}	6.67 ± 1.35^{a}	6.00 ± 1.56^{abc}
50	PBD	60 °C	5.07 ± 1.94^{a}	6.33 ± 1.45^{a}	5.40 ± 2.13^{a}
		80 °C	4.87 ± 2.07^{a}	6.33 ± 1.11^{a}	5.40 ± 2.06^{a}
	MW	180 W	4.93 ± 1.87^{a}	6.40 ± 1.24^{a}	5.20 ± 2.08^{a}
		360 W	4.93 ± 1.67^{a}	6.60 ± 1.40^{a}	5.33 ± 1.88^{a}

*PBD: Packed Bed Dryer. MW: Microwave. Each column followed by different superscripts is significantly different ($p\leq0.05$).

3.2.1.3 Optimum results of African couscous

According to color (L*, a*, b* and YI) and sensory values after the drying operations, the optimum processing parameters and recipes were determined such as 1) 50 % (w/w) of water for dough preparation, 50 % of bulgur flour, 60 °C drying temperature for packed bed dryer; 2) 50 % (w/w) of water for dough preparation, 50 % of bulgur flour, 180 W drying power for microwave dryer. As a note, the quantity of water was calculated according to total semolina and bulgur flour weight to obtain suitable dough stickiness and consistency. According to these optimum conditions, the further analyses were made for the optimum products.

3.2.2 Analysis of the optimum products/formulations of African couscous

For the optimum products, chemical and physical analyses were made to determine some functional and engineering properties of couscous. In order to compare the results, the control couscous sample results were also used.

3.2.2.1 Bulk density for African couscous

It was found that bulk densities of control samples (semolina-couscous) were a little higher than bulgur containing couscous samples, which were produced with packed bed (at 60 ºC) and microwave (at 180 W) dryers (Table 3.11). However, the quantity of bulgur flour was not significantly ($p>0.05$) effective on bulk density. Additionally, the control samples were not significantly ($p>0.05$) different from bulgur containing couscous. Bulk density of granular products increases with the increase in the size of granules due to low surface area and void fraction between particles. Due to porous form and small particle size in couscous-like product, their bulk densities were lower, for example, than the hammer (663.9 kg/m^3), stone (741.6 kg/m^3) and disc milled (735.0 kg/m^3) coarse bulgur (Bayram and Öner, 2005).

3.2.2.2 Weight increase for African couscous

Weight increase is used to analyze the water absorption ability of couscous. The texture of cooked couscous is dependent on the weight increase. It was found that there was slight but no significant ($p>0.05$) weight increase difference between the packed bed and microwave dried semolina and bulgur containing couscous samples (Table 3.11). Hallen et al. (2004) substituted cowpea flour with wheat flour to investigate the rheological and baking properties of flour blends. They found a correlation between the flour water absorption and increasing levels of cowpea flour.

The water absorption in blends was increased by higher bran content and more damaged starch.

3.2.2.3 Protein and ash contents for African couscous

Protein and ash contents of bulgur containing couscous samples were significantly ($p \leq 0.05$) higher than semolina-couscous due to the raw materials properties (Table 3.11). Bulgur, which has higher protein and ash contents than semolina, caused increase of these properties in couscous product. Ash comes from bran layer of wheat and bran is not removed completely during bulgur production. Protein and ash contents of bulgur flour were similar to durum wheat (the level of 8 % debranned), where Singh and Singh (2010) observed as between 12.9 and 13.2 % (d.b.) and between 1.40 and 1.56 % (d.b.), respectively. Moreover, durum wheat has the highest ash content, i.e. 1.95 % against a lowest value of 1.70 % for bread wheat according to the study made by Singh et al. (1998). Rahmani and Muller (1996) measured ash and protein contents of five traditional and four commercial couscous samples and found that protein and ash contents were between 12.2-14.3 g/100 g sample (d.b.) and 1.03-1.49 g/100 g sample (d.b.), respectively.

3.2.2.4 Crude fiber contents for African couscous

Crude fiber contents of bulgur flour and semolina were 6.20±0.44 and 0.75±0.05 % (d.b.), respectively (Table 3.1). Due to the high bran content of bulgur flour, crude fiber contents of bulgur containing samples were significantly ($p \leq 0.05$) higher than control samples. According to Duncan's multiple range tests, bulgur containing couscous samples were significantly ($p \leq 0.05$) different than semolina-couscous samples (Table 3.11). Similar results obtained by Cardenas-Hernandez et al. (2016) whom investigated the effects of dried amaranth leaves and amaranth seed flour on functional properties of pasta. The results showed that the addition of amaranth seed flour and dried amaranth leaves increased crude fiber content of pasta. Crude fiber contents of enriched pasta samples were in between of 1.62 and 4.14 % which were higher than the control sample (100 % of semolina, 0.72 % of crude fiber).

Kaur et al. (2012) produced fiber enriched pasta by adding bran of wheat, rice, barley and oat to durum wheat semolina. Crude fiber contents of semolina, wheat bran, rice bran, barley bran and oat bran were 1.41, 7.75, 11.5, 14.9 and 3.31 %, respectively. In another study of Lamacchia et al. (2010), toasted and defatted soy flour were used in spaghetti production with crude fiber content of 4.94 and 2.52 %, respectively. They blended semolina with various concentrations.

3.2.2.5 Total phenol and total flavonoid contents and % DPPH scavenging activity for African couscous

Phenolics provide essential functions in the reproduction and growth of the plants and acting as defense mechanisms. In addition, phenolic substances in our diet may provide health benefits associated with reduced risk of chronic diseases. Phenolic compounds in whole grains contribute to antioxidant activity (Liu, 2007). Total phenol and flavonoid contents of bulgur flour and semolina were determined as 73.83 and 83.53 mg gallic acid/100 g sample and 105.88 and 63.92 mg catechin/100 g sample, respectively. Their % DPPH scavenging activities were 70.58 % for bulgur flour and 68.67 % for semolina (Table 3.1). According to the statistical analysis, total phenol content and % DPPH scavenging activity were not significantly ($p>0.05$) affected by the quantity of bulgur flour in contrast to the total flavonoid content. Moreover, antioxidant activities of semolina-couscous and bulgur containing couscous were not significantly ($p>0.05$) different from each other (Table 3.11).

The results of the present study are similar with the results of other studies made in cereal commodities. Yu et al. (2002) examined and compared three hard winter wheat varieties for their free radical scavenging properties and total phenolic contents. They found that the total phenolic contents were in the range of 48.8-92.8 mg gallic acid/100 g of grain. Caba et al. (2012) determined total phenols and DPPH scavenging activity % of five different bulgur brands and they found that the average total phenol content and % DPPH values are 59.5±5.2 mg gallic acid/100 g dry sample and 22.2±2.4 %, respectively. Higher percentage of DPPH activity resulted due to the high quantities of bran in bulgur flour. Similarly, due to the higher pigment content of semolina, antioxidant activities of control sample were high. Where radical scavenging activities of higher pigment content containing red sorghum and black rice were 92 and 87 %, respectively; non-pigmented cereals have DPPH activity of 7 – 67 % (Choi et al., 2007).

3.2.2.6 Texture Profile Analysis (TPA) for African couscous

Texture profile of cooked African/Arabic type couscous samples are given in Table 3.12. Hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness and resilience were measured using texture analyzer. It was found that the resilience values of bulgur and semolina containing samples were significantly ($p \leq 0.05$) changed. In contrast to the resilience, the hardness, adhesiveness, cohesiveness, springiness, gumminess and chewiness of the product were not changed significantly ($p > 0.05$). The hardness of bulgur containing couscous samples was higher than semolina-couscous for each drying technique.

Adhesiveness of packed bed dried couscous samples was higher (not preferred) than microwave dried ones. Moreover, the samples containing 0 and 50 % of bulgur flour dried by using packed bed and microwave dryers were not significantly ($p > 0.05$) different for adhesiveness, springiness, cohesiveness, chewiness and resilience. Bulgur-couscous dried with microwave dryer, which had the highest values for TPA parameters of hardness, cohesiveness, gumminess, chewiness and resilience. According to the study made by Singh and Singh (2010), the increase in the debraning level of wheat caused decrease in textural properties. They observed that cohesiveness and chewiness values of wheat varieties ranging from 0.27 to 0.37 and 4.16 to 9.62 N, respectively, where similar values of cohesiveness of couscous-like products were observed ranging from 0.30 to 0.41. However, chewiness values of bulgur containing couscous products were higher than wheat varieties, i.e. between 20.58 and 91.73.

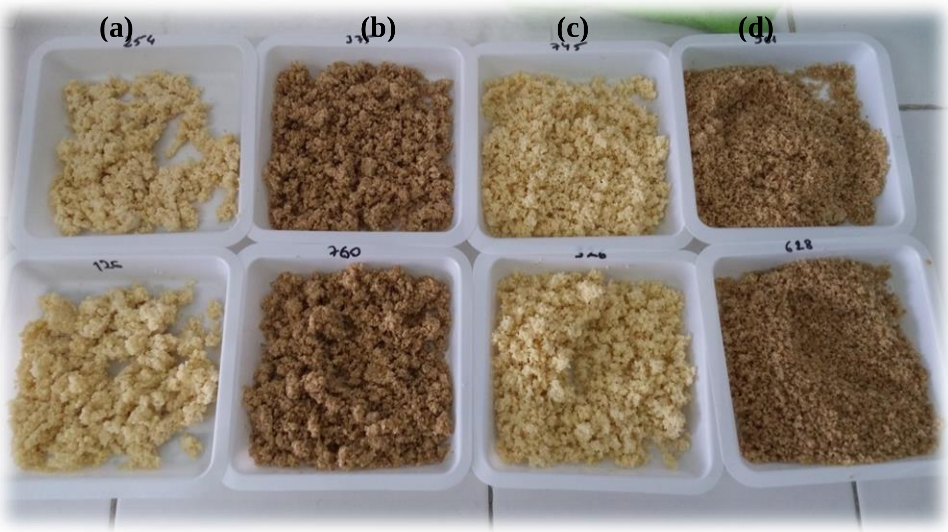

Figure 3.25 Cooked African couscous (a) packed bed dried at 60 °C control and (b) 50 % of bulgur flour containing couscous, (c) microwave dried at 180 W control and (d) 50 % of bulgur flour containing couscous

3.2.2.7 Sensory analysis for African couscous

Sensory analysis showed that the quantity of bulgur flour was significantly ($p \leq 0.05$) effective on all sensory attributes (Table 3.13). It was obtained that bulgur containing couscous had higher sensory scores than semolina-couscous generally. Bulgur containing couscous dried with microwave dryer had the highest scores for all sensory attributes. However, semolina-couscous dried with packed bed dryer had lowest scores for all sensory attributes. Couscous samples with bulgur flour dried with packed bed and microwave dryers were more preferable for consumers. In Figure 3.25, cooked African couscous samples are shown.

Table 3.11 Quality and functional properties of optimum African couscous products

			Quality Properties					Functional Properties		
Quantity of bulgur flour [%]	**Drying technique***	**Drying parameters**	**Bulk density [kg/m^3]**	**Weight increase [%, w/w]**	**Protein content [d.b., %]**	**Ash content [d.b., %]**	**Crude fiber content [d.b., %, w/w]**	**Total phenol content [mg gallic acid/100 g sample]**	**Total flavonoid content [mg catechin/100 g sample]**	**% DPPH scavenging activity**
0	PBD	60 °C	610.32±49.94^{a}	70.06±0.11^{a}	10.95±0.07^{a}	0.93±0.01^{a}	1.01±0.08^{a}	60.43±2.43^{b}	35.27±4.99^{b}	73.55±0.61^{a}
50			519.95±11.24^{a}	70.76±2.46^{a}	11.92±0.1^{c}	2.01±0.07^{b}	2.79±0.00^{b}	50.99±6.79^{ab}	54.26±5.07^{c}	71.48±1.80^{a}
0	MW	180 W	628.28±67.49^{a}	70.48±0.98^{a}	11.05±0.16^{ab}	0.88±0.03^{a}	1.22±0.21^{a}	32.98±11.07^{a}	22.05±2.77^{a}	71.57±1.44^{a}
50			593.08±38.91^{a}	70.63±1.50^{a}	11.58±0.32^{bc}	1.90±0.04^{b}	3.42±0.07^{c}	52.93±6.25^{ab}	39.55±0.84^{b}	73.00±2.76^{a}

*PBD: Packed Bed Dryer. MW: Microwave. Each column followed by different superscripts is significantly different ($p \leq 0.05$).

Table 3.12 Texture properties of optimum African couscous products

			Texture Properties						
Quantity of bulgur flour [%]	**Drying technique***	**Drying parameters**	**Hardness (N)**	**Adhesiveness (N.s)**	**Springiness**	**Cohesiveness**	**Gumminess**	**Chewiness**	**Resilience**
0	PBD	60 °C	122.54±36.14[a]	-172.16±218.20[a]	0.52±0.21[a]	0.36±0.07[a]	45.48±21.95[a]	26.08±20.86[a]	0.09±0.01[a]
50			216.92±61.33[ab]	-59.20±32.23[a]	0.28±0.03[a]	0.34±0.00[a]	73.74±20.90[ab]	20.58±3.91[a]	0.12±0.00[a]
0	MW	180 W	276.35±81.47[ab]	-20.24±0.25[a]	0.53±0.24[a]	0.30±0.03[a]	84.38±32.67[ab]	48.99±37.59[a]	0.11±0.02[a]
50			433.75±125.83[b]	-14.10±0.26[a]	0.50±0.05[a]	0.41±0.04[a]	181.56±67.43[b]	91.73±42.13[a]	0.16±0.01[b]

*PBD: Packed Bed Dryer. MW: Microwave. Each column followed by different superscripts is significantly different ($p \leq 0.05$).

Table 3.13 Sensory properties of optimum African couscous products

Quantity of bulgur flour [%]	Drying technique*	Drying parameters	Sensory Properties					
			Chewiness	Hardness	Odor	Taste	Color	General acceptability
0	PBD	60 °C	4.57±2.40[a]	4.60±2.33[a]	5.52±2.45[a]	5.57±2.52[a]	5.93±2.33[a]	5.12±2.59[a]
50			6.80±1.98[b]	6.20±2.10[b]	7.10±0.97[b]	7.42±1.24[b]	7.67±1.02[b]	7.28±1.12[b]
0	MW	180 W	7.03±1.56[b]	6.70±1.44[b]	6.63±2.29[b]	7.18±1.98[b]	7.20±2.10[b]	7.25±1.95[b]
50			8.38±1.15[c]	8.50±0.98[c]	8.48±1.57[c]	8.82±1.05[c]	8.72±1.24[c]	8.97±0.94[c]

*PBD: Packed Bed Dryer. MW: Microwave. Each column followed by different superscripts is significantly different ($p \leq 0.05$).

3.2.2.8 Drying curves of optimum products for African couscous

Drying curves of optimum products of African couscous were given in Figure 3.26-3.35. Free moisture contents of packed bed dried (60 °C) samples containing 0 and 50 % of bulgur flour were 30 and 39 %, respectively. The difference of moisture contents could be due to the different moisture contents of semolina and bulgur flour. Water absorption capacity of bulgur flour was higher than semolina.

Representative drying rate curves for bulgur containing couscous samples dried with packed bed (60 and 80 °C) and microwave (180 and 360 W) are shown in Fig. 3.27. Microwave drying at 360 W had high drying rates during drying in comparison with 180 W power level and packed bed drying. Drying time was reduced 27 % with increasing air temperature from 60 to 80 °C. It was reduced 58.41 % with increasing microwave power from 180 to 360 W. It can be concluded that microwave power increment is more effective on drying time of bulgur containing couscous product than increment of drying air temperature.

The moisture contents of the samples were decreased with time, however after warming-up period, drying rates were decreased and increased continuously for each drying technique. The average drying rates of packed bed dryer at 60 and 80 °C were 0.0159 and 0.0209 (kg m^{-2} $hour^{-1}$), respectively. The results obtained were 0.0179 and 0.0395 (kg m^{-2} $hour^{-1}$) at 180 and 360 W for microwave drying, respectively. Therefore, it was found that the drying rates increased with the increment of microwave power from 180 to 360 W and the temperature of packed bed dryer from 60 to 80 °C. Similarly, Bal et al. (2010) observed constant rate period during the drying of bamboo shoot slices with microwave dryer and McMinn (2006) observed warming-up, constant rate and two falling rate periods. According to the drying curves, drying times decreased with increasing drying air temperature and microwave power. It revealed that mass and heat transfer through the samples were faster at higher temperature and microwave power.

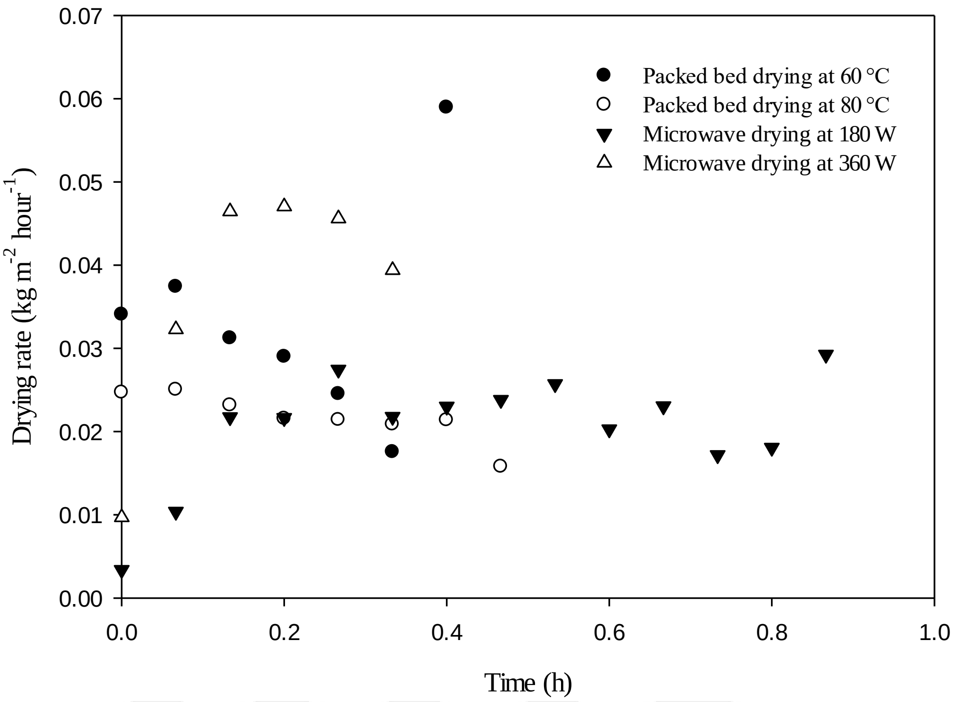

Figure 3.26 Drying rate curves against time of packed bed and microwave dried African semolina-couscous (0 % of bulgur flour)

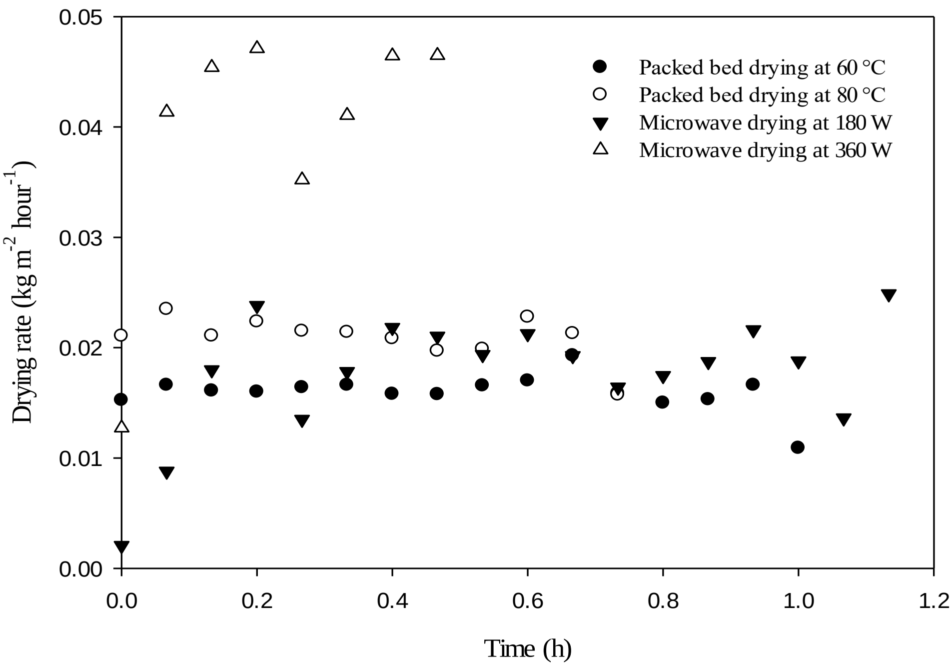

Figure 3.27 Drying rate curves against time of packed bed and microwave dried African bulgur-couscous (50 % of bulgur flour)

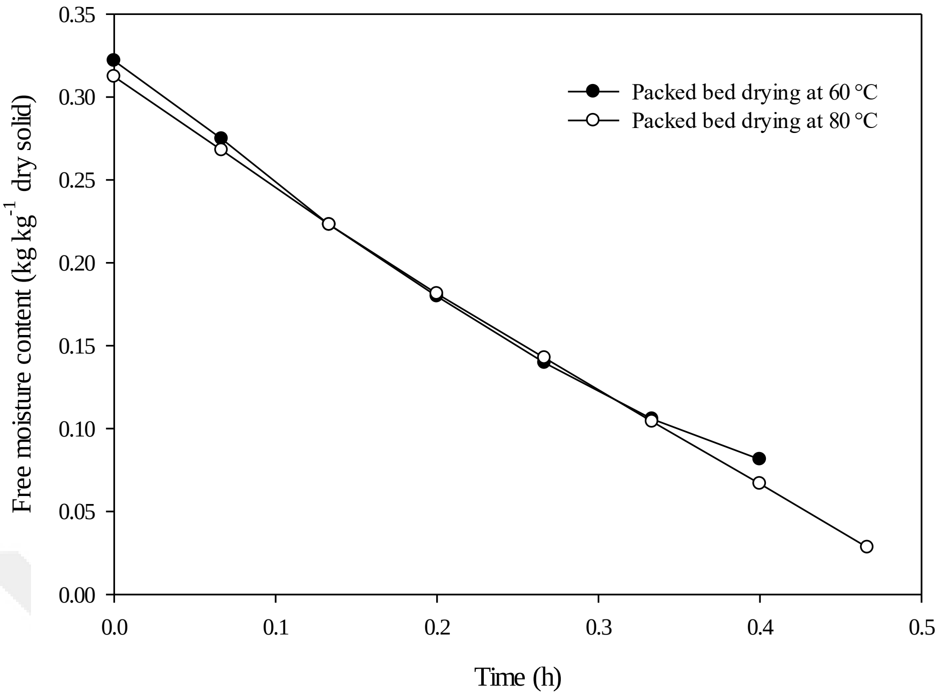

Figure 3.28 Free moisture content versus time graph of packed bed dried African couscous containing 0 % of bulgur flour

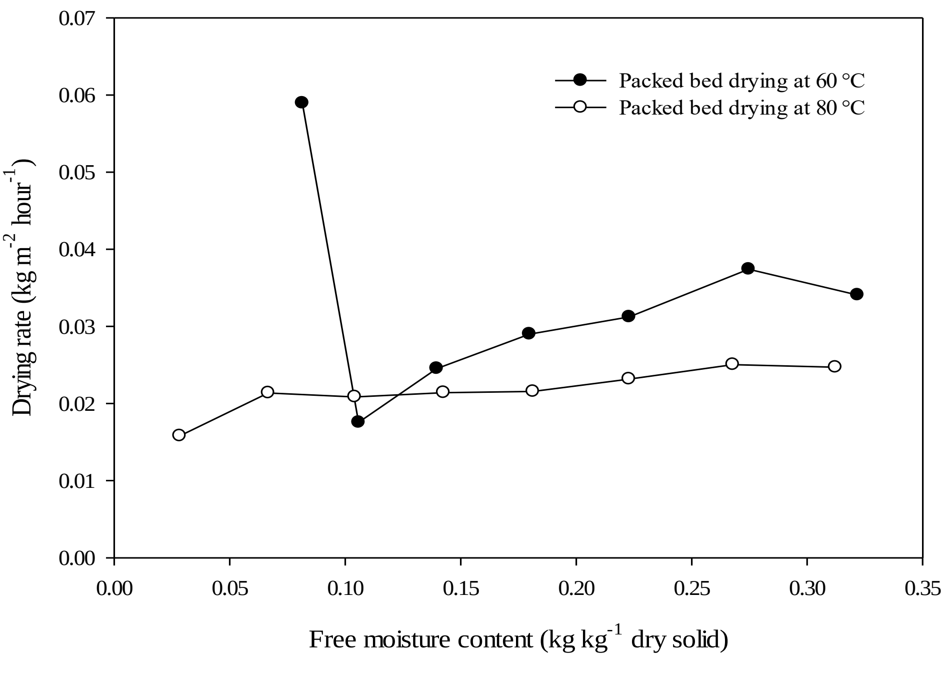

Figure 3.29 Drying rate versus free moisture content graph of packed bed dried African couscous containing 0 % of bulgur flour

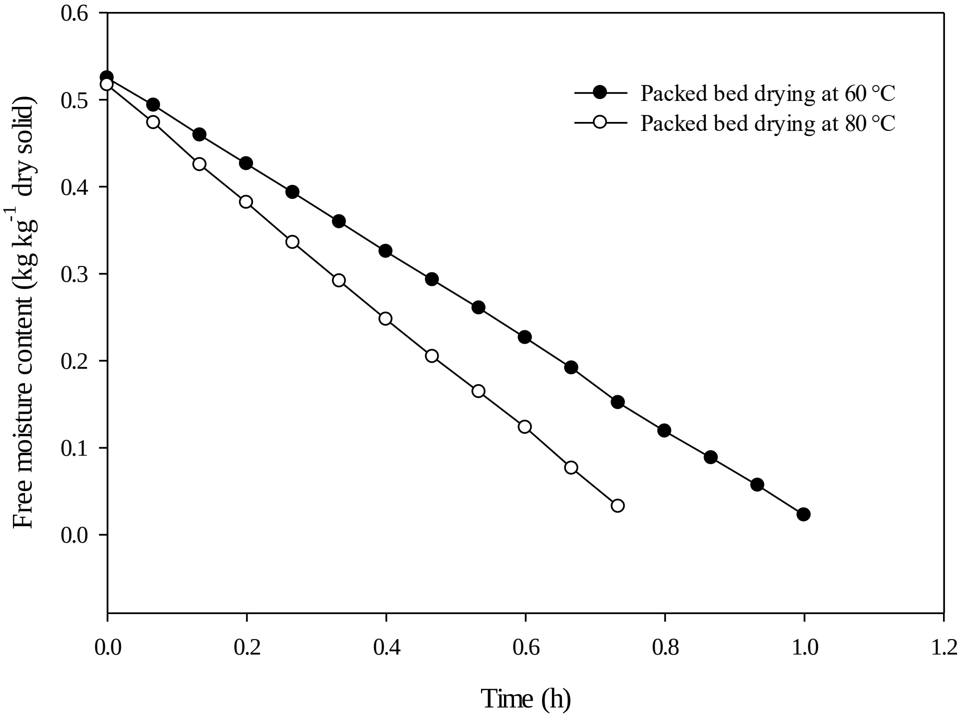

Figure 3.30 Free moisture content versus time graph of packed bed dried African couscous containing 50 % of bulgur flour

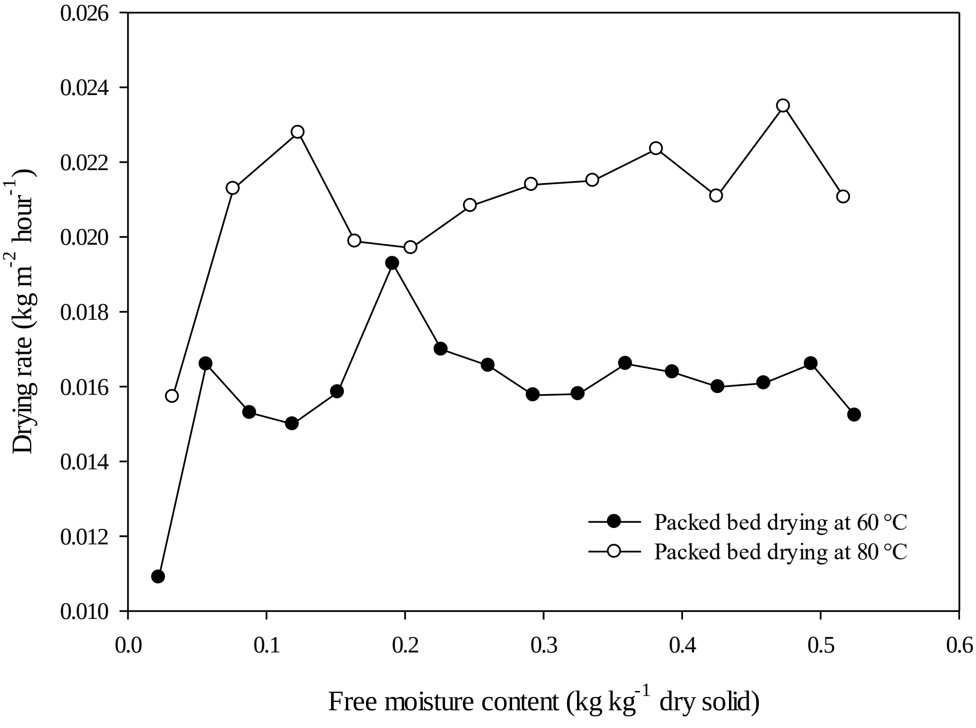

Figure 3.31 Drying rate versus free moisture content graph of packed bed dried African couscous containing 50 % of bulgur flour

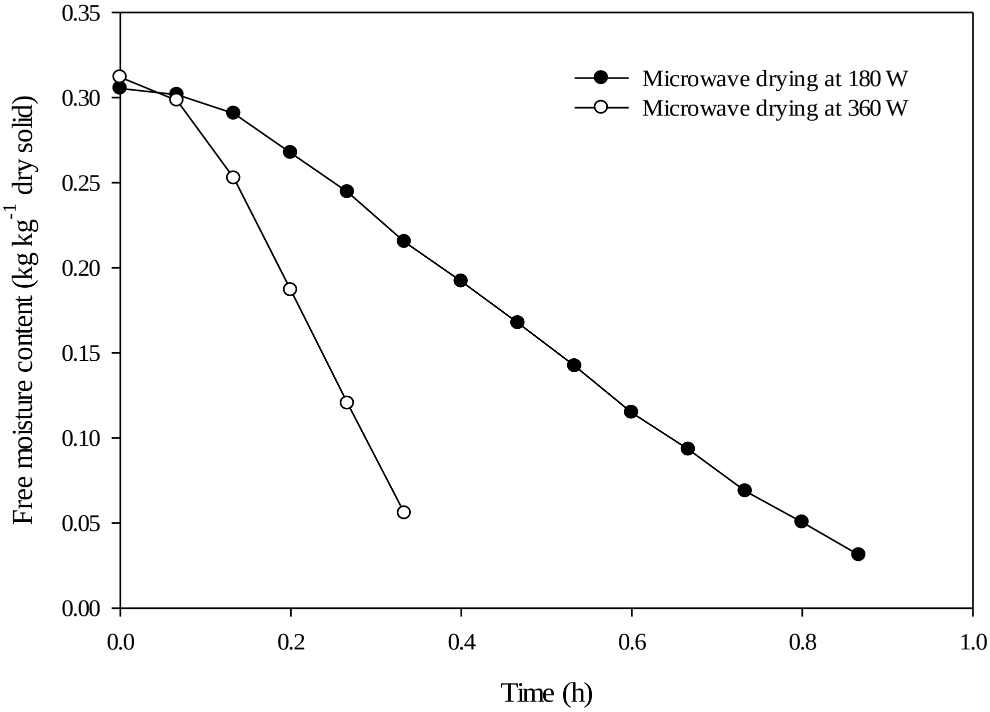

Figure 3.32 Free moisture content versus time graph of microwave dried African couscous containing 0 % of bulgur flour

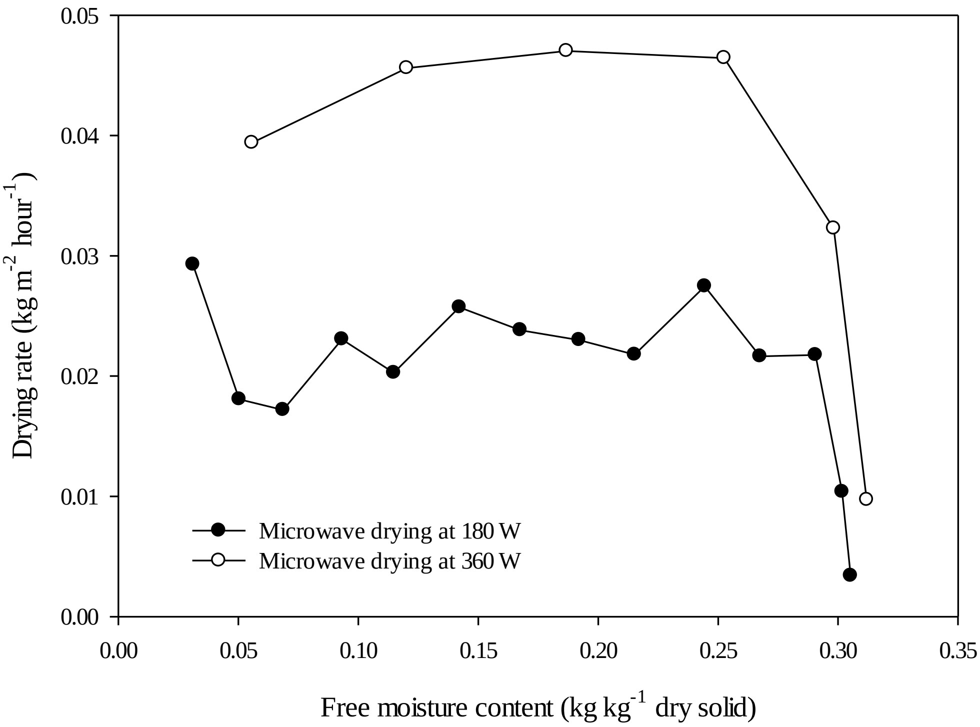

Figure 3.33 Drying rate versus free moisture content graph of microwave dried African couscous containing 0 % of bulgur flour

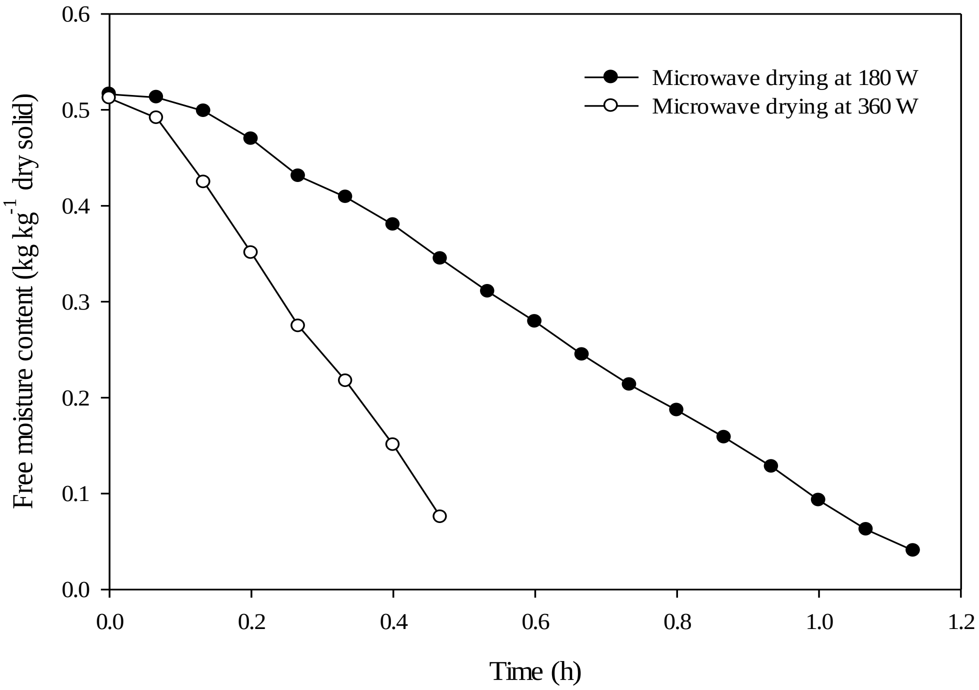

Figure 3.34 Free moisture content versus time graph of microwave dried African couscous containing 50 % of bulgur flour

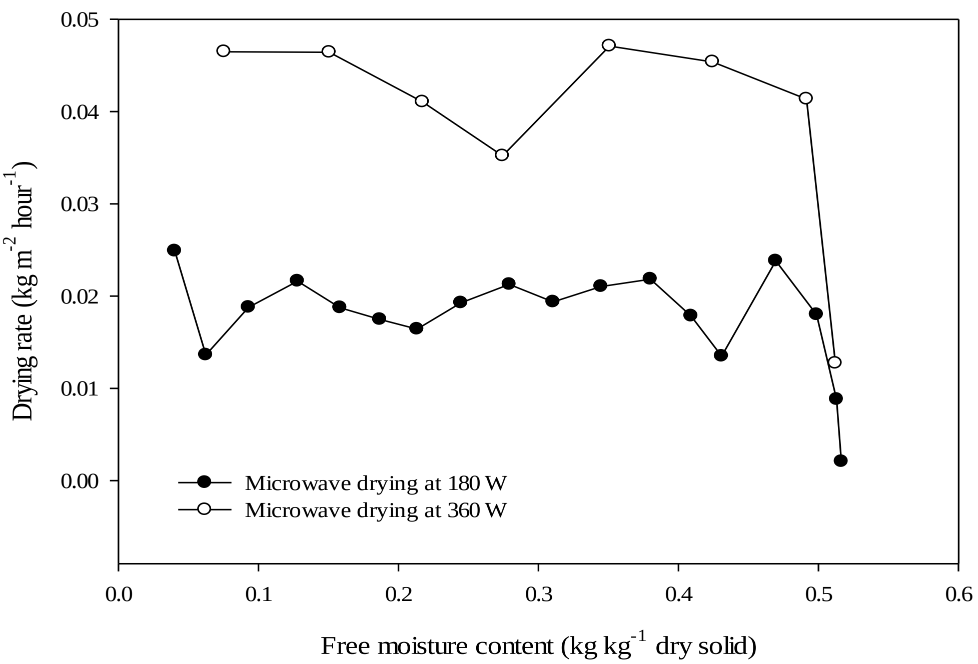

Figure 3.35 Drying rate versus free moisture content graph of microwave dried African couscous containing 50 % of bulgur flour

3.2.2.9 Mathematical modeling of packed bed and microwave dried African couscous

The effective moisture diffusivities of African couscous samples were between $5.65x10^{-9}$-$10.84x10^{-9}$ m^2s^{-1} (Table 3.14). D_{eff} values of African couscous products increase with increasing air temperature and power intensity of microwave. Bal et al. (2010) found the effective moisture diffusivities of bamboo shoot slices as $4.153x10^{-10}$, $7.378x10^{-10}$, $13.839x10^{-10}$ and $22.835x10^{-10}$ m^2s^{-1} corresponding to microwave powers of 140, 210, 280 and 350 W, respectively. Chayjan and Kaveh (2014) determined the effective moisture diffusivities of fix (packed) and fluidized bed dried (40, 50, 60, 70 and 80 °C) terebinth seeds between $1.1x10^{-10}$ and $1.26x10^{-9}$ m^2s^{-1}. Similar behavior of D_{eff} was reported by various authors: working with amaranth grains $0.65x10^{-9}$-$2.15x10^{-9}$ m^2s^{-1} for 40-70 °C (Resio et al., 2004); basil $2.17x10^{-10}$ - $7.90x10^{-10}$ m^2s^{-1} for 180-900 W (Demirhan and Ozbek, 2010b); pomegranate peels varies from $4.02x10^{-9}$ to $5.31x10^{-9}$ m^2s^{-1} for drying at 50, 60 and 70 °C (Doymaz, 2011).

Table 3.14 Effective moisture diffusivities of African couscous

Dryer	Drying Parameter	Effective Diffusivity (D_{eff} x 10^{-9} m^2 s^{-1})
Packed Bed	60 °C	7.88
	80 °C	9.07
Microwave	180 W	5.65
	360 W	10.84

The dimensionless moisture ratio against drying time for the experimental data at two different drying air temperature and drying power intensities was fitted to Modified Page II, Hii and others, Wang and Singh, Midilli and others, Weibull and Peleg models available in the literature. The results of fittings are displayed in Tables 3.15 and 3.16, which show the values of estimated constants with their corresponding statistical R^2, RMSE, χ^2 and RSS values. The results showed that experimental data fitted adequately to the models used in this study. The correlation coefficients were obtained between 0.9841-0.9998. High values of correlation coefficient, low root mean square errors, low reduced chi-square and low residual sum of squares indicate a good fitting of the model in predicting drying kinetics of the product (Kucuk et al., 2014). According to the results, the models that best fitted to the experimental data, considering as the first criterion of selection, the correlation coefficient (R^2>0.99) were high for Wang and Singh, and Midilli and others models for all drying techniques and parameters. However, when evaluating the fitting quality with other statistical values, Midilli and others model for packed bed drying at 60 and 80 °C and for microwave drying at 180 and 360 W was observed to be the most suitable for the experimental data with the highest values of R^2, and the lowest values of RMSE, χ^2 and RSS. Moisture ratio against time for packed bed and microwave drying; comparing experimental data with predicted data of best models are shown in Figures 3.36 and 3.37. Akpinar et al. (2003) found the best fitting model as the approximation of the diffusion model to represent the thin layer drying behavior of red pepper. Wang and Singh and Page model were found as the best for microwave drying of bamboo shoot slices (Bal et al., 2010) and spinach (Dadali et al., 2007), respectively. Similar to this study, for convective drying of lemon slices and pomegranate peels, Midilli and Kucuk model was found as the most suitable model by Torki-Harchegani et al. (2016) and Doymaz (2011), respectively and also for microwave drying of purslane (Demirhan and Ozbek, 2010a).

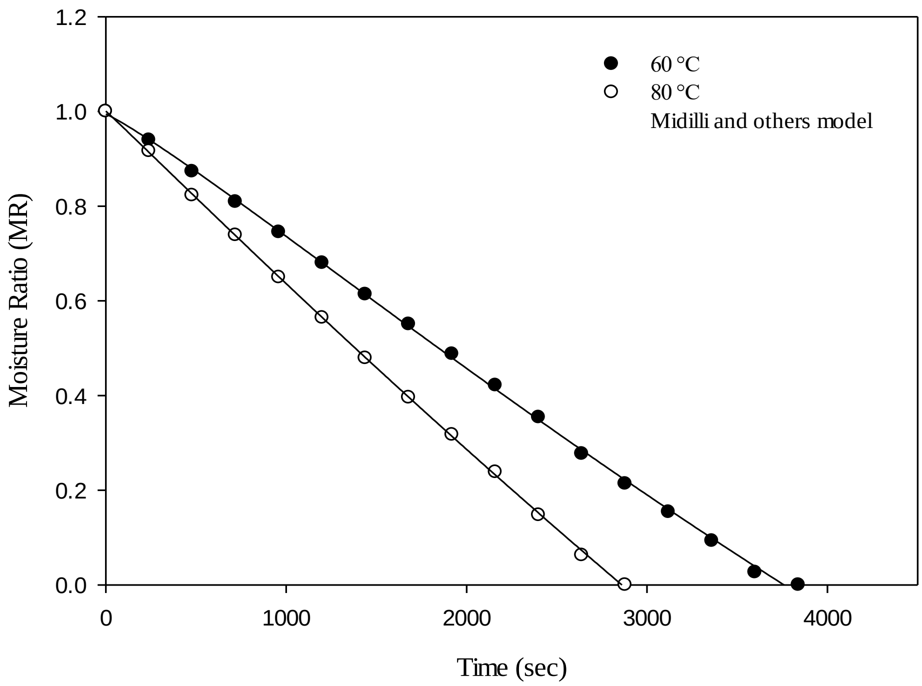

Figure 3.36 Moisture ratios against time for packed bed drying, comparing experimental data with predicted Midilli and others model for African couscous

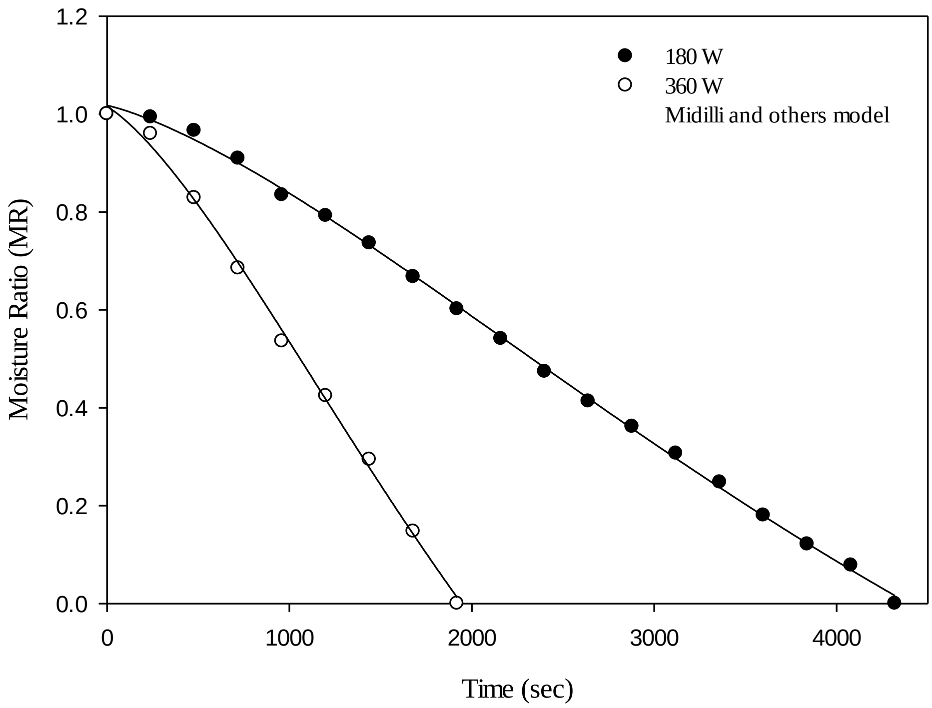

Figure 3.37 Moisture ratio against time for microwave drying, comparing experimental data with predicted Midilli and others model for African couscous

Table 3.15 Parameters of drying models for African couscous

Model Name		Packed Bed Drying 60 °C	Packed Bed Drying 80 °C	Microwave Drying 180 W	Microwave Drying 360 W
Modified Page	*k*	0.0005	0.0006	0.0004	0.0008
	n	1.6827	1.6091	1.9327	1.9898
Hii and others	*a*	0.4705	0.4754	0.4907	0.4921
	b	0.4707	0.4754	0.4902	0.4920
	k	$3.6138*10^{-7}$	$1.6279*10^{-6}$	$1.1760*10^{-7}$	$4.3433*10^{-7}$
	g	$3.6139*10^{-7}$	$1.6283*10^{-6}$	$1.1759*10^{-7}$	$4.3425*10^{-7}$
	n	1.9169	1.7894	2.0135	2.0572
Wang and Singh	*a*	$-2.7241*10^{-4}$	$-3.7174*10^{-4}$	$-1.7620*10^{-4}$	$-3.7741*10^{-4}$
	b	$1.2955*10^{-9}$	$7.6347*10^{-9}$	$-1.3686*10^{-8}$	$-7.7548*10^{-8}$
Peleg	*a*	3671.6778	2686.2352	4509.6828	2017.5450
	b	0.0175	0.0598	$5.8582*10^{-17}$	$7.6761*10^{-17}$
Midilli and others	*a*	0.9947	1.0007	1.0178	1.0155
	k	$2.6938-10^{-5}$	$1.1605*10^{-4}$	$1.9589*10^{-6}$	$4.1531*10^{-6}$
	b	$-1.2720*10^{-4}$	$-2.1515*10^{-4}$	$-7.7360*10^{-5}$	$-2.0548*10^{-4}$
	n	1.2404	1.0479	1.5778	1.6273
Weibull	*a*	1.6827	1.6091	1.9327	1.9898
	b	2190.4874	1649.3601	2728.1152	1224.2480

Table 3.16 Statistical results for various drying model for African couscous

Drying Parameters	Packed Bed Drying								Microwave Drying							
	60 °C				80 °C				180 W				360 W			
Model Name	**R^2**	**RMSE**	**χ^2**	**RSS**	**R^2**	**RMSE**	**χ^2**	**RSS**	**R^2**	**RMSE**	**χ^2**	**RSS**	**R^2**	**RMSE**	**χ^2**	**RSS**
Modified Page	0.9843	0.0397	0.0018	0.0268	0.9841	0.0397	0.0019	0.0205	0.9919	0.0288	0.0009	0.0158	0.9878	0.0370	0.0018	0.0123
Hii and others	0.9883	0.0342	0.0017	0.0198	0.9870	0.0359	0.0021	0.0167	0.9924	0.0279	0.0011	0.0148	0.9882	0.0364	0.0030	0.0119
Wang and Singh	0.9992	0.0092	0.0001	0.0014	0.9998	0.0042	0.0000	0.0002	0.9947	0.0232	0.0006	0.0102	0.9951	0.0234	0.0007	0.0049
Peleg	0.9992	0.0092	0.0001	0.0014	0.9998	0.0042	0.0000	0.0002	0.9861	0.0377	0.0016	0.0270	0.9845	0.0417	0.0022	0.0157
Midilli and others	**0.9994**	0.0076	0.0001	0.0010	**0.9998**	0.0041	0.0000	0.0002	**0.9991**	0.0096	0.0001	0.0017	**0.9980**	0.0150	0.0003	0.0020
Weibull	0.9843	0.0397	0.0019	0.0268	0.9841	0.0397	0.0020	0.0205	0.9919	0.0288	0.0010	0.0158	0.9878	0.0370	0.0021	0.0123

3.3 Turkish Couscous

3.3.1 Determination of optimum processing parameters and recipes

The couscous was produced by substitution of *Triticum durum* wheat semolina with undersize bulgur (bulgur flour) at various quantities (25, 50, 75 and 100 %) with egg and milk. However, the yields of products with 75 and 100 % of bulgur flour were lower than 50 %, which was the target yield to produce enough couscous for further processes. For that reason, samples with 25 and 50 % of bulgur flour were only used. The prepared couscous samples were dried by using packed bed (60 and 80 °C) and microwave (180 and 360 W) dryers. After all products were obtained from the drying operations, screen analysis (in order to determine the production yield), sensory analysis and instrumental color measurements (L*, a*, b*and YI) were made to determine the optimum processing parameters and product compositions.

3.3.1.1 Optimization based on yield for Turkish couscous

After the preparation of the samples, screen analysis was made before the drying operations. Before drying, the yields were 62.58±1.87, 57.46±0.58 and 52.69±1.35 % for the couscous consisting quantity of 0, 25 and 50 % bulgur flour, respectively. Quantity of bulgur flour was significantly ($p \leq 0.05$) effective on the yield of couscous samples before the drying. Similarly, Aboubacar et al. (2006) defined the couscous yield calculation based on the obtained amount from 1-2 mm particles. Yields were given in Figures 3.38 and 3.39.

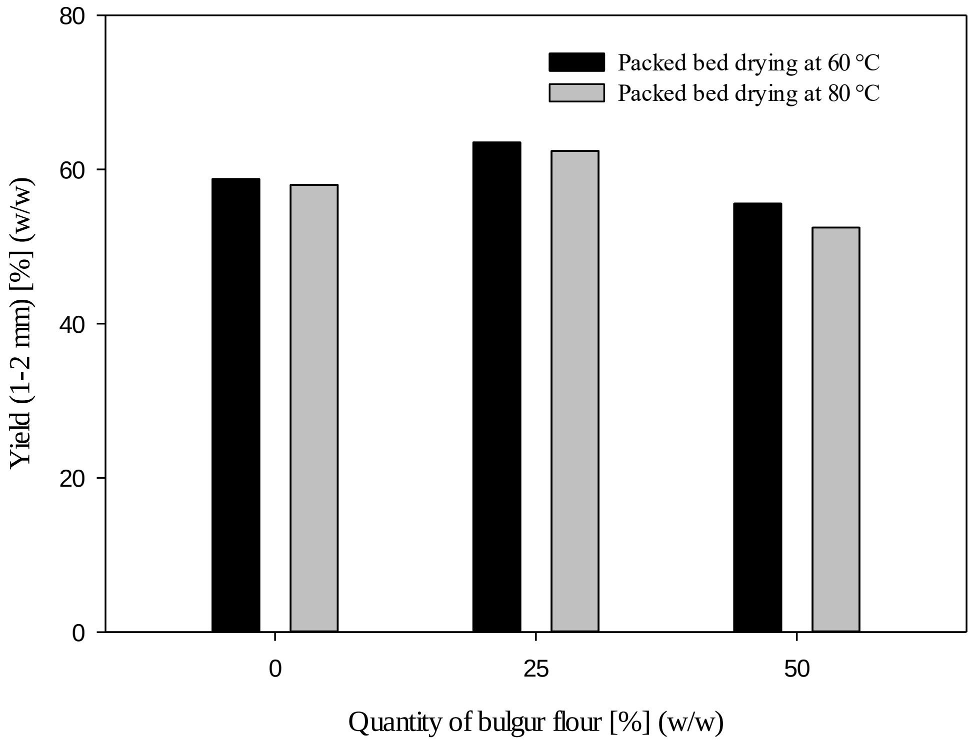

Figure 3.38 Yields of packed bed dried Turkish couscous

For packed bed drying at 60 °C, the yields were 58.78±0.47, 63.52±4.72 and 55.57±5.64 % for the couscous consisting quantity of 0, 25 and 50 % bulgur flour, respectively. Moreover, at 80 °C the yields were 58.00±0.67, 62.40±1.76 and 52.47±2.84 % for the couscous consisting quantity of 0, 25 and 50 % bulgur flour, respectively. Even though quantity of bulgur flour was not significantly ($p>0.05$) effective on the yield of couscous for drying at 60 °C, it was significantly ($p\leq0.05$) effective on yield of couscous for drying at 80 °C. It can be said that increasing temperature caused decreasing yield of couscous for packed bed drying. There was no significant ($p>0.05$) difference between couscous samples dried at 60 °C.

The difference between desired particle size couscous samples may be resulted by the production technique. Flour mixture was mixed well before the production and same brands and batch of eggs and milk were used in order to supply homogeneity. Moreover, the lower fraction of desired size couscous was due to the high amount of bran in bulgur flour competes with starch for water and results in less available water for starch gelatinization (Aboubacar et al., 2006).

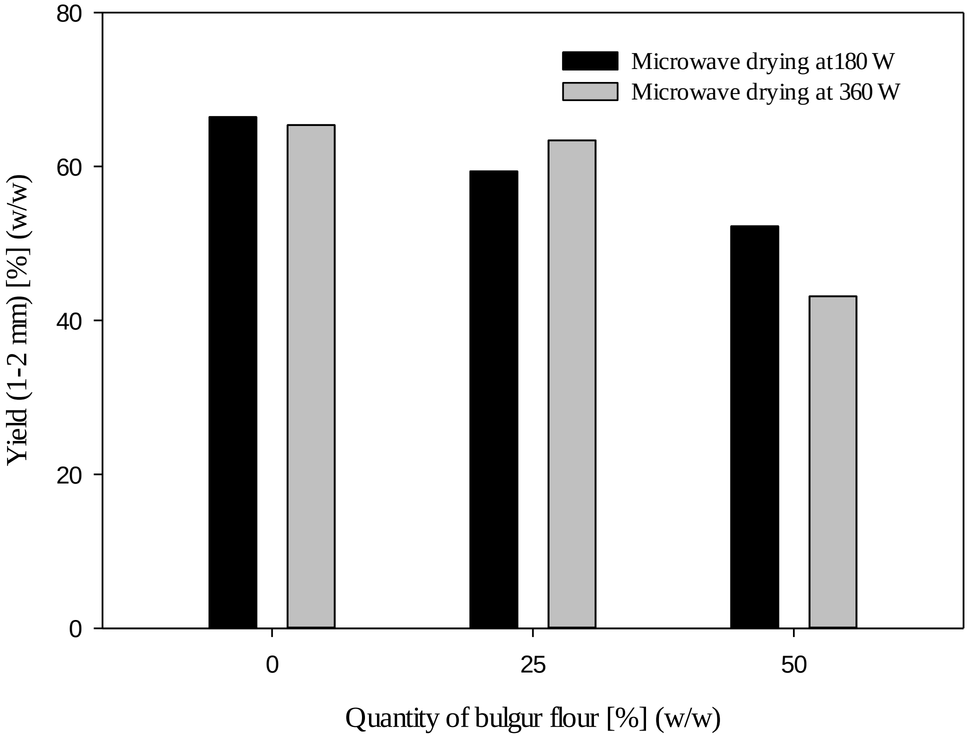

Figure 3.39 Yields of microwave dried Turkish couscous

For microwave drying at power intensity of 180 W, the yields were 66.42±0.16, 59.38±4.47 and 52.24 ±1.78 % for the couscous consisting quantity of 0, 25 and 50 %, respectively. For microwave drying at power intensity of 360 W, the yields were 65.37±0.16, 63.39±7.42 and 43.14±4.91 % for the couscous consisting quantity of 0, 25 and 50 %, respectively. The quantity of bulgur flour was significantly ($p \leq 0.05$) effective on the yield of couscous for drying at 180 and 360 W.

The yield of couscous values were slightly higher for microwave drying compared with packed bed drying except couscous containing 50 % of bulgur flour. When compared to control (semolina-couscous), the yields of Turkish couscous decreased for both drying operations.

3.3.1.2 Optimization based on color values and sensory analysis for Turkish couscous

The changes in L*, a*, b* and YI values based on the quantity of bulgur flour of samples are shown in Figures 3.40-3.43. For all dried and non-dried couscous, the quantity of bulgur flour was significantly ($p \leq 0.05$) effective on lightness, yellowness and redness in contrast to cloudiness-opaqueness (Yellowness index, YI value). Lightness (L*) values of couscous samples were decreased with increasing the quantity of bulgur flour after both drying operations. Although lightness values of packed bed dried and non-dried couscous were similar, microwave dried couscous had lower lightness values at different quantities of bulgur flour. Lower differences between lightness values may be resulted from using eggs and milk in the formulations.

According to the Duncan's multiple range tests non-dried, packed bed dried at 80°C and microwave dried at 180 and 360 W, L* values of couscous were significantly ($p \leq 0.05$) different. L* values of packed bed dried bulgur flour containing couscous samples at 60°C were significantly ($p \leq 0.05$) different from control couscous. b* values of non-dried, packed bed dried at 80°C and microwave dried at 180 and 360 W couscous were significantly ($p \leq 0.05$) different from each other. a* (redness) values of couscous non-dried, packed bed dried at 60 and 80°C and microwave dried at 180 and 360 W were not significantly ($p > 0.05$) different from each other for couscous samples containing 25 and 50 % of bulgur flour.

It is well known that yellow and brown coloration are correlated to both pigment content and enzymatic reactions, while the red index is strictly related to the development of Maillard reaction products (Oliver et al., 1993). YI values of couscous non-dried, packed bed dried at 60 and 80°C and microwave dried at 180 and 360 W were not significantly ($p > 0.05$) different from each other. Balcı and Bayram (2017) 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 bulgur samples.

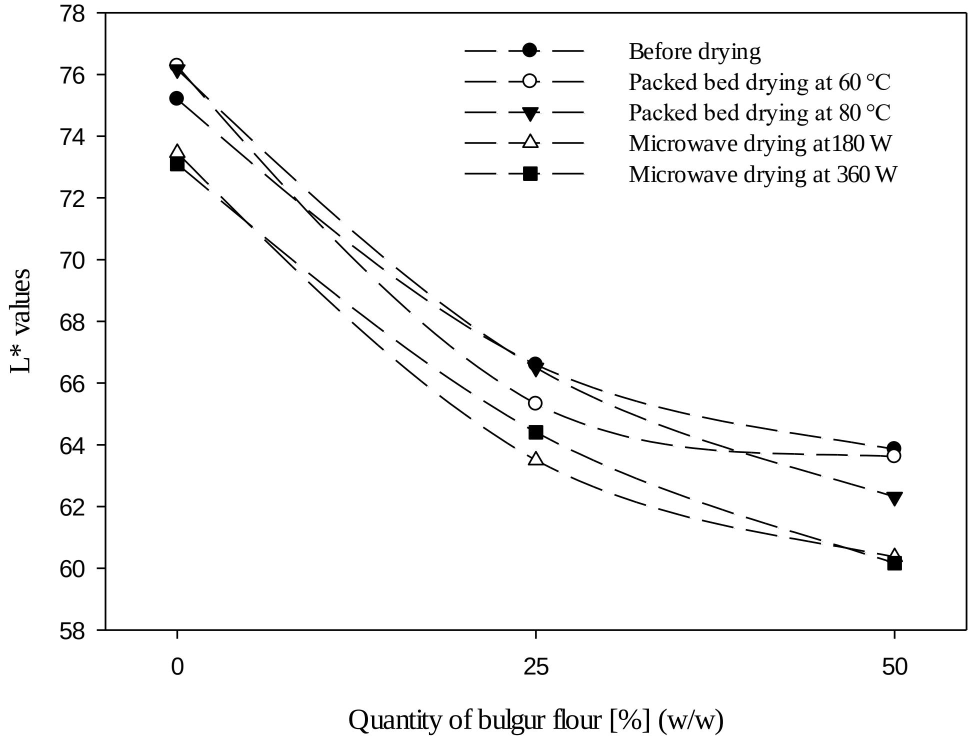

Figure 3.40 L* values of uncooked Turkish couscous

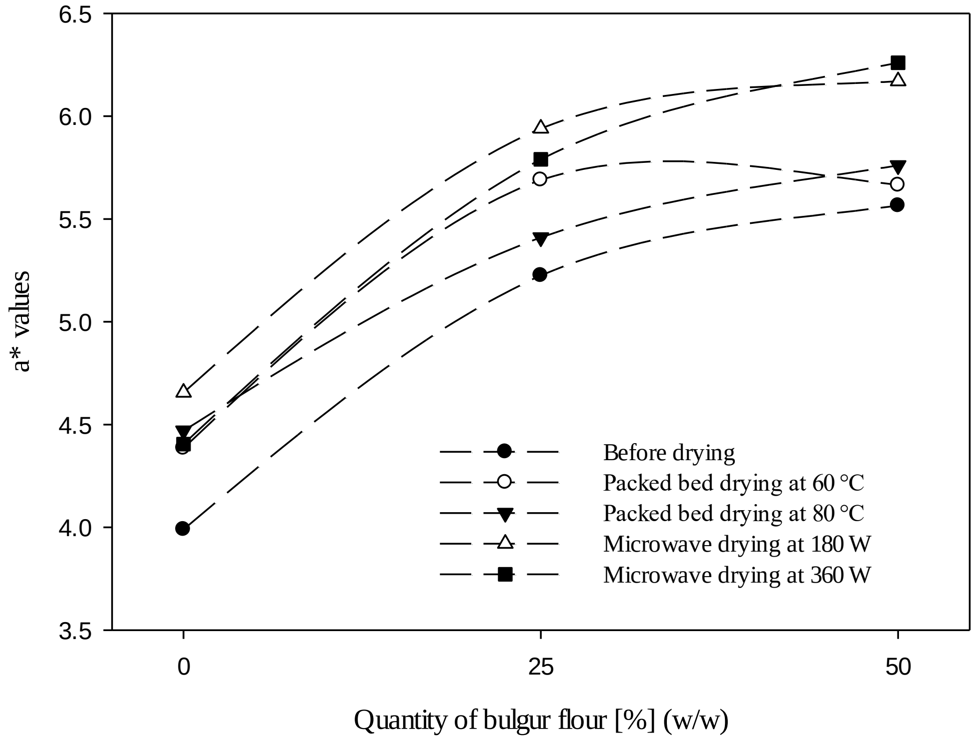

Figure 3.41 a* values of uncooked Turkish couscous

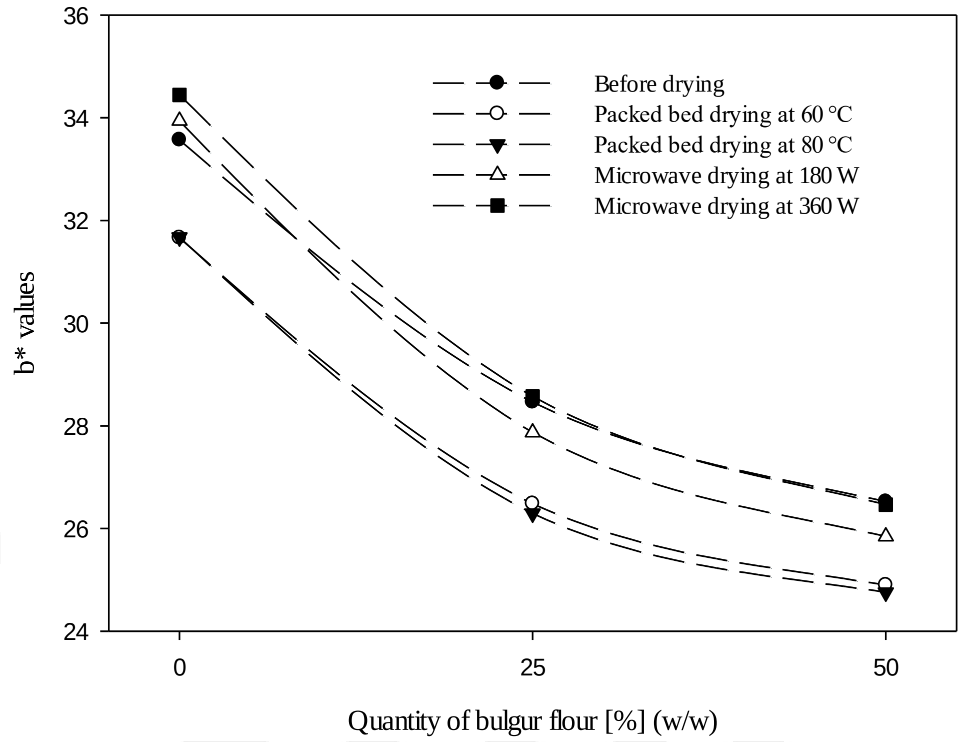

Figure 3.42 b* values of uncooked Turkish couscous

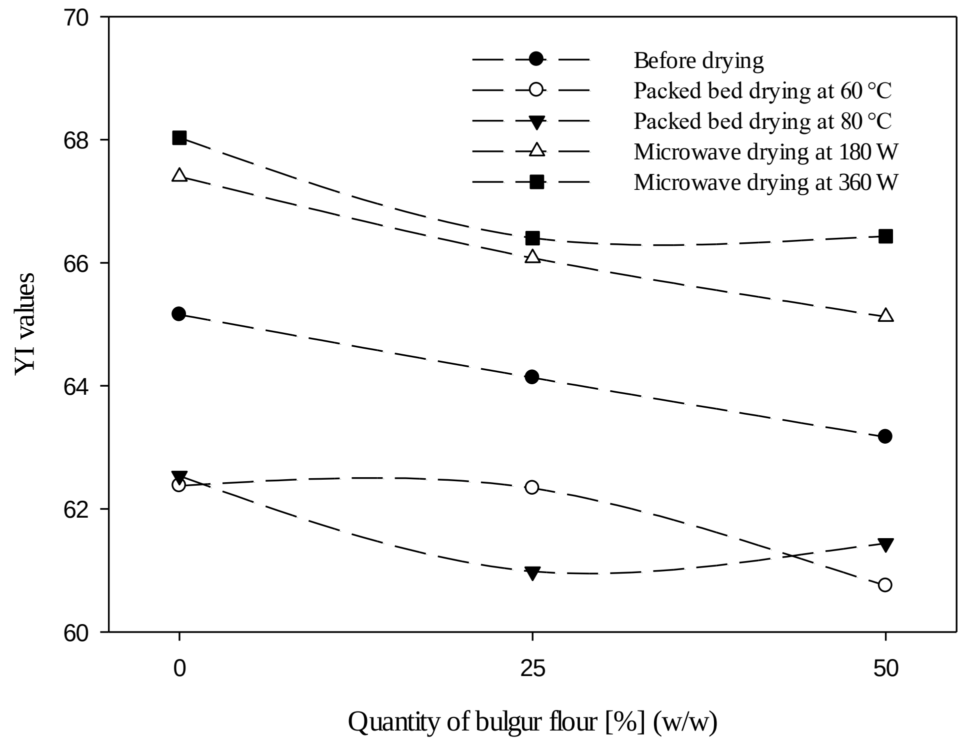

Figure 3.43 YI values of uncooked Turkish couscous

The sensory analysis after the drying operations were made and the results were given in Table 3.17. It was found that the quantity of bulgur flour (i.e. 0, 25 and 50 %) was not significantly ($p>0.05$) effective on odor, color and general appearance.

Table 3.17 Results of sensory analysis of uncooked Turkish couscous

			Sensory Attributes		
Quantity of bulgur flour [%]	**Drying technique***	**Drying parameters**	**Color**	**Odor**	**General Appearance**
0	PBD	60 °C	6.58±2.35[a]	5.83±2.33[a]	6.42±2.11[a]
		80 °C	6.50±2.32[a]	5.92±2.11[a]	6.42±1.98[a]
	MW	180 W	6.92±2.58[a]	6.00±2.30[a]	6.83±1.90[a]
		360 W	7.08±2.47[a]	5.92±2.11[a]	6.92±1.93[a]
25	PBD	60 °C	5.58±1.62[a]	5.75±1.91[a]	6.42±1.68[a]
		80 °C	6.08±1.56[a]	5.58±2.31[a]	6.33±1.67[a]
	MW	180 W	6.42±1.73[a]	5.75±2.26[a]	6.75±1.60[a]
		360 W	6.08±1.44[a]	6.00±2.17[a]	6.33±1.37[a]
50	PBD	60 °C	5.25±1.55[a]	5.42±2.07[a]	5.42±1.68[a]
		80 °C	5.67±2.27[a]	5.83±2.62[a]	6.42±2.02[a]
	MW	180 W	5.25±1.91[a]	6.00±2.73[a]	5.67±1.56[a]
		360 W	5.75±2.09[a]	6.33±2.87[a]	5.92±1.88[a]

*PBD: Packed Bed Dryer. MW: Microwave. Each column followed by different superscripts is significantly different ($p \leq 0.05$).

3.3.1.3 Optimum results for Turkish couscous

According to yield, color (L*,a*,b* and YI) and sensory values after the drying operations, the optimum processing parameters and recipes were determined such as 1) 30.63 % (w/w) of milk and 4.38 % of egg for dough preparation, 25 % of bulgur flour, 75 % of semolina, 80 °C drying temperature for packed bed dryer; 2) 35 % (w/w) of milk and 5 % of egg for dough preparation, 50 % of bulgur flour, 50 % of semolina, 180 W drying power for microwave dryer. As a note, the quantities of milk and egg were calculated according to total flour weight to obtain suitable dough stickiness and consistency. According to these optimum conditions, the other analyses were made by using the optimum products. In Figures 3.44 and 3.45 the pictures of Turkish couscous dried and during production are given.

Figure 3.44 25 % of bulgur flour containing Turkish dried couscous

Figure 3.45 The production of 50 % of bulgur flour containing Turkish couscous

3.3.2 Analysis of the optimum products/formulations produced at optimum parameters for Turkish couscous

At the optimum products, the chemical and physical analyses were made to determine some functional and engineering properties (bulk density, weight increase, functional and texture properties etc.) of the couscous. In order to compare the results, the control couscous (semolina-couscous) sample results were also used.

3.3.2.1 Bulk density for Turkish couscous

It was found that the bulk densities of control samples (semolina-couscous) were higher than Turkish couscous samples, which were produced by using packed bed (at 80 ºC) and microwave (180 W) dryers. However, the quantity of bulgur flour was not significantly ($p>0.05$) effective on bulk density and the control samples were not significantly ($p>0.05$) different from Turkish couscous (Table 3.18).

3.3.2.2 Weight increase for Turkish couscous

It was found that there was no significant ($p>0.05$) difference for the packed bed and microwave dried control and Turkish couscous samples (Table 3.18).

3.3.2.3 Protein and ash contents for Turkish couscous

The quantity of bulgur flour was not significantly ($p>0.05$) effective on protein content. Ash contents of Turkish couscous samples were significantly ($p\leq0.05$) higher than semolina-couscous due to the raw materials properties (Table 3.18). Bulgur has higher protein and ash contents than semolina; therefore it caused a functional positive gain to finished product. Ash comes from bran layer of wheat and bran is not removed completely during bulgur production. Therefore, bulgur is a good dietary fiber source (Bayram, 2005) for couscous by increasing bran content without phytic acid. Aalami et al. (2007) observed similar protein and ash contents of semolina produced from six different Indian durum wheat varieties, which protein and ash contents were between 9.30-13.83 % (d.b.) and 0.79-0.86 % (d.b.), respectively. Moreover, in a study where bulgur was used in production of couscous, protein and ash contents of non-cooked traditional couscous, couscous with eggs, couscous with soy flour and couscous with oat flour were measured by Çelik et al. (2004). They found protein and ash contents in range of 11.04-13.62 % and 0.73-1.23 %, respectively.

3.3.2.4 Crude fiber contents for Turkish couscous

Crude fiber contents of couscous samples were not significantly ($p>0.05$) affected by bulgur flour content. According to Duncan's multiple range tests, Turkish couscous samples were not significantly ($p>0.05$) different than semolina-couscous samples (Table 3.18).

3.3.2.5 Total phenol and total flavonoid content and % DPPH scavenging activity for Turkish couscous

The statistical analysis indicated that total phenol and total flavonoid contents and % DPPH scavenging activity were not significantly ($p>0.05$) affected by the quantity of bulgur flour. Moreover, total phenol contents and antioxidant activities of semolina and Turkish couscous were not significantly ($p>0.05$) different from each other (Table 3.19).

Similarly, Yu et al. (2002) examined and compared three hard winter wheat varieties for their free radical scavenging properties and total phenolic contents. They found that the total phenolic contents were in range of 48.8-92.8 mg gallic acid/100 g of grain. Yilmaz and Koca (2017) found total phenolic content and DPPH activity of traditional cooked and hot-air dried bulgur produced from durum wheat approximately 140 mg/100 g gallic acid (d.b.) and 17 % DPPH.

Higher percentage of DPPH activity resulted due to the high quantities of bran in bulgur flour. Similarly, due to the higher pigment content of semolina, antioxidant activities of control sample were high, where, radical scavenging activities of higher pigment content containing red sorghum and black rice were 92 and 87 %, respectively; non-pigmented cereals have DPPH activity of 7 – 67 % (Choi et al., 2007).

Table 3.18 Quality and functional properties of Turkish couscous produced using optimum compositions and parameters

Quality Properties							
Quantity of bulgur flour [%]	**Drying technique***	**Drying parameters**	**Bulk density [kg/m^3]**	**Weight increase [%, w/w]**	**Protein content [d.b., %]**	**Ash content [d.b., %]**	**Crude fiber content [d.b., %, w/w]**
0	PBD	80 °C	631.10±53.13[a]	67.31±3.81[a]	11.49±0.49[a]	1.11±0.04[a]	0.94±0.05[a]
25			607.87±27.76[a]	68.62±1.57[a]	12.12±0.12[a]	1.62±0.08[b]	1.29±0.61[a]
0	MW	180 W	672.41±65.28[a]	70.33±1.71[a]	11.54±0.37[a]	1.10±0.06[a]	0.97±0.16[a]
50			592.05±49.26[a]	70.58±1.25[a]	12.27±0.10[a]	2.03±0.04[c]	2.10±1.43[a]

*PBD: Packed Bed Dryer. MW: Microwave. Each column followed by different superscripts is significantly different ($p \leq 0.05$).

Table 3.19 Functional properties of Turkish couscous produced using optimum compositions and parameters

			Functional Properties		
Quantity of bulgur flour [%]	**Drying technique***	**Drying parameters**	**Total phenol content [mg gallic acid/100 g sample]**	**Total flavonoid content[mg catechin/100 g sample]**	**% DPPH scavenging activity**
0	PBD	80 °C	57.68±23.17[a]	32.09±3.52[ab]	72.99±4.19[a]
25			51.44±7.53[a]	39.91±2.04[ab]	73.95±4.81[a]
0	MW	180 W	26.43±9.43[a]	27.38±6.21[a]	73.52±4.04[a]
50			56.73±30.60[a]	42.50±5.71[b]	73.35±0.17[a]

*PBD: Packed Bed Dryer. MW: Microwave. Each column followed by different superscripts is significantly different (p≤0.05).

Table 3.20 Texture properties of Turkish couscous produced using optimum compositions and parameters

			Texture Properties						
Quantity of bulgur flour [%]	**Drying technique***	**Drying parameters**	**Hardness (N)**	**Adhesiveness (N.s)**	**Springiness**	**Cohesiveness**	**Gumminess**	**Chewiness**	**Resilience**
0	PBD	80 °C	322.01±92.29[a]	-503.68±121.04[a]	0.28±0.01[a]	0.31±0.02[a]	99.87±23.64[a]	27.35±5.67[a]	0.08±0.01[a]
25			450.99±235.94[ab]	-239.76±299.85[ab]	0.45±0.04[b]	0.31±0.01[a]	139.75±68.55[a]	64.19±36.36[a]	0.09±0.01[a]
0	MW	180 W	287.99±14.59[a]	-21.98±1.65[b]	0.47±0.05[b]	0.36±0.04[ab]	101.87±6.73[a]	47.73±7.91[a]	0.15±0.03[b]
50			719.53±26.75[b]	-13.31±0.83[b]	0.42±0.01[b]	0.41±0.03[b]	297.00±8.23[b]	125.40±5.36[b]	0.17±0.00[b]

*PBD: Packed Bed Dryer. MW: Microwave. Each column followed by different superscripts is significantly different ($p \leq 0.05$).

Table 3.21 Sensory properties of Turkish couscous produced using optimum compositions and parameters

			Sensory Properties					
Quantity of bulgur flour [%]	**Drying technique***	**Drying parameters**	**Chewiness**	**Hardness**	**Odor**	**Taste**	**Color**	**General acceptability**
0	PBD	80 °C	5.41±2.27[a]	5.56±2.41[a]	5.68±2.38[a]	5.88±2.34[a]	6.55±1.74[a]	5.41±2.23[a]
25			6.14±2.13[b]	6.36±2.20[b]	6.74±1.53[b]	6.68±1.65[b]	6.98±1.46[a]	6.62±1.42[b]
0	MW	180 W	7.14±1.19[c]	7.36±0.78[c]	7.33±1.43[c]	6.80±1.68[b]	7.92±0.85[b]	7.56±0.93[c]
50			7.76±1.47[c]	7.95±1.12[c]	8.15±1.01[d]	7.95±1.23[c]	8.27±1.02[b]	8.32±1.11[d]

*PBD: Packed Bed Dryer. MW: Microwave. Each column followed by different superscripts is significantly different ($p \leq 0.05$).

3.3.2.6 Texture Profile Analysis (TPA) for Turkish couscous

Texture profile of the cooked couscous samples were given in Table 3.20. It was found that the quantity of bulgur flour was significantly ($p \leq 0.05$) effective on springiness, gumminess, chewiness and resilience, in contrast to hardness, adhesiveness and cohesiveness. The hardness of Turkish couscous samples was higher than semolina-couscous for each drying technique. According to the study made by Singh and Singh (2010), the increase in the debraning level of wheat caused decrease in textural properties. They observed that cohesiveness and chewiness values of wheat varieties ranging from 0.27 to 0.37 and 4.16 to 9.62 N, respectively, where similar values of cohesiveness of couscous samples were observed ranging from 0.31 to 0.41. However, the chewiness values of couscous products were higher than wheat varieties, i.e. between 27.35 and 125.40.

Adhesiveness of control couscous samples was higher (not preferred) than bulgur flour containing couscous samples. Moreover, the samples containing 50 % of bulgur flour dried using microwave dryer were significantly ($p \leq 0.05$) different for gumminess and chewiness. Turkish couscous dried with microwave dryer, which had the highest values for TPA parameters of hardness, cohesiveness, gumminess, chewiness and resilience.

3.3.2.7 Sensory analysis for Turkish couscous

Sensory analysis showed that the quantity of bulgur flour was significantly ($p \leq 0.05$) effective on all sensory attributes (Table 3.21). It was obtained that Turkish couscous had higher sensory scores than semolina-couscous generally. Bulgur containing Turkish couscous dried with microwave dryer had the highest scores for all sensory attributes. However, semolina-couscous dried with packed bed dryer had lowest scores for all sensory attributes. Couscous samples with bulgur flour dried with packed bed and microwave dryers were more preferable for consumers. Cooked Turkish couscous samples are shown in Figure 3.46.

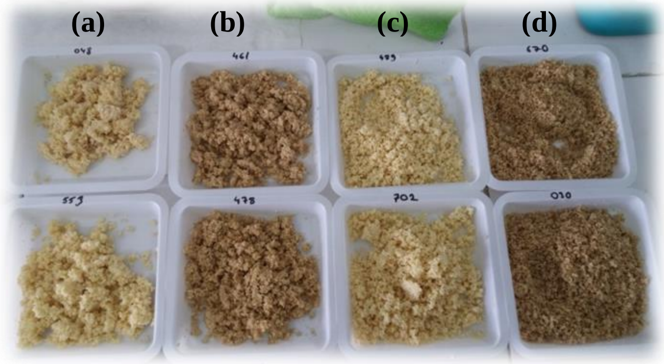

Figure 3.46 Cooked Turkish couscous products (a) packed bed dried at 80 °C control and (b) 25 % of bulgur flour containing couscous, (c) microwave dried at 180 W control and (d) 50 % of bulgur flour containing couscous

3.3.2.8 Drying curves of optimum products for Turkish couscous

Drying curves of optimum products of Turkish couscous were given in Figures 3.47-3.57. Free moisture contents of packed bed dried (80 °C) samples containing 0 and 25 % of bulgur flour were 28 and 29 %, respectively. Drying curves of Turkish couscous samples (containing 25 and 50 % of bulgur flour); which dried with packed bed (60 and 80 °C) and microwave (180 and 360 W) dryers are shown in Figures 3.48 and 3.49. Average drying rates increased with the increment of temperature and microwave power for both Turkish couscous samples. For couscous containing 25 % of bulgur flour, average drying rate increased 25.94 % with increase in air temperature from 60 to 80 °C. It increased 120.42 % with increase in microwave power from 180 to 360 W. For couscous containing 50 % of bulgur flour, average drying rate increased 27.29 % with increase in air temperature from 60 to 80 °C. It increased 122.42 % with increase in microwave power from 180 to 360 W.

Drying time reduced 20.90 % with increase in air temperature from 60 to 80 °C; however it reduced 58.75 % with increase in microwave power from 180 to 360 W for couscous containing 25 % of bulgur flour. As expected, the shortest drying time was observed at the highest temperature and microwave power. About couscous containing 50 % of bulgur flour, drying time reduced 17.81 % with increase in air temperature from 60 to 80 °C; however it reduced 58.75 % with increase in microwave power from 180 to 360 W. It can be concluded that microwave power increment is more effective on drying rate and time of bulgur flour containing couscous samples than increment of drying air temperature in packed bed drying.

The free moisture contents of the samples decreased with time. For packed bed drying of both compositions, there were two periods (Figs 3.48 and 3.49): constant and falling rate; however for microwave drying of both compositions, there were three periods: warming-up, constant rate and falling rate. According to the drying curves, the drying time decreased with increasing drying air temperature in packed bed and microwave power in microwave dryers. It revealed that mass and heat transfer through the enriched couscous were faster at higher temperature and microwave power.

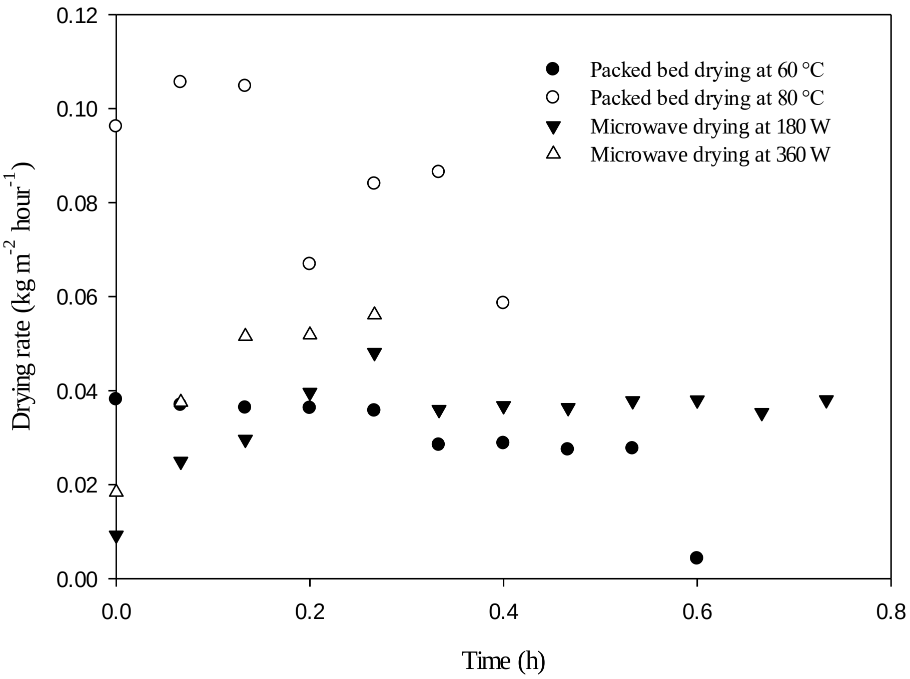

Figure 3.47 Drying rate curves against time of packed bed and microwave dried Turkish semolina-couscous (0 % of bulgur flour)

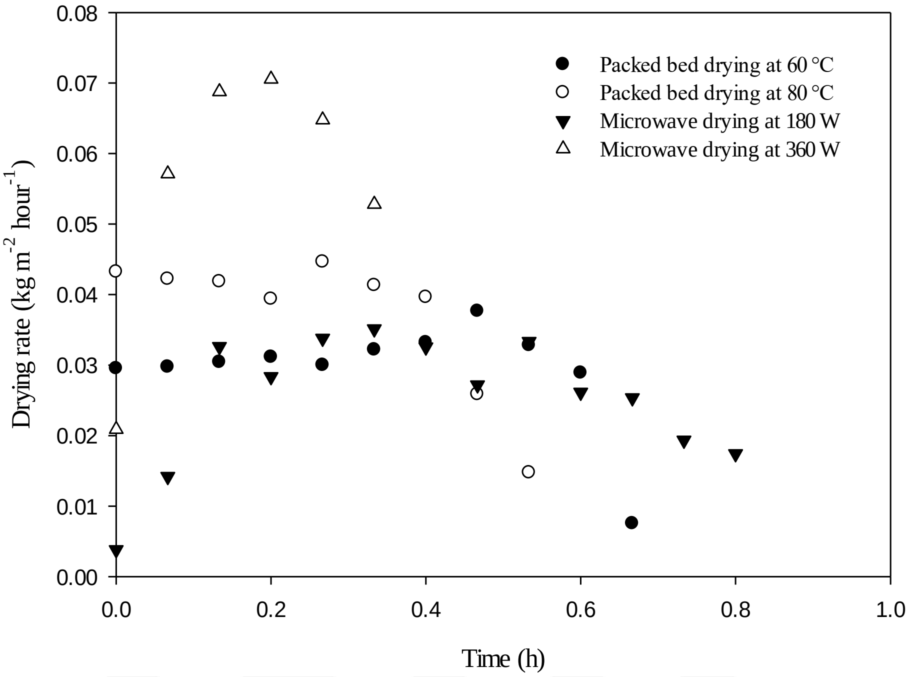

Figure 3.48 Drying rate curves against time of packed bed and microwave dried Turkish bulgur-couscous (25 % of bulgur flour)

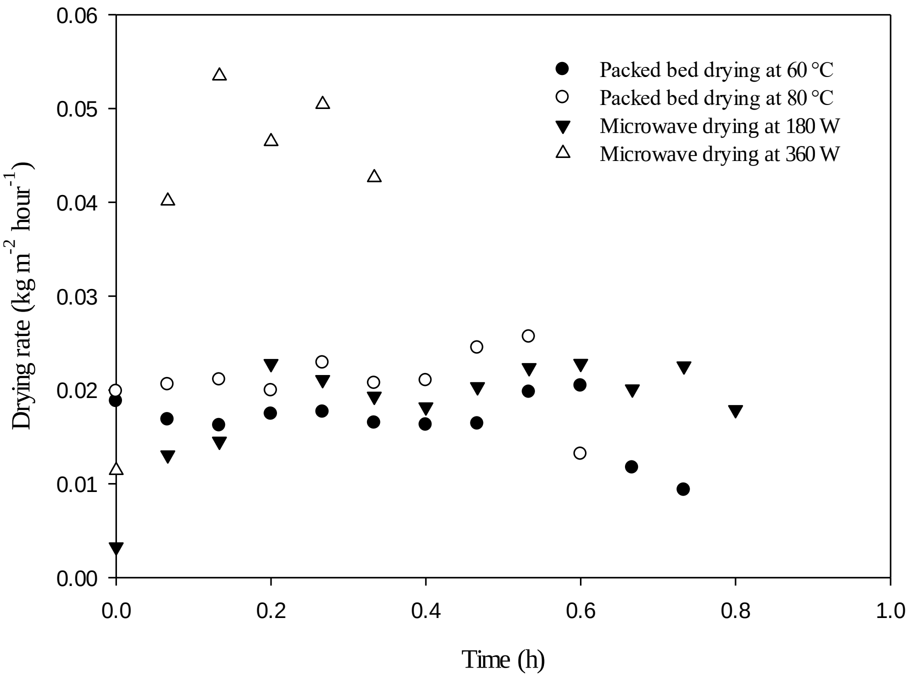

Figure 3.49 Drying rate curves against time of packed bed and microwave dried Turkish bulgur-couscous (50 % of bulgur flour)

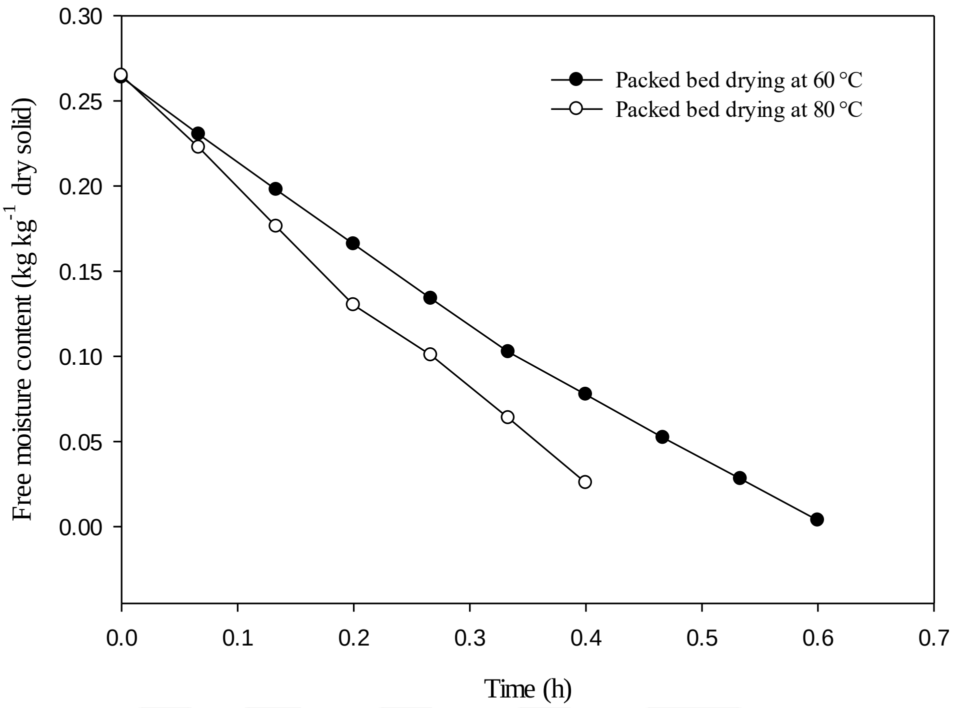

Figure 3.50 Free moisture content versus time graph of packed bed dried Turkish couscous containing 0 % of bulgur flour

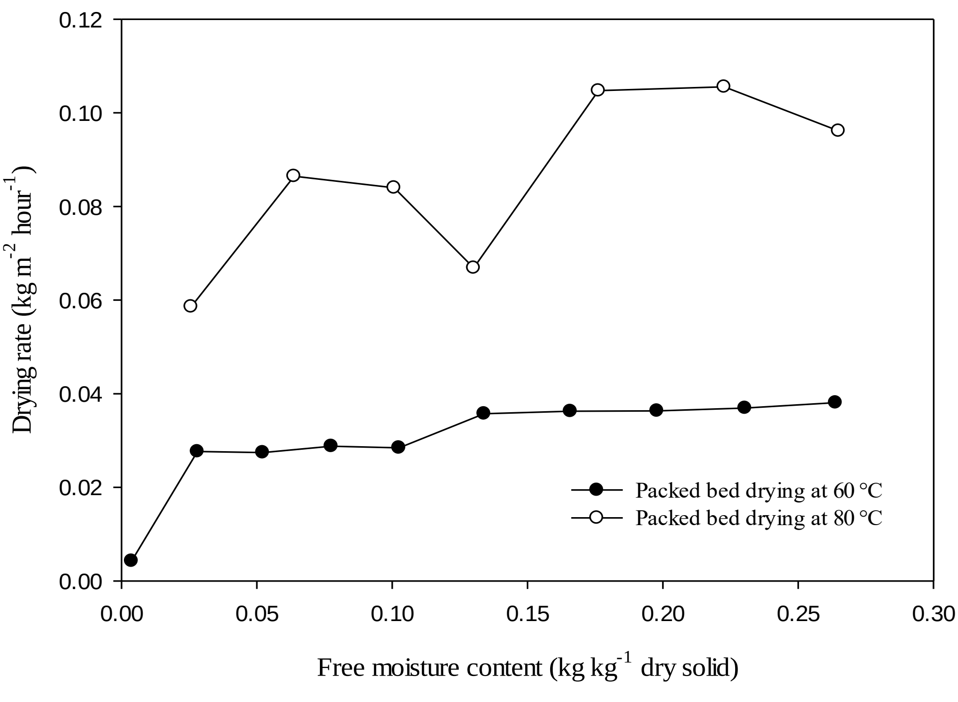

Figure 3.51 Drying rate versus free moisture content graph of packed bed dried Turkish couscous containing 0 % of bulgur flour

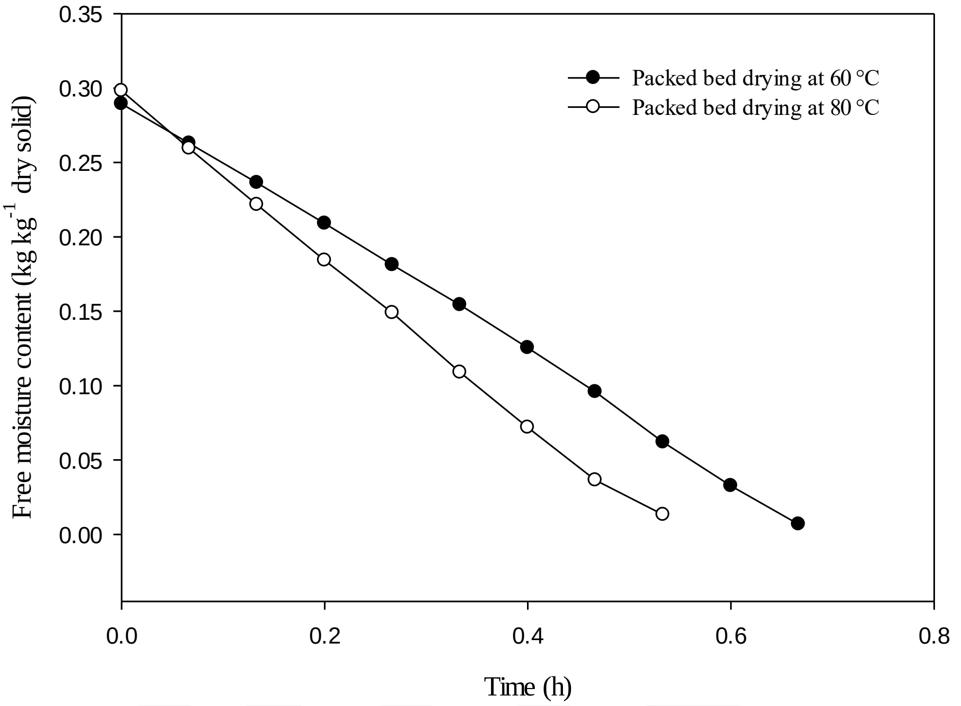

Figure 3.52 Free moisture content versus time graph of packed bed dried Turkish couscous containing 25 % of bulgur flour

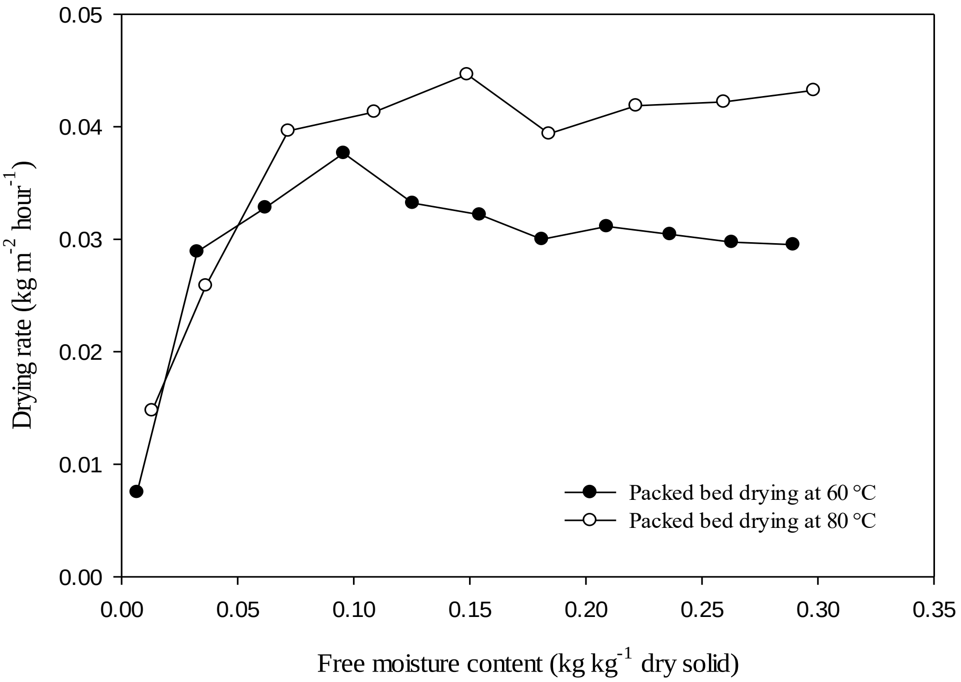

Figure 3.53 Drying rate versus free moisture content graph of packed bed dried Turkish couscous containing 25 % of bulgur flour

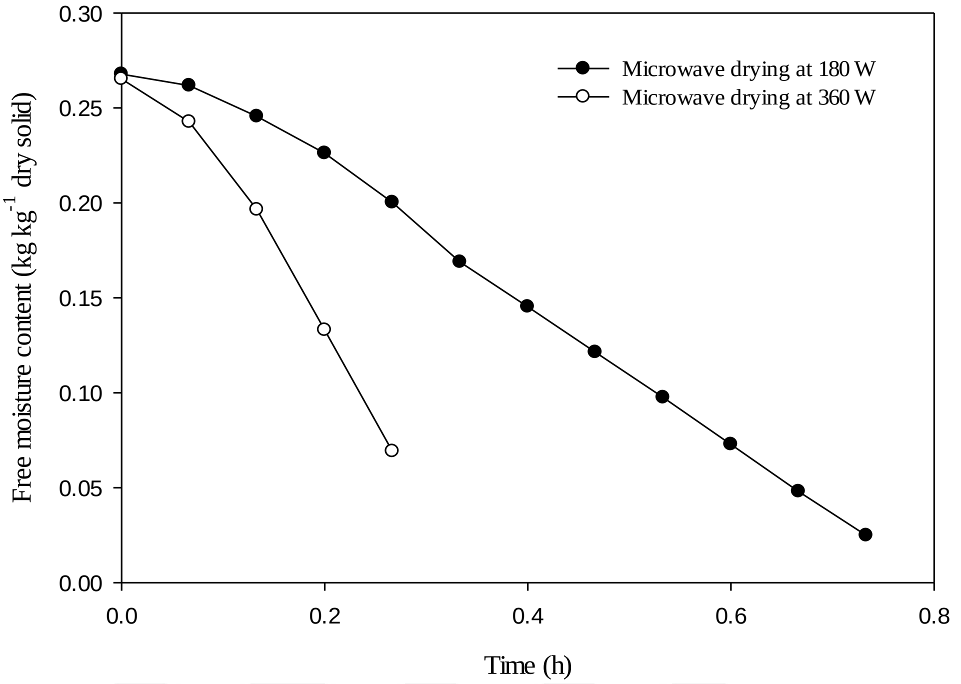

Figure 3.54 Free moisture content versus time graph of microwave dried Turkish couscous containing 0 % of bulgur flour

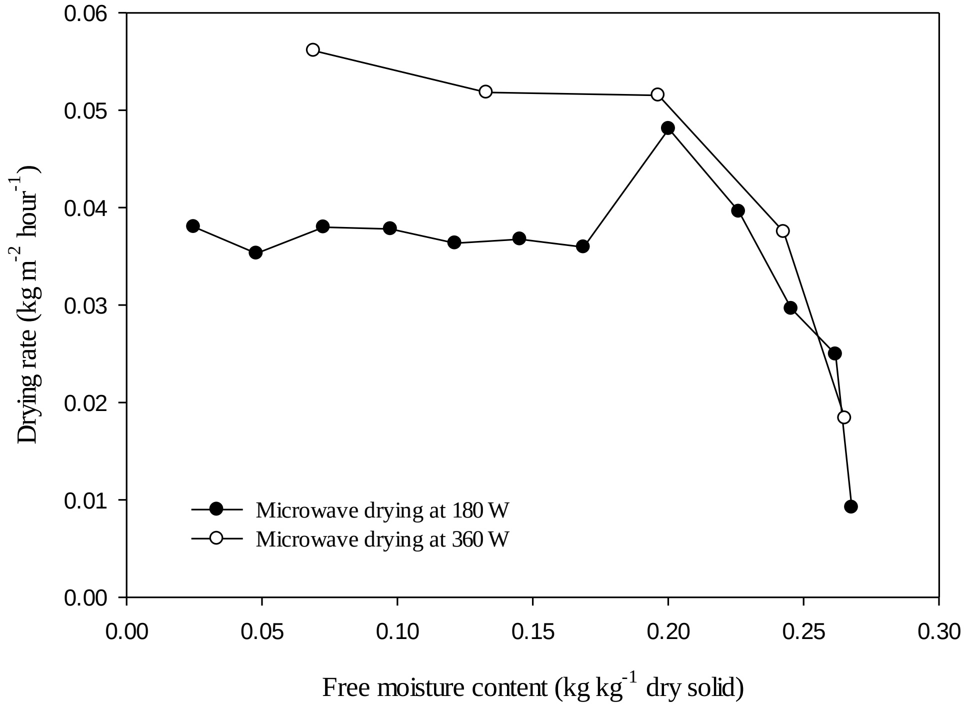

Figure 3.55 Drying rate versus free moisture content graph of microwave dried Turkish couscous containing 0 % of bulgur flour

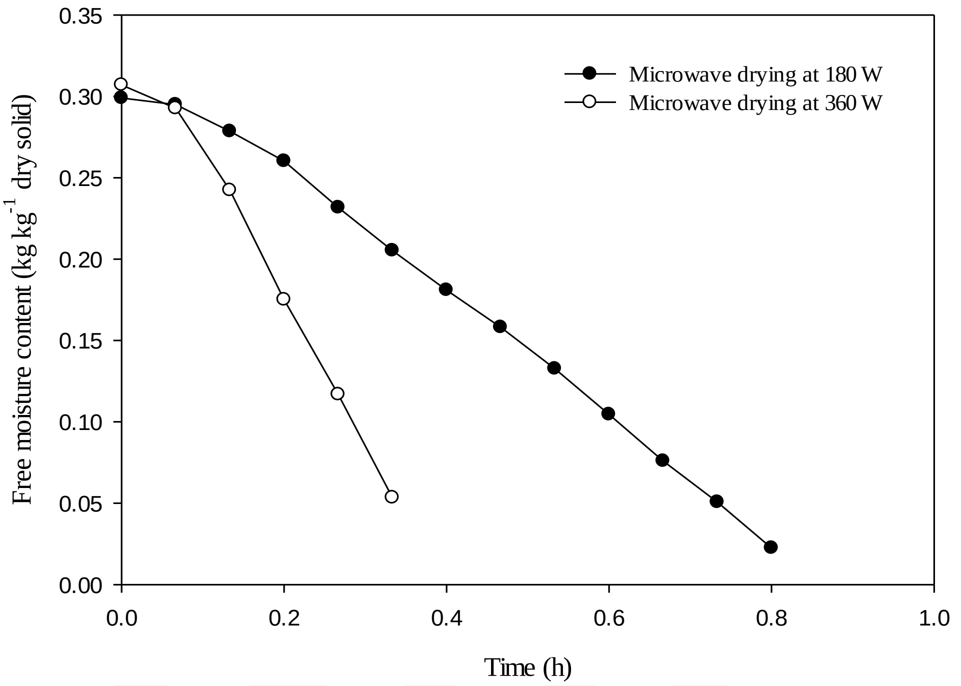

Figure 3.56 Free moisture content versus time graph of microwave dried Turkish couscous containing 50 % of bulgur flour

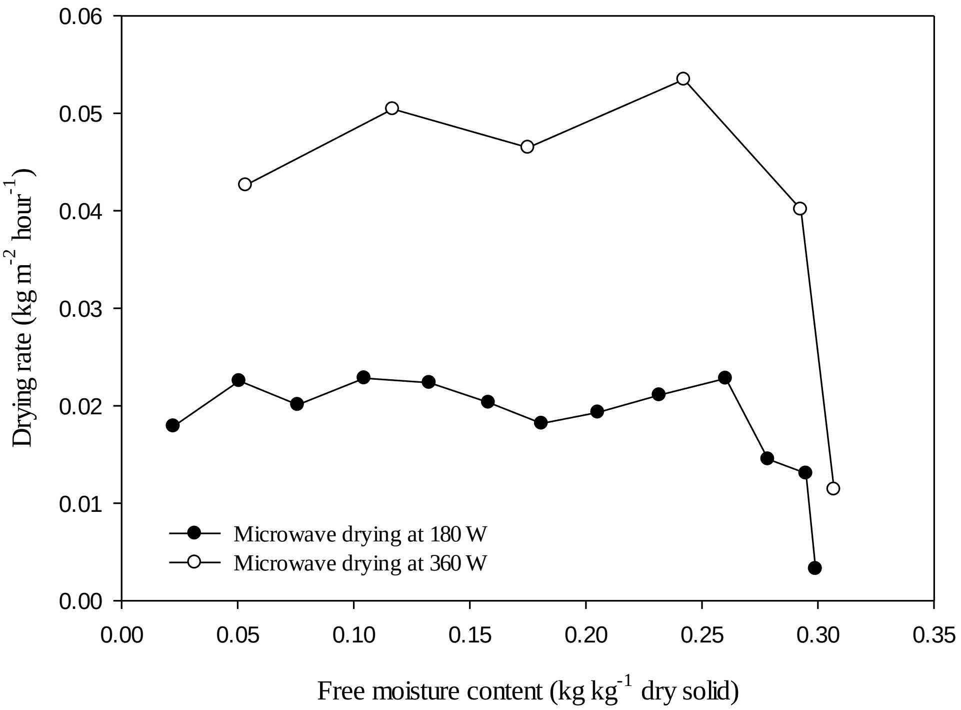

Figure 3.57 Drying rate versus free moisture content graph of microwave dried Turkish couscous containing 50 % of bulgur flour

3.3.2.9 Mathematical modeling of packed bed and microwave dried Turkish couscous

The effective moisture diffusivities of Turkish couscous produced with 25 and 50 % of bulgur flour were between 0.93×10^{-8}-1.68×10^{-8} and 0.86×10^{-8}-1.42×10^{-8} $m^2 s^{-1}$, respectively (Table 3.22). Increasing air temperature led to increase in the effective diffusivity. Several authors have shown similar D_{eff} values when working on Aloe vera (Vega et al., 2007), okra (Doymaz, 2005), amaranth grains (Resio et al., 2004) and terebinth seeds made by Chayjan and Kaveh (2014), who determined the effective moisture diffusivities of fix (packed) and fluidized bed dried (40, 50, 60, 70 and 80 °C) between 1.1×10^{-10} and 1.26×10^{-9} $m^2 s^{-1}$. The effective diffusivity of microwave dried basil was found between 2.17×10^{-10}-7.90×10^{-10} $m^2 s^{-1}$ for 180-900 W (Demirhan and Ozbek, 2010b).

Table 3.22 Effective moisture diffusivities of Turkish couscous

Quantity of bulgur flour (%, w/w)	Dryer	Drying Parameter	Effective Diffusivity ($D_{eff} \times 10^{-8}$ $m^2 s^{-1}$)
25	Packed Bed	60 °C	1.27
		80 °C	1.68
	Microwave	180 W	0.93
		360 W	1.51
50	Packed Bed	60 °C	1.01
		80 °C	1.09
	Microwave	180 W	0.86
		360 W	1.42

The dimensionless moisture ratio against drying time for the experimental data at two different drying air temperatures and drying power intensities was fitted to Modified Page II, Silva and others, Wang and Singh, Logarithmic, Midilli and others and Weibull and Peleg models available in the literature (Table 1.1). The results of fittings for Turkish couscous samples (containing 25 and 50 % of bulgur flour) are displayed in Tables 3.23, 3.24 and 3.25, which show the values of estimated constants with their corresponding statistical, values, e.g. R^2, RMSE, χ^2 and RSS.

High values of correlation coefficient, low root mean square errors, low reduced chi-square and low residual sum of squares indicate a good fitting of the model in predicting drying kinetics of the product (Kucuk et al., 2014). The results showed that experimental data fitted adequately to the models used in this study. The correlation coefficients of couscous containing 25 and 50 % of bulgur flour were obtained between 0.9561-0.9998 and 0.9544-0.9991, respectively.

The values of R^2 of the Midilli and others model for the drying temperatures and microwave powers of both Turkish couscous samples (containing 25 and 50 % of bulgur flour) were more than 0.99, indicating good fit and also the lowest values of RMSE, χ^2 and RSS. In contrast, among the applied models, Silva and others model was found the worst fit. Similar to the present study, for convective drying of lemon slices and pomegranate peels, Midilli and Kucuk model was found the most suitable by Torki-Harchegani et al. (2016) and Doymaz (2011), respectively and also for microwave drying of purslane (Demirhan and Ozbek, 2010a).

Moisture ratio against time for packed bed and microwave drying; comparing experimental data with predicted data of best models were illustrated in Figures 3.58 and 3.59. It was an interesting that the shapes of drying curves of microwave were exponential (Figure 3.59). However, in Figure 3.58, the shapes of drying graphs of packed bed were linear. This difference between the drying operations can be explained as an increase in temperature caused the drying curve become steeper, indicating an increase in drying rate. This similar result in microwave drying of bamboo shoot slices was also observed by the study of Bal et al. (2010).

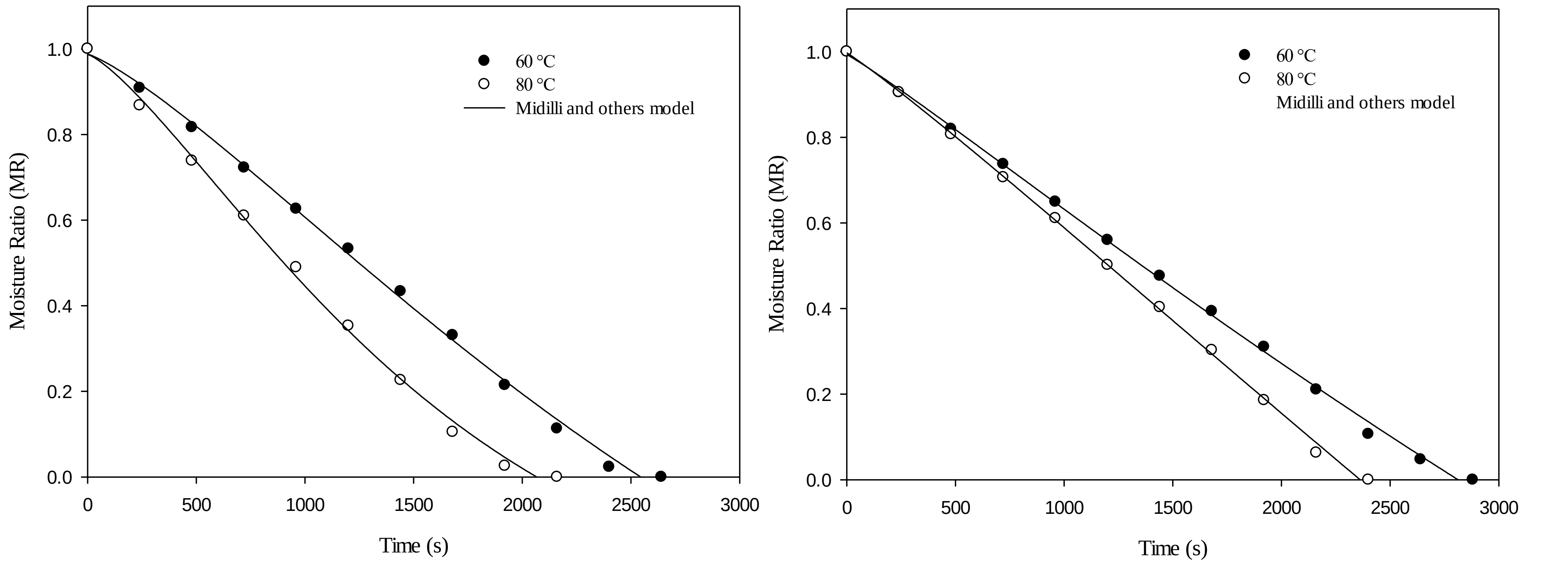

Figure 3.58 Moisture ratio against time for packed bed drying, comparing experimental data with predicted Midilli and others model (Turkish couscous containing 25 % of bulgur flour (left), Turkish couscous containing 50 % of bulgur flour (right))

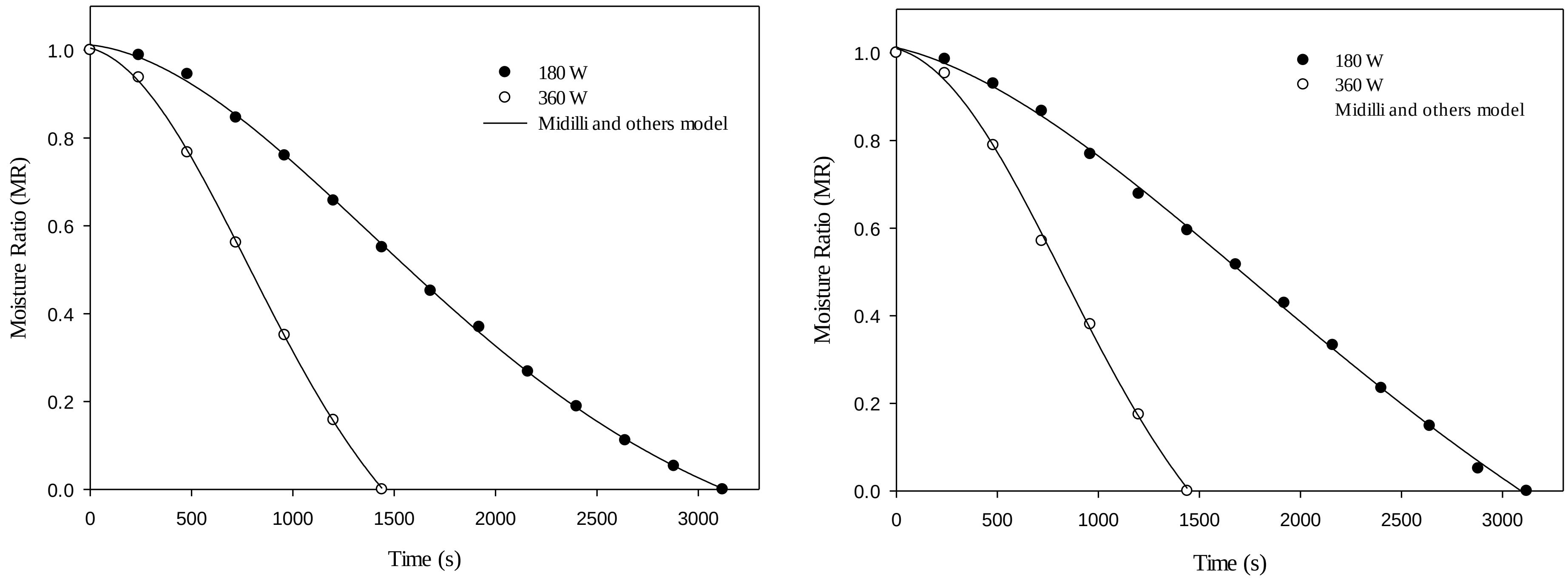

Figure 3.59 Moisture ratio against time for microwave drying, comparing experimental data with predicted Midilli and others model (Turkish couscous containing 25 % of bulgur flour (left), Turkish couscous containing 50 % of bulgur flour (right))

Table 3.23 Statistical results for various drying models (Turkish couscous containing 25 % of bulgur flour)

Drying Parameters	Packed Bed Drying								Microwave Drying							
	60 °C				80 °C				180 W				360 W			
Model Name	**R^2**	**RMSE**	**χ^2**	**RSS**	**R^2**	**RMSE**	**χ^2**	**RSS**	**R^2**	**RMSE**	**χ^2**	**RSS**	**R^2**	**RMSE**	**χ^2**	**RSS**
Modified Page II	0.9832	0.0430	0.0020	0.0222	0.9880	0.0371	0.0015	0.0137	0.9965	0.0203	0.0004	0.0058	0.9943	0.0269	0.0008	0.0051
Wang and Singh	0.9965	0.0196	0.0005	0.0046	0.9956	0.0225	0.0006	0.0051	0.9860	0.0409	0.0019	0.0234	0.9906	0.0346	0.0017	0.0084
Silva and others	0.9561	0.0695	0.0058	0.0579	0.9691	0.0595	0.0044	0.0354	0.9676	0.0622	0.0045	0.0541	0.9630	0.0688	0.0066	0.0331
Peleg	0.9965	0.0196	0.0005	0.0046	0.9949	0.0241	0.0007	0.0058	0.9853	0.0418	0.0020	0.0245	0.9888	0.0378	0.0020	0.0100
Logarithmic	0.9967	0.0190	0.0004	0.0043	0.9955	0.0227	0.0006	0.0052	0.9916	0.0316	0.0012	0.0139	0.9878	0.0396	0.0022	0.0110
Midilli and others	**0.9976**	0.0161	0.0003	0.0031	**0.9974**	0.0173	0.0004	0.0030	**0.9996**	0.0072	0.0001	0.0007	**0.9998**	0.0045	0.0000	0.0001
Weibull	0.9832	0.0430	0.0022	0.0222	0.9880	0.0371	0.0017	0.0137	0.9965	0.0203	0.0005	0.0058	0.9943	0.0269	0.0010	0.0051

Table 3.24 Statistical results for various drying models (Turkish couscous containing 50 % of bulgur flour)

Drying Parameters	**Packed Bed Drying**								**Microwave Drying**							
	60 °C				**80 °C**				**180 W**				**360 W**			
Model Name	**R^2**	**RMSE**	**χ^2**	**RSS**	**R^2**	**RMSE**	**χ^2**	**RSS**	**R^2**	**RMSE**	**χ^2**	**RSS**	**R^2**	**RMSE**	**χ^2**	**RSS**
Modified Page II	0.9822	0.0428	0.0020	0.0238	0.9815	0.0440	0.0021	0.0213	0.9905	0.0327	0.0012	0.0150	0.9933	0.0293	0.0010	0.0060
Wang and Singh	0.9986	0.0121	0.0002	0.0019	0.9990	0.0100	0.0001	0.0011	0.9939	0.0261	0.0008	0.0095	0.9905	0.0349	0.0017	0.0085
Silva and others	0.9593	0.0646	0.0049	0.0542	0.9564	0.0676	0.0056	0.0503	0.9544	0.0717	0.0060	0.0719	0.9607	0.0709	0.0070	0.0351
Peleg	0.9986	0.0122	0.0002	0.0019	0.9990	0.0101	0.0001	0.0011	0.9925	0.0290	0.0010	0.0118	0.9877	0.0396	0.0022	0.0110
Logarithmic	0.9986	0.0121	0.0002	0.0019	0.9989	0.0107	0.0001	0.0013	0.9930	0.0280	0.0009	0.0110	0.9842	0.0449	0.0028	0.0141
Midilli and others	**0.9986**	0.0118	0.0002	0.0018	**0.9991**	0.0095	0.0001	0.0010	**0.9991**	0.0100	0.0001	0.0014	**0.9991**	0.0106	0.0002	0.0008
Weibull	0.9822	0.0428	0.0022	0.0238	0.9815	0.0440	0.0024	0.0213	0.9905	0.0327	0.0013	0.0150	0.9933	0.0293	0.0012	0.0060

Table 3.25 Parameters of Turkish couscous for the drying models

Quantity of bulgur flour (%, w/w)	Model Name		Packed Bed Drying		Microwave Drying	
			60 °C	80 °C	180 W	360 W
25	Modified Page II	*k*	$6.7738x10^{-4}$	$9.1165x10^{-4}$	$5.4095x10^{-4}$	$1.1009x10^{-3}$
		n	1.7717	1.6640	2.0885	2.2777
	Wang and Singh	*a*	$-4.0188x10^{-4}$	$-6.0901x10^{-4}$	$-2.7129x10^{-4}$	$-4.6841x10^{-4}$
		b	$2.2375x10^{-9}$	$5.8742x10^{-8}$	$-2.1692x10^{-8}$	$-1.7402x10^{-7}$
	Silva and others	*a*	0.0012	0.0016	0.0011	0.0024
		b	-0.0181	-0.0208	-0.0225	-0.0378
	Peleg	*a*	2489.5101	1623.8632	3541.0643	1919.3130
		b	0.0134	0.2025	-0.1855	-0.3627
	Logarithmic	*a*	11.7906	2.4154	528.2023	4843.9469
		c	-10.7789	-1.3989	-527.1339	-4842.8745
		k	$3.5499x10^{-5}$	$2.6738x10^{-4}$	$6.7375x10^{-7}$	$1.5288x10^{-7}$
	Midilli and others	*a*	0.9882	0.9873	1.0116	1.0047
		k	$1.8006x10^{-5}$	$4.2627x10^{-5}$	$7.4003x10^{-7}$	$8.0402x10^{-7}$
		b	$-1.3320x10^{-4}$	$-9.0075x10^{-5}$	$-4.0601x10^{-5}$	$-1.2090x10^{-4}$
		n	1.4018	1.3853	1.8447	2.0059
	Weibull	*a*	1.7717	1.6640	2.0885	2.2777
		b	1476.2810	1096.9067	1848.5969	908.3646
50	Modified Page II	*k*	$6.1822x10^{-4}$	$7.0755x10^{-4}$	$5.0827x10^{-4}$	$1.0732x10^{-3}$
		n	1.6543	1.7368	2.1164	2.3487
	Wang and Singh	*a*	$-3.7790x10^{-4}$	$-4.0260x10^{-4}$	$-2.2034x10^{-4}$	$-4.0808x10^{-4}$
		b	$7.6359x10^{-9}$	$-9.3431x10^{-9}$	$-3.6822x10^{-8}$	$-2.1457x10^{-7}$
	Silva and others	*a*	$1.0128x10^{-3}$	$1.2028x10^{-3}$	$9.8194x10^{-4}$	$2.3808x10^{-3}$
		b	-0.0150	-0.0178	-0.0205	-0.0384
	Peleg	*a*	2644.5547	2478.9833	4139.4761	2081.0815
		b	0.0569	-0.0525	-0.3691	-0.4724
	Logarithmic	*a*	8.5077	3778.1950	5915.4388	5119.7170
		c	-7.5064	-3777.1851	-5914.3611	-5118.6323
		k	$4.4636x10^{-5}$	$1.1280x10^{-7}$	$5.8443x10^{-8}$	$1.4437x10^{-7}$
	Midilli and others	*a*	0.9932	0.9974	1.0121	1.0101
		k	$6.2894x10^{-5}$	$2.1087x10^{-5}$	$6.7848x10^{-7}$	$5.0820x10^{-7}$
		b	$-1.7985x10^{-4}$	$-2.8443x10^{-4}$	$-9.7503x10^{-5}$	$-1.3340x10^{-4}$
		n	1.1686	1.2666	1.7911	2.0600
	Weibull	*a*	1.6543	1.7368	2.1164	2.3487
		b	1617.5556	1413.3293	1967.4613	931.7959

3.4 Comparison of all couscous types

Pasta like, African and Turkish couscous were compared by the properties of quality, functional and texture. One-way ANOVA results showed that springiness, bulk density, total phenol content and DPPH scavenging activity were not significantly ($p>0.05$) different in contrast to weight increase, total flavonoid content, protein, ash and crude fiber contents, hardness, adhesiveness, cohesiveness, gumminess, chewiness and resilience. Functional, quality and textural properties of all couscous types were given in Tables 3.26 and 3.27.

Protein, ash and crude fiber contents of bulgur containing couscous samples were higher than their controls. Bulgur flour containing pasta-like couscous samples have the highest crude fiber contents due to formulations with the 100 % of bulgur flour. On the other hand, higher crude fiber contents were observed for bulgur containing couscous samples in contrast to their control couscous. Moreover, microwave dried samples have more crude fiber than packed bed dried ones. Bulk densities were decreased with the addition of bulgur flour in couscous samples. However, microwave drying increased the bulk density for bulgur-couscous samples in contrast to Turkish couscous.

In terms of hardness, for African and Turkish couscous samples, it was increased by bulgur flour addition in contrast to pasta-like couscous. Total phenol contents of couscous samples decreased with microwave drying. For all couscous types, for packed bed dried samples, control couscous samples have higher phenol contents in contrast to microwave dried samples. On the other hand, bulgur flour containing couscous samples have higher total flavonoid contents for all couscous samples.

There were very small increments for weight increase values of African and Turkish couscous samples when compared to their control samples for each drying technique. However, bulgur flour addition and microwave drying decreased the weight increase values of pasta-like couscous samples.

In terms of sensory attributes of African couscous containing bulgur flour has the highest general acceptance score and microwave drying increased sensory scores of African, Turkish and pasta-like couscous except chewiness, hardness and color values of pasta-like couscous.

Table 3.26 Functional and quality properties of all couscous types

Couscous type	Drying technique*	Quantity of bulgur flour [%]	Drying parameters	Functional Properties: Total phenol content [mg gallic acid/100 g sample]	Functional Properties: Total flavonoid content[mg catechin/100 g sample]	Functional Properties: % DPPH scavenging activity	Quality Properties: Weight increase [%, w/w]	Quality Properties: Protein content [d.b., %]	Quality Properties: Ash content [d.b., %]	Quality Properties: Crude fiber content [d.b., %, w/w]	Quality Properties: Bulk density [kg/m^3]
Pasta-like	PBD	0	80 °C	62.40±29.54^{b}	39.23±8.67^{abcde}	74.06±1.43^{b}	137.67±13.92^{d}	10.35±0.16^{a}	0.77±0.06^{ab}	0.84±0.04^{a}	670.00±0.95^{b}
		100		41.61±3.97^{ab}	48.54±9.09^{de}	63.55±11.26^{a}	105.38±2.83^{c}	12.84±0.23^{g}	2.89±0.01^{f}	5.00±0.03^{e}	515.20±17.95^{a}
	MW	0	360 W	22.032.89^{a}	23.65±8.01^{ab}	74.01±2.86^{b}	98.96±2.88^{c}	10.57±0.11^{ab}	0.73±0.01^{a}	1.00±0.14^{ab}	630.30±56.15^{b}
		100		34.42±12.13^{ab}	35.55±16.29^{abcd}	70.60±1.81^{ab}	86.90±2.07^{b}	12.43±0.18^{fg}	2.80±0.22^{f}	5.52±0.73^{e}	590.30±1.25^{ab}
African	PBD	0	60 °C	60.43±2.43^{b}	35.27±4.99^{abcd}	73.55±0.61^{ab}	70.06±0.11^{a}	10.95±0.07^{bc}	0.93±0.01^{bc}	1.01±0.08^{ab}	610.32±49.94^{ab}
		50		50.99±6.79^{ab}	54.26±5.07^{e}	71.48±1.80^{ab}	70.76±2.46^{a}	11.92±0.1^{ef}	2.01±0.07^{e}	2.79±0.00^{cd}	519.95±11.24^{a}
	MW	0	180 W	32.98±11.07^{ab}	22.05±2.77^{a}	71.57±1.44^{ab}	70.48±0.98^{a}	11.05±0.16^{bcd}	0.88±0.03^{ab}	1.22±0.21^{ab}	628.28±67.49^{b}
		50		52.93±6.25^{ab}	39.55±0.84^{abcde}	73.00±2.76^{ab}	70.63±1.50^{a}	11.58±0.32^{de}	1.90±0.04^{e}	3.42±0.07^{d}	593.08±38.91^{ab}
Turkish	PBD	0	80 °C	57.68±23.17^{ab}	32.09±3.52^{abcd}	72.99±4.19^{ab}	67.31±3.81^{a}	11.49±0.49^{cde}	1.11±0.04^{c}	0.94±0.05^{ab}	631.10±53.13^{b}
		25		51.44±7.53^{ab}	39.91±2.04^{bcde}	73.95±4.81^{b}	68.62±1.57^{a}	12.12±0.12^{f}	1.62±0.08^{d}	1.29±0.61^{ab}	607.87±27.76^{ab}
	MW	0	180 W	26.43±9.43^{ab}	27.38±6.21^{abc}	73.52±4.04^{ab}	70.33±1.71^{a}	11.54±0.37^{de}	1.10±0.06^{c}	0.97±0.16^{ab}	672.41±65.28^{b}
		50		56.73±30.60^{ab}	42.50±5.71^{cde}	73.35±0.17^{ab}	70.58±1.25^{a}	12.27±0.10^{f}	2.03±0.04^{e}	2.10±1.43^{bc}	592.05±49.26^{ab}

*PBD: Packed Bed Dryer. MW: Microwave Dryer. Each column followed by different superscripts is significantly different (p≤0.05).

Table 3.27 Texture properties of all couscous types

				Texture Properties						
Couscous type	**Drying technique***	**Quantity of bulgur flour [%]**	**Drying parameters**	**Hardness (N)**	**Adhesiveness (N.s)**	**Springiness**	**Cohesiveness**	**Gumminess**	**Chewiness**	**Resilience**
Pasta-like	PBD	0	80 °C	879.79±438.01^{a}	-53.36±22.88^{b}	0.55±0.10^{a}	0.45±0.01^{e}	398.41±207.20^{a}	230.79±154.37^{b}	0.23±0.00^{f}
		100		200.76±11.52^{a}	-34.65±16.25^{b}	0.41±0.02^{a}	0.28±0.01^{ab}	55.31±1.46^{a}	22.55±0.40^{a}	0.09±0.01^{abc}
	MW	0	360 W	475.86±86.74^{ab}	-17.86±8.89^{b}	0.41±0.01^{a}	0.37±0.02^{cd}	175.93±23.79^{ab}	72.73±8.54^{a}	0.19±0.02^{e}
		100		125.13±2.71^{a}	-32.25±1.57^{b}	0.39±0.22^{a}	0.25±0.01^{a}	30.83±0.62^{a}	12.01±6.46^{a}	0.08±0.00^{ab}
African	PBD	0	60 °C	122.54±36.14^{a}	-172.16±218.20^{b}	0.52±0.21^{a}	0.36±0.07^{cd}	45.48±21.95^{a}	26.08±20.86^{a}	0.09±0.01^{abc}
		50		216.92±61.33^{a}	-59.20±32.23^{b}	0.28±0.03^{a}	0.34±0.00^{bc}	73.74±20.90^{a}	20.58±3.91^{a}	0.12±0.00^{c}
	MW	0	180 W	276.35±81.47^{a}	-20.24±0.25^{b}	0.53±0.24^{a}	0.30±0.03^{abc}	84.38±32.67^{a}	48.99±37.59^{a}	0.11±0.02^{bc}
		50		433.75±125.83^{ab}	-14.10±0.26^{b}	0.50±0.05^{a}	0.41±0.04^{de}	181.56±67.43^{ab}	91.73±42.13^{a}	0.16±0.01^{de}
Turkish	PBD	0	80 °C	322.01±92.29^{a}	-503.68±121.04^{a}	0.28±0.01^{a}	0.31±0.02^{abc}	99.87±23.64^{a}	27.35±5.67^{a}	0.08±0.01^{a}
		25		450.99±235.94^{ab}	-239.76±299.85^{b}	0.45±0.04^{a}	0.31±0.01^{abc}	139.75±68.55^{ab}	64.19±36.36^{a}	0.09±0.01^{abc}
	MW	0	180 W	287.99±14.59^{a}	-21.98±1.65^{b}	0.47±0.05^{a}	0.36±0.04^{cd}	101.87±6.73^{a}	47.73±7.91^{a}	0.15±0.03^{d}
		50		719.53±26.75^{bc}	-13.31±0.83^{b}	0.42±0.01^{a}	0.41±0.03^{de}	297.00±8.23^{bc}	125.40±5.36^{ab}	0.17±0.00^{de}

*PBD: Packed Bed Dryer. MW: Microwave Dryer. Each column followed by different superscripts is significantly different ($p \leq 0.05$).

CONCLUSION

It was found that increasing quantity of bulgur flour decreased lightness and yellowness values for pasta-like couscous. Quantity of bulgur flour was significantly ($p \leq 0.05$) effective on lightness and yellowness for all dried and non-dried couscous. Optimum processing parameters were predicted as 80 °C for packed bed drying and 360 W for microwave drying for the production of pasta-like couscous samples with 100 % bulgur flour.

The quantity of bulgur flour was significantly effective ($p \leq 0.05$) on sensory attributes (chewiness, hardness, odor, taste, color and general acceptability), bulk density, the amount of cooking loss, volume and weight increases, protein and ash contents of pasta-like couscous. Couscous samples containing bulgur flour have higher amount of protein than control samples due to higher protein content of bulgur. There were no significant differences between functional properties of control and couscous samples for both drying techniques.

The lightness (L*) values of samples were decreased with increasing the quantity of bulgur flour after both drying operations for African couscous. Yellowness (b*) values of microwave dried African couscous at 180 and 360 W were higher than non-dried ones. The quantity of bulgur flour (i.e. 0, 25 and 50 %) was not significantly ($p > 0.05$) effective on odor, in contrast to color and general appearance. During production of African couscous; i) 50 % (w/w) of water for dough preparation, 50 % of bulgur flour, 60 °C drying temperature for packed bed dryer; ii) 50 % (w/w) of water for dough preparation, 50 % of bulgur flour, 180 W drying power for microwave dryer were selected as optimum recipes and drying parameters.

Results indicated that protein and ash contents of bulgur containing African couscous samples were significantly ($p \leq 0.05$) higher than semolina containing samples as expected based on raw materials compositions. The quantity of bulgur flour was significantly effective ($p \leq 0.05$) on sensory attributes (chewiness, hardness, odor, taste, color and general acceptability), protein and ash contents, total flavonoid content and resilience of African couscous.

For Turkish couscous, it was found that the quantity of bulgur flour (i.e. 0, 25 and 50 %) was not significantly ($p>0.05$) effective on odor, in contrast to color and general appearance. Lightness (L*) values of couscous samples were decreased with increase in the quantity of bulgur flour. Yellowness (b*) values of microwave dried couscous samples were higher than packed bed dried ones. As optimum product compositions and drying parameters; 1) 30.63 % (w/w) of milk and 4.38 % of egg for dough preparation, 25 % of bulgur flour, 80 °C drying temperature for packed bed dryer; 2) 35 % (w/w) of milk and 5 % of egg for dough preparation, 50 % of bulgur flour, 180 W drying power for microwave dryer were selected.

Turkish couscous results revealed that the quantity of bulgur flour was not significantly ($p>0.05$) effective on protein content but was significantly effective ($p\leq 0.05$) on sensory attributes (chewiness, hardness, odor, taste, color and general acceptability), ash content and TPA parameters of springiness, gumminess, chewiness and resilience properties.

The study shows that packed bed and microwave drying can be used as an innovative technology to develop production technology of couscous. Consumers' scores were higher for Turkish and African couscous types compared to pasta like. The value-added food product was successfully produced by utilizing by-product (bulgur flour, which is used as an animal feed).

For the future of food industry, milk and egg containing Turkish type couscous is recommended to increase the nutritional property of couscous. Very fine particles collected on sifters' pan can be recycled through the mixing step to improve yield content for African and Turkish couscous. In addition, higher substitution percentage may be obtained. By using pasta-machine, different shapes of pasta types can be studied by using bulgur flour to improve taste, functionality and nutritional quality.

REFERENCES

Aalami, M., Rao, U. J. S. P., and Leelavathi, K. (2007). Physicochemical and biochemical characteristics of Indian durum wheat varieties: Relationship to semolina milling and spaghetti making quality. *Food Chemistry*, **102(4)**, 993-1005.

Aboubacar, A., and Hamaker, B. R. (2000). Low molecular weight soluble starch and its relationship with sorghum couscous stickiness. *Journal of Cereal Science,* **31(2)**, 119-126.

Aboubacar, A., Yazici, N., and Hamaker, B. R. (2006). Extent of decortication and quality of flour, couscous and porridge made from different sorghum cultivars. *International Journal of Food Science and Technology,* **41(6)**, 698-703.

Acquistucci, R. (1996). The Maillard reaction in pasta: Preliminary classification by multivariate techniques. *Food Science and Technology-Lebensmittel-Wissenschaft & Technologie*, **29(7)**, 626-631.

Akpinar, E. K., Bicer, Y., and Yildiz, C. (2003). Thin layer drying of red pepper. *Journal of Food Engineering,* **59(1)**, 99-104.

Altan, A., and Maskan, M. (2004). Microwave assisted drying of short-cut (ditalini) macaroni: Cooking process and textural properties. *Food Science and Technology International*, **10(3)**, 187-196.

Anonymous. (2013). FAO Statistical Yearbook 2013, World food and agriculture. Retrieved 09.06.2017, from http://www.fao.org/docrep/018/i3107e/i3107e00.htm

Anonymous. (2014). Makarna Üretimi. Retrieved 29.05.2017, from http://www.makarna.org.tr/d/makarna-sektoru/makarna-uretimi/41/

Anonymous. (2015). World Pasta Production. Retrieved 29.05.2017, from http://www.pasta-unafpa.org/ingstatistics5.htm

Anonymous. (2016). History of couscous. Retrieved 04.02.2016, from http://www.couscousdari.com/en/saga_ang.htm

Anonymous. (2017a). Couscous production line. Retrieved 24.10.2017, from http://www.clextral.com/technologies-and-lines/line-food/automated-couscous-production-lines/

Anonymous. (2017b). History of bulgur wheat. Retrieved 08.05.2017, from http://sunnylandmills.com/2016/05/20/history-of-bulgur-wheat/

Anonymous. (2017c). List of importers and exporters in the world for couscous. Retrieved 29.05.2017, from http://trademap.org/Index.aspx

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

Aravind, N., Sissons, M., Egan, N., and Fellows, C. (2012). Effect of insoluble dietary fibre addition on technological, sensory, and structural properties of durum wheat spaghetti. *Food Chemistry,* **130(2)**, 299-309.

Bal, L. M., Kar, A., Satya, S., and Naik, S. N. (2010). Drying kinetics and effective moisture diffusivity of bamboo shoot slices undergoing microwave drying. *International Journal of Food Science and Technology,* **45(11)**, 2321-2328.

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

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

Bayram, M., Oner, M. D., and Eren, S. (2004). 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, Mustafa, and Öner, Mehmet D. (2007). Bulgur milling using roller, double disc and vertical disc mills. *Journal of Food Engineering,* **79(1)**, 181-187.

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

Benatallah, L., Agli, A., and Zidoune, M. N. (2008). Gluten-free couscous preparation: Traditional procedure description and technological feasibility for three rice-leguminous supplemented formulae. *Journal of Food Agriculture & Environment,* **6(2)**, 105-112.

Berteli, M. N., and Marsaioli, A. (2005). Evaluation of short cut pasta air dehydration assisted by microwaves as compared to the conventional drying process. *Journal of Food Engineering,* **68(2)**, 175-183.

Betschart, Antoinette A. (1988). Nutritional Quality of Wheat and Wheat Foods. In Y. Pomeranz (Ed.), *Wheat: Chemistry and Technology* (Third ed., Vol. II, pp. 91-130). St. Paul, Minnesota, USA: American Association of Cereal Chemists, Inc.

Borrelli, G. M., Troccoli, A., Di Fonzo, N., and Fares, C. (1999). Durum wheat lipoxygenase activity and other quality parameters that affect pasta color. *Cereal Chemistry,* **76(3)**, 335-340.

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.

Cardenas-Hernandez, A., Beta, T., Loarca-Pina, G., Castano-Tostado, E., Nieto-Barrera, J. O., and Mendoza, S. (2016). Improved functional properties of pasta: Enrichment with amaranth seed flour and dried amaranth leaves. *Journal of Cereal Science,* **72**, 84-90.

Çelik, İlyas, Işık, Fatma, and Gürsoy, Oğuz. (2004). Couscous, a traditional Turkish food product: production method and some applications for enrichment of nutritional value. *International Journal of Food Science & Technology,* **39(3)**, 263-269.

Chayjan, R. A., and Kaveh, M. (2014). Physical Parameters and Kinetic Modeling of Fix and Fluid Bed Drying of Terebinth Seeds. *Journal of Food Processing and Preservation,* **38(3)**, 1307-1320.

Choi, Y., Jeong, H. S., and Lee, J. (2007). Antioxidant activity of methanolic extracts from some grains consumed in Korea. *Food Chemistry,* **103(1)**, 130-138.

Colak, N., Erbay, Z., and Hepbasli, A. (2013). Performance assessment and optimization of industrial pasta drying. *International Journal of Energy Research,* **37(8)**, 913-922.

Coskun, Fatma. (2013). Production of couscous using the traditional method in Turkey and couscous in the world. *African Journal of Agricultural Research,* **8(22)**, 2609-2615.

Crank, J. (1975). *Mathematic of Diffusion* (2nd ed.). London: Oxford University Press.

da Silva, W. P., Rodrigues, A. F., Silva, C. M. D. P. S. E., de Castro, D. S., and Gomes, J. P. (2015). Comparison between continuous and intermittent drying of whole bananas using empirical and diffusion models to describe the processes. *Journal of Food Engineering,* **166**, 230-236.

da Silva, W. P., Silva, C. M. D. P. S. E., de Sousa, J. A. R., and Farias, V. S. O. (2013). Empirical and diffusion models to describe water transport into chickpea (Cicer arietinum L.). *International Journal of Food Science and Technology*, **48(2)**, 267-273.

Dadali, G., Demirhan, E., and Ozbek, B. (2007). Microwave heat treatment of spinach: Drying kinetics and effective moisture diffusivity. *Drying Technology*, **25(10)**, 1703-1712.

De Noni, I., and Pagani, M. A. (2010). Cooking Properties and Heat Damage of Dried Pasta as Influenced by Raw Material Characteristics and Processing Conditions. *Critical Reviews in Food Science and Nutrition*, **50(5)**, 465-472.

De Pilli, T., Giuliani, R., Derossi, A., and Severini, C. (2009). Study of cooking quality of spaghetti dried through microwaves and comparison with hot air dried pasta. *Journal of Food Engineering*, **95(3)**, 453-459.

De Pilli, Teresa, Lovino, Raffaella, Maenza, Silvia, Derossi, Antonio, and Severini, Carla. (2008). Study On Operating Conditions Of Orange Drying Processing: Comparison Between Conventional And Combined Treatment. *Journal of Food Processing and Preservation*, **32(5)**, 751-769.

Debbouz, A., Dick, J. W., and Donnelly, B. J. (1994). Influence of Raw-Material on Couscous Quality. *Cereal Foods World*, **39(4)**, 231-236.

Debbouz, A., and Doetkott, C. (1996). Effect of process variables on spaghetti quality. *Cereal Chemistry*, **73(6)**, 672-676.

Debbouz, A., and Donnelly, B. J. (1996). Process effect on couscous quality. *Cereal Chemistry*, **73(6)**, 668-671.

Demir, B., Bilgicli, N., Elgun, A., and Demir, M. K. (2010). The Effect of Partial Substitution of Wheat Flour with Chickpea Flour on the Technological, Nutritional and Sensory Properties of Couscous. *Journal of Food Quality*, **33(6)**, 728-741.

Demir, M. K., and Demir, B. (2016). Utilisation of buckwheat (*Fagopyrum esculentum* M.) and different legume flours in traditional couscous production in Turkey. *Quality Assurance and Safety of Crops & Foods*, **8(1)**, 157-163.

Demirhan, E., and Ozbek, B. (2010a). Drying kinetics and effective moisture diffusivity of purslane undergoing microwave heat treatment. *Korean Journal of Chemical Engineering*, **27(5)**, 1377-1383.

Demirhan, E., and Ozbek, B. (2010b). Microwave-Drying Characteristics of Basil. *Journal of Food Processing and Preservation*, **34(3)**, 476-494.

Dick, J. W., and Matsuo, R. R. (1988). Durum Wheat and Pasta Products. In Y. Pomeranz (Ed.), *Wheat: Chemistry and Technology* (Third ed., Vol. II, pp. 507-547). St. Paul, Minnesota, USA: American Association of Cereal Chemists, Inc.

Doymaz, I. (2011). Experimental Study on Drying Characteristics of Pomegranate Peels. *Food Science and Biotechnology*, **20(4)**, 965-970.

Doymaz, I., and Ismail, O. (2011). Drying characteristics of sweet cherry. *Food and Bioproducts Processing*, **89(C1)**, 31-38.

Doymaz, İbrahim. (2005). Drying characteristics and kinetics of okra. *Journal of Food Engineering*, **69(3)**, 275-279.

Erbay, Zafer, and Icier, Filiz. (2010). A Review of Thin Layer Drying of Foods: Theory, Modeling, and Experimental Results. *Critical Reviews in Food Science and Nutrition*, **50(5)**, 441-464.

Erle, U. (2010). Drying using microwave processing. In Helmar; Schubert andMarc Regier (Eds.), *The microwave processing of foods* (pp. 142-152). United Kingdom: Woodhead Publishing Limited.

Fuad, T., and Prabhasankar, P. (2010). Role of Ingredients in Pasta Product Quality: A Review on Recent Developments. *Critical Reviews in Food Science and Nutrition*, **50(8)**, 787-798.

Galiba, M., Waniska, R. D., Rooney, L. W., and Miller, F. R. (1988). Couscous Quality of Sorghum with Different Kernel Characteristics. *Journal of Cereal Science*, **7(2)**, 183-193.

Gazza, L., Sgrulletta, D., Cammerata, A., Gazzelloni, G., Perenzin, M., and Pogna, N. E. (2011). Pastamaking and breadmaking quality of soft-textured durum wheat lines. *Journal of Cereal Science,* **54(3)**, 481-487.

Gely, M. C., and Santalla, E. M. (2007). Moisture diffusivity in quinoa (Chenopodium quinoa Willd.) seeds: Effect of air temperature and initial moisture content of seeds. *Journal of Food Engineering,* **78(3)**, 1029-1033.

Gimenez, M. A., Drago, S. R., De Greef, D., Gonzalez, R. J., Lobo, M. O., and Samman, N. C. (2012). Rheological, functional and nutritional properties of wheat/broad bean (Vicia faba) flour blends for pasta formulation. *Food Chemistry,* **134(1)**, 200-206.

Hallen, E., Ibanoglu, S., and Ainsworth, P. (2004). Effect of fermented/germinated cowpea flour addition on the rheological and baking properties of wheat flour. *Journal of Food Engineering,* **63(2)**, 177-184.

Hashemi, G., Mowla, D., and Kazemeini, M. (2009). Moisture diffusivity and shrinkage of broad beans during bulk drying in an inert medium fluidized bed dryer assisted by dielectric heating. *Journal of Food Engineering,* **92(3)**, 331-338.

Hayta, M. (2002). Bulgur Quality as Affected by Drying Methods. *Journal of Food Science,* **67(6)**, 2241-2244.

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

Hii, C. L., Law, C. L., and Cloke, M. (2009). Modeling using a new thin layer drying model and product quality of cocoa. *Journal of Food Engineering*, **90(2)**, 191-198.

Hoseney, R. C. (1994). *Principles of Cereal Science and Technology* (Second ed.). St. Paul, Minnesota, USA: American Association of Cereal Chemists, Inc.

Hruskova, M., and Svec, I. (2009). Wheat Hardness in Relation to Other Quality Factors. *Czech Journal of Food Sciences*, **27(4)**, 240-248.

Ikeda, S., Yabuzoe, T., Takaya, T. and Nishinari, K. (2001). Effects of sugars on gelatinization and retrogradation of corn starch. In Barsby, T. L., Donald, A. M. And Frazier, P. J. (Eds.), *Starch Advances in Structure and Function* (pp. 67-76). Royal Society of Chemistry, Cambridge.

ISO. (1981). International Organization of Standardization. Agricultural food products-Determination of crude fibre content-Modified Scharrer method (ISO 6541:1981).

Jayasena, V., and Nasar-Abbas, S. M. (2012). Development and Quality Evaluation of High-Protein and High-Dietary-Fiber Pasta Using Lupin Flour. *Journal of Texture Studies,* **43(2)**, 153-163.

Jeffers, H.C.; Noguchi, G.; Rubenthaler, G.L. (1979). Effects of Legume Fortifiers on the Quality of Udon Noodles. *Cereal Chemistry* **56**, 573-580.

Kahyaoglu, L. N., Sahin, S., and Sumnu, G. (2010). Physical properties of parboiled wheat and bulgur produced using spouted bed and microwave assisted spouted bed drying. *Journal of Food Engineering,* **98(2)**, 159-169.

Kaup, S. M., and Walker, C. E. (1986). Couscous in North-Africa. *Cereal Foods World*, **31(2)**, 179-182.

Kaur, G., Sharma, S., Nagi, H. P. S., and Dar, B. N. (2012). Functional properties of pasta enriched with variable cereal brans. *Journal of Food Science and Technology-Mysore*, **49(4)**, 467-474.

Khraisheh, M. A. M., Cooper, T. J. R., and Magee, T. R. A. (1997). Microwave and air drying I. Fundamental considerations and assumptions for the simplified thermal calculations of volumetric power absorption. *Journal of Food Engineering*, **33(1-2)**, 207-219.

Kpomasse, Charlotte Fifame; Padonou, Segla Wilfrid; Ahounou, Jean Louis and Houssou, Paul. (2014). Towards the development of sweet potato-based couscous for human consumption in Benin. *African Journal of Biotechnology*, **13(43)**, 4165-4168.

Krishnan, M., and Prabhasankar, P. (2010). Studies on Pasting, Microstructure, Sensory, and Nutritional Profile of Pasta Influenced by Sprouted Finger Millet (Eleucina Coracana) and Green Banana (Musa Paradisiaca) Flours. *Journal of Texture Studies*, **41(6)**, 825-841.

Kucuk, H., Midilli, A., Kilic, A., and Dincer, I. (2014). A Review on Thin-Layer Drying-Curve Equations. *Drying Technology*, **32(7)**, 757-773.

Kulp, Karel and Ponte, Joseph G. Jr. (Ed.). (2000). *Handbook of Cereal Science and Technology, Revised and Expanded* (Second ed.): CRC Press.

Lamacchia, C., Baiano, A., Lamparelli, S., Padalino, L., La Notte, E., and Di Luccia, A. (2010). Study on the interactions between soy and semolina proteins during pasta making. *Food Research International*, **43(4)**, 1049-1056.

Lefkir, Samia; Yahiaoui, Karima; Yesli, Abdenour and Ounane, Ghania. (2017). Hydration rate influence on the couscous quality. *Journal of Food Agriculture & Environment*, **15(1)**, 5-11.

Liu, R. H. (2007). Whole grain phytochemicals and health. *Journal of Cereal Science,* **46(3)**, 207-219.

López, Jéssica, Vega-Gálvez, Antonio, Rodríguez, Angela, Uribe, Elsa, and Díaz, Pilar. (2016). Vacuum drying of Chilean murta (Ugni molinae Turcz) berries: Effect of temperature on kinetic parameters and assessment of energy consumption. *Journal of Food Processing and Preservation*, e13162: 1-8.

Maskan, M. (2000). Microwave/air and microwave finish drying of banana. *Journal of Food Engineering,* **44(2)**, 71-78.

McMinn, W. A. M. (2006). Thin-layer modelling of the convective, microwave, microwave-convective and microwave-vacuum drying of lactose powder. *Journal of Food Engineering,* **72(2)**, 113-123.

Midilli, A., Kucuk, H., and Yapar, Z. (2002). A new model for single-layer drying. *Drying Technology,* **20(7)**, 1503-1513.

Mujumdar, Arun S. (2014). *Handbook of Industrial Drying* (Fourth ed.): CRC Press.

Oliver, J. R., Blakeney, A. B., and Allen, H. M. (1993). The Color of Flour Streams as Related to Ash and Pigment Contents. *Journal of Cereal Science,* **17(2)**, 169-182.

Omolola, A. O., Jideani, A. I. O., and Kapila, P. F. (2014). Modeling microwave drying kinetics and moisture diffusivity of Mabonde banana variety. *International Journal of Agricultural and Biological Engineering,* **7(6)**, 107-113.

Onwude, D. I., Hashim, N., Janius, R. B., Nawi, N. M., and Abdan, K. (2016). Modeling the Thin-Layer Drying of Fruits and Vegetables: A Review. *Comprehensive Reviews in Food Science and Food Safety,* **15(3)**, 599-618.

Opata, D. D.; Asiedu-Larbi, J.; Ellis, W. O. and Oduro, I. (2007, 11-13 September). *Production of Couscous and French Fries from Dioscorea Alata (Water*

Yam). Paper presented at the Securing Livelihoods through Yams, Accra, Ghana.

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.

Philippsen, C. G., Vilela, A. C. F., and Dalla Zen, L. (2015). Fluidized bed modeling applied to the analysis of processes: review and state of the art. *Journal of Materials Research and Technology-Jmr&T,* **4(2)**, 208-216.

Prabhanjan, D. G., Ramaswamy, H. S., and Raghavan, G. S. V. (1995). Microwave-Assisted Convective Air-Drying of Thin-Layer Carrots. *Journal of Food Engineering,* **25(2)**, 283-293.

Rahman, M. Shafiur. (2007). *Handbook of Food Preservation* (Second ed.). Boca Raton, Florida: CRC Press.

Rahmani, N., and Muller, H. G. (1996). The fate of thiamin and riboflavin during the preparation of couscous. *Food Chemistry,* **55(1)**, 23-27.

Resio, A. N. C., Aguerre, R. J., and Suarez, C. (2004). Drying characteristics of amaranth grain. *Journal of Food Engineering,* **65(2)**, 197-203.

Sabanis, D., Makri, E., and Doxastakis, G. (2006). Effect of durum flour enrichment with chickpea flour on the characteristics of dough and lasagne. *Journal of the Science of Food and Agriculture,* **86(12)**, 1938-1944.

Schiffmann, Robert F. (2001). Microwave processes for the food industry. In Ashim K.; Datta andRamaswamy C. Anantheswaran (Eds.), *Handbook of Microwave Technology For Food Applications* (pp. 299-337). USA: Marcel Dekker, Inc.

Senadeera, W., Bhandari, B. R., Young, G., and Wijesinghe, B. (2003). Influence of shapes of selected vegetable materials on drying kinetics during fluidized bed drying. *Journal of Food Engineering,* **58(3)**, 277-283.

Sidibe, S.;Diarra, M. and Scheuring, J.F. . (1981, 28-31 October). *Sorghum Couscous: Quality Considerations.* Paper presented at the International Symposium on Sorghum Grain Quality, ICRISAT Center Patancheru, India.

Singh, N., Singh, H., and Bakshi, M. S. (1998). Determining the distribution of ash in wheat using debranning and conductivity. *Food Chemistry,* **62(2)**, 169-172.

Singh, R. Paul; , and Heldman, Dennis R. (2009). *Introduction to Food Engineering* (Fourth ed.). San Diego, California, USA: Academic Press, Elsevier Inc.

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.

Togrul, I. T., and Pehlivan, D. (2003). Modelling of drying kinetics of single apricot. *Journal of Food Engineering,* **58(1)**, 23-32.

Torki-Harchegani, M., Ghasemi-Varnamkhasti, M., Ghanbarian, D., Sadeghi, M., and Tohidi, M. (2016). Dehydration characteristics and mathematical modelling of lemon slices drying undergoing oven treatment. *Heat and Mass Transfer,* **52(2)**, 281-289.

Uribe, E., Lemus-Mondaca, R., Vega-Galvez, A., Lopez, L. A., Pereira, K., Lopez, J., Ah-Hen, K., Di Scala, K. (2013). Quality Characterization of Waste Olive Cake During Hot Air Drying: Nutritional Aspects and Antioxidant Activity. *Food and Bioprocess Technology,* **6(5)**, 1207-1217.

Uthayakumaran, S. (2010). *Wheat: characteristics and quality requirements* (C.W. and Batey Wrigley, I.L. Ed.). Cambridge: Woodhead Publishing Limited and CRC Press LLC.

Vadivambal, R., and Jayas, D. S. (2007). Changes in quality of microwave-treated agricultural products - a review. *Biosystems Engineering,* **98(1)**, 1-16.

Vega-Galvez, A., San Martin, R., Sanders, M., Miranda, M., and Lara, E. (2010). Characteristics and Mathematical Modeling of Convective Drying of Quinoa (Chenopodium Quinoa Willd.): Influence of Temperature on the Kinetic Parameters. *Journal of Food Processing and Preservation,* **34(6)**, 945-963.

Vega, A., Uribe, E., Lemus, R., and Miranda, M. (2007). Hot-air drying characteristics of Aloe vera (Aloe barbadensis Miller) and influence of temperature on kinetic parameters. *Lwt-Food Science and Technology,* **40(10)**, 1698-1707.

West, R., Seetharaman, K., and Duizer, L. M. (2013). Effect of drying profile and whole grain content on flavour and texture of pasta. *Journal of Cereal Science,* **58(1)**, 82-88.

Yıldırım, A. (2018). Kinetics and thermodynamic properties of parboiled burgos wheat (*Triticum durum*) in Turkey during drying. *Applied Ecology and Environmental Research,* **16(1),** 495-510.

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.

Yilmaz, V. A., and Koca, A. F. (2017). Effect of different production techniques on bioactive compounds and antioxidant capacity of einkorn (Triticum monococcum L.) and durum (Triticum turgidum subsp durum) bulgur. *Journal of the Science of Food and Agriculture,* **97(1)**, 269-277.

Yu, L. L., Haley, S., Perret, J., Harris, M., Wilson, J., and Qian, M. (2002). Free radical scavenging properties of wheat extracts. *Journal of Agricultural and Food Chemistry,* **50(6)**, 1619-1624.

Zenoozian, M. S., Feng, H., Razavi, S. M. A., Shahidi, F., and Pourreza, H. R. (2008). Image analysis and dynamic modeling of thin-layer drying of osmotically dehydrated pumpkin. *Journal of Food Processing and Preservation,* **32(1)**, 88-102.

Zhao, Y. H., Manthey, F. A., Chang, S. K. C., Hou, H. J., and Yuan, S. H. (2005). Quality characteristics of spaghetti as affected by green and yellow pea, lentil, and chickpea flours. *Journal of Food Science,* **70(6)**, S371-S376.

Zhishen, Jia, Mengcheng, Tang, and Jianming, Wu. (1999). The determination of flavonoid contents in mulberry and their scavenging effects on superoxide radicals. *Food Chemistry,* **64(4)**, 555-559.

Zweifel, C., Conde-Petit, B., and Escher, F. (2000). Thermal modifications of starch during high-temperature drying of pasta. *Cereal Chemistry,* **77(5)**, 645-651.

APPENDIX

A1. Results of statistical analysis of pasta like couscous

Table A.1 Color values of non-dried pasta like couscous

Couscous Samples	**Color values**			
Quantity of bulgur flour [%]	**L***	**a***	**b***	**YI**
0	67.88±0.83[a]	4.67±0.20[a]	29.81±0.00[a]	64.76±0.74[a]
25	55.37±0.01[b]	6.08±0.03[b]	22.09±0.07[b]	61.74±0.12[b]
50	50.37±0.60[c]	5.98±0.08[b]	18.69±0.40[c]	58.41±0.55[c]
75	46.19±0.81[d]	5.94±0.28[b]	17.44±0.44[d]	58.82±2.10[c]
100	41.22±0.95[e]	5.89±0.17[b]	16.33±0.17[e]	60.25±0.65[bc]

Each column followed by different superscripts is significantly different ($p \leq 0.05$).

Table A.2 Color values of packed bed dried at 60 ºC pasta like couscous

Couscous Samples	**Color values**			
Quantity of bulgur flour [%]	**L***	**a***	**b***	**YI**
0	69.34±0.74[a]	4.98±0.27[a]	29.66±0.04[a]	64.05±0.83[ab]
25	57.20±0.54[b]	6.31±0.02[b]	22.81±0.37[b]	62.06±0.96[ab]
50	51.99±0.13[c]	6.44±0.04[b]	20.37±0.06[c]	61.37±0.10[a]
75	48.37±1.95[d]	6.29±0.26[b]	19.26±0.11[d]	61.61±2.14[ab]
100	45.08±0.57[e]	6.59±0.09[b]	19.27±0.30[d]	64.81±1.34[b]

Each column followed by different superscripts is significantly different ($p \leq 0.05$).

Table A.3 Color values of packed bed dried at 80 ºC pasta like couscous

Couscous samples	Color values			
Quantity of bulgur flour [%]	L*	a*	b*	YI
0	68.64±0.54[a]	5.11±0.31[a]	29.81±0.07[a]	64.82±0.57[a]
25	56.40±0.12[b]	6.50±0.09[b]	23.05±0.18[b]	63.38±0.28[abc]
50	51.99±0.90[c]	6.26±0.04[b]	20.32±0.04[c]	61.04±0.52[c]
75	47.56±0.61[d]	6.21±0.24[b]	18.80±0.52[d]	61.14±1.94[bc]
100	45.41±1.26[e]	6.41±0.13[b]	19.29±0.15[d]	64.27±1.61[ab]

Each column followed by different superscripts is significantly different ($p \leq 0.05$).

Table A.4 Color values of microwave dried at 180 W pasta like couscous

Couscous samples	Color values			
Quantity of bulgur flour [%]	L*	a*	b*	YI
0	61.26±1.29[a]	8.18±0.99[a]	35.52±0.31[a]	81.71±2.65[a]
25	48.74±0.70[b]	7.81±0.25[ab]	23.92±0.37[b]	73.03±1.67[b]
50	45.47±0.28[c]	6.99±0.18[ab]	20.78±0.01[c]	68.43±0.59[bc]
75	40.83±0.52[d]	6.58±0.17[b]	18.69±0.41[d]	67.43±1.67[c]
100	39.17±1.05[d]	6.58±0.13[b]	18.34±0.21[d]	68.21±1.80[c]

Each column followed by different superscripts is significantly different ($p \leq 0.05$).

Table A.5 Color values of microwave dried at 360 W pasta like couscous

Couscous samples	**Color values**			
Quantity of bulgur flour [%]	**L***	**a***	**b***	**YI**
0	58.67±1.04^{a}	10.06±2.09^{a}	35.18±1.15^{a}	85.73±5.19^{a}
25	49.54±1.03^{b}	7.79±0.11^{ab}	24.04±0.40^{b}	72.52±0.01^{b}
50	46.27±0.41^{c}	6.97±0.01^{b}	20.86±0.31^{c}	67.86±0.25^{b}
75	42.67±1.77^{d}	7.01±0.28^{b}	20.00±0.10^{cd}	68.09±3.65^{b}
100	39.66±0.76^{e}	6.80±0.19^{b}	19.09±0.18^{d}	69.86±1.61^{b}

Each column followed by different superscripts is significantly different (p≤0.05).

A2. Results of statistical analysis of African couscous

Table A.6 Yields of African couscous

Couscous samples	**Drying parameters**				
Quantity of bulgur flour [%]	**Non-dried**	**60 ºC**	**80 ºC**	**180 W**	**360W**
0	52.60±2.28^{a}	54.28±3.78^{a}	51.34±0.77^{a}	48.26±1.92^{a}	48.18±0.67^{a}
25	54.81±2.44^{a}	47.70±1.73^{a}	44.84±1.18^{b}	52.56±0.96^{a}	56.60±1.19^{b}
50	50.49±1.33^{a}	52.57±7.04^{a}	46.13±1.28^{b}	51.36±3.03^{a}	49.74±2.06^{a}

Each column followed by different superscripts is significantly different (p≤0.05).

Table A.7 Color values of non-dried African couscous

Couscous samples	Color values			
Quantity of bulgur flour [%]	L*	a*	b*	YI
0	75.99±0.40^{a}	3.65±0.10^{a}	32.68±0.07^{a}	63.18±0.23^{a}
25	63.68±0.30^{b}	5.54±0.10^{b}	27.51±1.22^{b}	64.82±1.86^{a}
50	61.57±0.49^{c}	5.73±0.16^{b}	26.04±0.11^{b}	64.05±0.71^{a}

Each column followed by different superscripts is significantly different (p≤0.05).

Table A.8 Color values of packed bed dried at 60 ºC African couscous

Couscous samples	Color values			
Quantity of bulgur flour [%]	L*	a*	b*	YI
0	76.82±0.37^{a}	3.73±0.13^{a}	29.98±0.74^{a}	59.05±1.13^{a}
25	63.65±0.71^{b}	5.71±0.11^{b}	25.40±0.01^{b}	61.62±0.57^{ab}
50	58.91±2.60^{b}	6.38±0.33^{b}	25.26±0.11^{b}	65.38±2.42^{b}

Each column followed by different superscripts is significantly different (p≤0.05).

Table A.9 Color values of packed bed dried at 80 ºC African couscous

Couscous samples	Color values			
Quantity of bulgur flour [%]	L*	a*	b*	YI
0	76.73±0.62^{a}	3.59±0.23^{a}	29.44±0.07^{a}	58.19±0.42^{a}
25	61.94±1.54^{b}	6.12±0.19^{b}	25.82±0.16^{b}	63.81±1.72^{b}
50	61.14±1.27^{b}	6.12±0.08^{b}	25.67±0.25^{b}	64.21±1.36^{b}

Each column followed by different superscripts is significantly different (p≤0.05).

Table A.10 Color values of microwave dried at 180 W African couscous

Couscous samples	**Color values**			
Quantity of bulgur flour [%]	**L***	**a***	**b***	**YI**
0	71.67±0.09[a]	4.31±0.16[a]	33.68±0.35[a]	67.71±0.71[a]
25	55.78±1.87[b]	7.23±0.35[b]	27.71±0.01[b]	73.02±1.92[b]
50	56.48±2.12[b]	6.96±0.33[b]	26.96±0.13[c]	70.87±1.85[ab]

Each column followed by different superscripts is significantly different ($p \leq 0.05$).

Table A.11 Color values of microwave dried at 360 W African couscous

Couscous samples	**Color values**			
Quantity of bulgur flour [%]	**L***	**a***	**b***	**YI**
0	72.08±0.45[a]	4.01±0.25[a]	33.46±0.42[a]	66.84±1.09[a]
25	54.89±0.81[b]	7.41±0.28[b]	28.07±1.32[b]	74.55±3.21[b]
50	56.11±1.31[b]	6.81±0.06[b]	26.67±0.22[b]	70.41±0.54[ab]

Each column followed by different superscripts is significantly different ($p \leq 0.05$).

A3. Results of statistical analysis of Turkish couscous

Table A.12 Yields of Turkish couscous

Couscous samples	Drying parameters				
Quantity of bulgur flour [%]	Non-dried	60 ºC	80 ºC	180 W	360W
0	62.58±1.87[a]	58.78±0.47[a]	58.00±0.67[ab]	66.42±0.16[a]	65.37±0.16[a]
25	57.46±0.58[b]	63.52±4.72[a]	62.40±1.76[b]	59.38±4.47[ab]	63.39±7.42[a]
50	52.69±1.35[c]	55.57±5.64[a]	52.47±2.84[a]	52.24±1.78[b]	43.14±4.91[b]

Each column followed by different superscripts is significantly different ($p \leq 0.05$).

Table A.13 Color values of non-dried Turkish couscous

Couscous samples	Color values			
Quantity of bulgur flour [%]	L*	a*	b*	YI
0	75.20±0.96[a]	3.99±0.31[a]	33.57±0.21[a]	65.16±0.59[a]
25	66.59±0.78[b]	5.23±0.18[b]	28.46±0.21[b]	64.13±1.00[a]
50	63.85±0.31[c]	5.57±0.11[b]	26.52±0.14[c]	63.17±0.54[a]

Each column followed by different superscripts is significantly different ($p \leq 0.05$).

Table A.14 Color values of packed bed dried at 60 ºC Turkish couscous

Couscous samples	Color values			
Quantity of bulgur flour [%]	L*	a*	b*	YI
0	76.27±1.13[a]	4.39±0.30[a]	31.66±0.86[a]	62.38±2.10[a]
25	65.32±0.81[b]	5.69±0.08[b]	26.48±0.30[b]	62.34±1.07[a]
50	63.62±1.27[b]	5.67±0.22[b]	24.90±0.22[b]	60.75±1.43[a]

Each column followed by different superscripts is significantly different ($p \leq 0.05$).

Table A.15 Color values of packed bed dried at 80 ºC Turkish couscous

Couscous samples	**Color values**			
Quantity of bulgur flour [%]	**L***	**a***	**b***	**YI**
0	76.16±0.59[a]	4.47±0.17[a]	31.67±0.41[a]	62.54±1.07[a]
25	66.49±0.20[b]	5.41±0.00[b]	26.29±0.44[b]	60.98±0.58[a]
50	62.31±1.47[c]	5.76±0.23[b]	24.76±0.50[c]	61.44±2.06[a]

Each column followed by different superscripts is significantly different (p≤0.05).

Table A.16 Color values of microwave dried at 180 W Turkish couscous

Couscous samples	**Color values**			
Quantity of bulgur flour [%]	**L***	**a***	**b***	**YI**
0	73.46±0.27[a]	4.66±0.16[a]	33.94±0.21[a]	67.40±0.64[a]
25	63.50±0.81[b]	5.94±0.21[b]	27.87±0.30[b]	66.08±1.28[a]
50	60.37±0.08[c]	6.17±0.11[b]	25.85±0.32[c]	65.12±0.64[a]

Each column followed by different superscripts is significantly different (p≤0.05).

Table A.17 Color values of microwave dried at 360 W Turkish couscous

Couscous samples	**Color values**			
Quantity of bulgur flour [%]	**L***	**a***	**b***	**YI**
0	73.10±0.75[a]	4.41±0.13[a]	34.45±0.46[a]	68.03±1.19[a]
25	64.41±0.57[b]	5.79±0.00[b]	28.57±0.28[b]	66.40±0.82[a]
50	60.17±1.92[c]	6.26±0.31[b]	26.47±0.30[c]	66.43±1.23[a]

Each column followed by different superscripts is significantly different (p≤0.05).

A.4 Sensory Analysis Form

Table A.18 Sensory analysis form

You will receive eight couscous samples. Taste each sample and write sample number on the score bar above the score you want to give. Before tasting each sample, rinse your mouth with water.

CHEWINESS (Çiğnenebilirlik)

1	2	3	4	5	6	7	8	9	10
Dislike								Like	

HARDNESS (Sertlik)

1	2	3	4	5	6	7	8	9	10
Dislike								Like	

ODOR (Koku)

1	2	3	4	5	6	7	8	9	10
Dislike								Like	

TASTE (Tat)

1	2	3	4	5	6	7	8	9	10
Dislike								Like	

COLOR (renk)

1	2	3	4	5	6	7	8	9	10
Dislike								Like	

OVERALL ACCEPTABILITY (Kabul edilebilirlik)

1	2	3	4	5	6	7	8	9	10
Dislike								Like	

CURRICULUM VITAE

AYŞE NUR YÜKSEL

(formerly TONAY)

EDUCATION

Gaziantep University Gaziantep/TURKEY

Ph.D., Faculty of Engineering Department of Food Engineering 2013-2018

- Dissertation: *Usage of Undersize Bulgur in Couscous and Pasta Production*
- GPA: 3.93/4.00

Ege University Izmir/TURKEY

M.Sc., Faculty of Engineering Department of Food Engineering 2010-2012

- Thesis: *Influence of rotational speed in colloid mill during production of multiple emulsions and the determination of their encapsulation efficiency*
- GPA: 86.10/100

Ege University Izmir/TURKEY

B.Sc., Faculty of Engineering Department of Food Engineering 2006-2010

- GPA: 3.34/4.00

PROFESSIONAL EXPERIENCE

Gaziantep University Gaziantep/TURKEY

Research Assistant 2012-Present

Karlsruhe Institute of Technology (KIT) Karlsruhe/GERMANY

Visiting Researcher 2011-2012

ADDITIONAL EXPERIENCE

Tukaş Gıda Sanayi ve Ticaret A.Ş. Izmir/TURKEY

Intern June 2009-July 2009

SKILLS

Language: English (Full professional proficiency)**,** Turkish (Native)**,** German (Beginner)

Computer: Microsoft Office Word, Excel, Powerpoint, Visio, SPSS Statistics, SigmaPlot, OriginLab, Matlab-Mathworks

Interest: Reading books, Turkish Classical Music

PUBLICATIONS

- **Yüksel, Ayşe Nur**, Öner, M.D., Bayram, M. 2017. Usage of Undersize Bulgur Flour in Production of Short-Cut Pasta Like Couscous, *Journal of Cereal Science, 77*: 102-109. http://dx.doi.org/10.1016/j.jcs.2017.08.001

- **Yüksel, Ayşe Nur**, Öner, M.D., Bayram, M. 2017. Development and Characterization of Couscous-like Product Using Bulgur By-product, *Journal of Food Science and Technology, 54(13)*: 4452-4463. https://doi.org/10.1007/s13197-017-2926-8

- Schuch, Anna; **Tonay, Ayse Nur**; Köhler, Karsten and Schuchmann, Heike P. 2014. Influence of the second emulsification step during production of W/O/W multiple emulsions: Comparison of different methods to determine encapsulation efficiency in W/O/W emulsions. *The Canadian Journal of Chemical Engineering, 92(2)*: 203-209.