# EFFECT OF DIFFERENT FLOURS ON QUALITY OF GLUTEN-FREE WAFER SHEETS

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

SELEN MERT

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
FOOD ENGINEERING

AUGUST 2014

Approval of the thesis:

**EFFECT OF DIFFERENT FLOURS ON QUALITY OF GLUTEN-FREE WAFER SHEETS**

submitted by **SELEN MERT** in partial fulfillment of the requirements for the degree of **Master of Science in Food Engineering Department, Middle East Technical University** by,

Prof. Dr. Canan Özgen
Dean, Graduate School of **Natural and Applied Sciences** _______________

Prof. Dr. Alev Bayındırlı
Head of Department, **Food Engineering** _______________

Prof. Dr. Serpil Şahin
Supervisor, **Food Engineering Dept., METU** _______________

Prof. Dr. Gülüm Şumnu
Co-Supervisor, **Food Engineering Dept., METU** _______________

**Examining Committee Members:**

Asst. Prof. Dr. İlkay Şensoy
Food Engineering Dept., METU _______________

Prof.Dr. Serpil Şahin
Food Engineering Dept., METU _______________

Prof. Dr. Gülüm Şumnu
Food Engineering Dept., METU _______________

Asst. Prof. Dr. Mecit Öztop
Food Engineering Dept., METU _______________

Asst. Prof. Dr. Elif Turabi Yolaçaner
Food Engineering Dept., Hacettepe University _______________

**Date:** 08.08.2014

**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.**

Name, Last name: Selen MERT

Signature:

## ABSTRACT

### EFFECT OF DIFFERENT FLOURS ON QUALITY OF GLUTEN-FREE WAFER SHEET

Mert, Selen
M.S., Department of Food Engineering
Supervisor: Prof. Dr. Serpil Şahin
Co-Supervisor: Prof. Dr. Gülüm Şumnu
August 2014, 85 pages

Lifelong gluten-free diet is essential for patients having celiac disease. Since wheat flour contains gluten, it is necessary to replace wheat flour with other types of gluten-free flours. Rice flour is commonly used in gluten-free baked products as an alternative to wheat flour. The main objective of this study was to develop gluten-free wafer sheet formulations by replacing rice flour partially with different gluten-free flours at different ratios. Rice-corn flour blends, rice-buckwheat flour blends and rice-chestnut flour blends with different ratios (80:20, 60:40, 40:60) were used in the experiments in order to find the higher quality and more nutritional gluten-free wafer sheet formulations. As a control, wafer sheet samples containing only rice flour and only wheat flour were used. Rheological properties of batters and color and texture of wafer sheets were determined. In the rheological analyses, it was observed that Power law model was suitable to explain the flow behavior of all samples. Among these samples buckwheat flour containing sample (60:40 RF:BF) had the closest value of consistency and flow behavior index to wheat flour containing sample. In texture analyses, samples containing only rice flour and all the samples with corn flours had harder texture compared to the other samples. In the color analyses of wafer sheets, the effects of natural color of the flours were clearly observed. According to quality, the best formulation for gluten-free wafer sheets was obtained by flour blend containing rice and buckwheat flour at a ratio of 60:40.

Keywords: Buckwheat flour, Chestnut flour, Corn flour, Gluten-free, Rice flour, Wafer sheet.

# ÖZ

## FARKLI UN ÇEŞİTLERİNİN GLÜTENSİZ GOFRET YAPRAĞI KALİTESİNE ETKİSİ

Mert, Selen
Yüksek Lisans, Gıda Mühendisliği Bölümü
Tez Yöneticisi: Prof. Dr. Serpil Şahin
Ortak Tez Yöneticisi: Prof. Dr. Gülüm Şumnu
Ağustos 2014, 85 sayfa

Çölyak hastalarının hayat boyu glütensiz bir beslenme diyeti uygulamaları gerekmektedir. Buğday unu glüten içerdiğinden dolayı farklı tür glütensiz unlarla yer değiştirmelidir. Buğday ununa alternatif olarak pirinç unu glütensiz ürünlerde yaygın olarak kullanılmaktadır. Bu çalışmanın ana amacı sadece pirinç unu yerine pirinç unu ile birlikte farklı oranlarda, farklı glütensiz un çeşitleri kullanarak glütensiz gofret yaprağı formülasyonları geliştirmektir. Pirinç-mısır unu, pirinç-karabuğday unu, pirinç-kestane unu karışımları farklı oranlarda karıştırılarak (80:20, 60:40, 40:60) daha yüksek kalitede ve besin değeri yüksek glütensiz gofret yaprağı formülasyonları oluşturmak için kullanılmıştır. Kontrol olarak sadece pirinç unu ve sadece buğday unu ile oluşturulmuş glütensiz gofret yaprakları kullanılmıştır. Gofret hamurunun reolojik özellikleri ve gofret yapraklarının rengi, yapısı ve duyusal özelikleri incelenmiştir. Reolojik analizlerde tüm örneklerin Power yasasına uyduğu bulunmuştur. Tüm örnekler arasında 60:40 oranında pirinç unu:karabuğday unu içeren örneğin tutarlılık göstergesi ve akış davranışı göstergesi değerleri bakımından buğday unu içeren örneğe en yakın olduğu gözlemlenmiştir. Tekstür analizlerine göre, diğer örnekler ile karşılaştırıldığında sadece pirinç unu içeren örnek ve pirinç-mısır unu karışımı örneklerin daha sert bir yapıya sahip oldukları bulunmuştur. Renk analizinde ise unların doğal renklerinin etkileri açıkça görülmüştür. Kalite açısından

60:40 oranında pirinç ve karabuğday unu karışımının glütensiz gofret yaprağı için en iyi formülasyon olduğu bulunmuştur.

Anahtar Kelimeler: Gofret yaprağı, Glütensiz, Kestane unu, Karabuğday unu, Mısır unu, Pirinç unu.

*To My Beloved Family*

## ACKNOWLEDGEMENT

I would like to thank my advisor Prof. Dr. Serpil Şahin for her continuous support, guidance, and encouragement throughout this study. She always tried to help me and it would be very hard to complete the research without her support and knowledge. Also, I am grateful to my co-advisor Prof. Dr. Gülüm Şumnu for her valuable advices throughout this study.

I would like to express my gratitude also to Assist. Prof. Mecit Öztop for his support and knowledge. I would like to thank members of my thesis committee, Prof. Dr. Gülüm Şumnu, Assist. Prof. İlkay Şensoy, Assist. Prof. Mecit Öztop, and Assist. Prof. Elif Turabi Yolaçaner for valuable comments.

I would also like to thank ETİ for its laboratory support during my experiments and their flexibility throughout the research.

I would like to extend my thanks to research assistants at our department, Hande Baltacıoğlu, Hazal Turasan, Sevil Çıkrıkçı, Bade Tonyalı, Oğuz Kaan Öztürk, Ayça Aydoğdu, and Emrah Kırtıl for their help and friendships.

My grateful thanks are extended to my best friends Sinem Nenni, Gizem Erkan, Sema Aydın, Şeyda Hastaoğlu, Mehmet Ali Çömlek and Hülya Duyan for their love, encouragement and patience in my stressful days. Also, I would like to special thanks to İrem Akıncı for her friendship, and support.

I would like to express my sincere thanks to Derya Uğurlar, one of my best friends, for her continuous support, encouragement, motivation, and warm friendship in my stressful days. I feel myself very lucky to have a friend like her. It would be hard for me to complete this study without her support.

Finally, my deepest gratitude goes to my family, my mother Sema Mert, my father Ahmet Yaşar Mert and my brother Volkan Mert for their endless love, support, encouragement and patience. Any word can exactly express my love and appreciation to them. I dedicate this work to my beloved family.

## TABLE OF CONTENTS

ABSTRACT ........................................................................................ v
ÖZ........................................................................................................ vii
ACKNOWLEDGEMENT ................................................................... xi
TABLE OF CONTENTS.................................................................xiii
LIST OF TABLES ...........................................................................xv
LIST OF FIGURES.........................................................................xvii
LIST OF ABBREVIATIONS ...........................................................xix
CHAPTERS
1. INTRODUCTION ............................................................................ 1
1.1 Celiac Disease ................................................................................ 1
1.2 Flour Types...................................................................................... 4
1.2.1 Wheat Flour ................................................................................ 4
1.2.2 Gluten-free Flour Types ............................................................ 5
1.2.2.1 Rice Flour ................................................................................ 5
1.2.2.2 Corn Flour ................................................................................ 6
1.2.2.3 Buckwheat Flour ...................................................................... 7
1.2.2.4 Chestnut Flour ......................................................................... 8
1.3 Gluten-free Product Development.................................................. 9
1.4 Wafer ............................................................................................. 12
1.4.1 Wafer Sheet Quality Parameters ............................................ 13
1.4.2 Ingredients Used in Wafer Sheet Production .......................... 13
1.4.2.1 Flour.........................................................................................15
1.4.2.2 Water........................................................................................15
1.4.2.3 Salt...........................................................................................16
1.4.2.4 Leavening Agent......................................................................16
1.4.2.5 Oil and Emulsifier....................................................................16
1.5 Objective of the Study ................................................................... 16
2. MATERIALS AND METHOD ....................................................... 19
2.1 Materials ......................................................................................... 19

2.2 Methods....19
2.2.1 Batter Preparation....19
2.2.2 Baking.... 20
2.2.3 Rheological Analyses of Wafer Sheet Batter.... 21
2.2.4 Analyses of Wafer Sheet.... 21
2.2.4.1 Weight loss....21
2.2.4.2 Color....21
2.2.4.3 Texture Profile Analysis....22
2.2.4.4 Sensory Analysis....22
2.2.5 Statistical Analysis.... 23
3. RESULTS AND DISCUSSION.... 25
3.1 Effects of Different Flour Types on Rheological Properties of Wafer Batters....25
3.2 Effects of Different Flour Types on Weight Loss of Wafer Sheets.... 30
3.3 Effects of Different Flour Types on Texture Properties of Wafer Sheets. 31
3.3.1 Hardness.... 31
3.3.2 Fracturability.... 33
3.4 Effects of Different Flour Types on Color of Wafer Sheets.... 34
3.4.1 L* Parameter.... 34
3.4.2 a* Parameter.... 35
3.4.3 b* Parameter.... 38
3.4.4 Total Color Difference (ΔE*).... 39
3.5 Effects of Different Flour Types on Sensory Analysis of Wafer Sheets.40
3.5.1 Color.... 41
3.5.2 Texture.... 41
3.5.3 Taste.... 42
4. CONCLUSION AND RECOMMENDATIONS.... 45
REFERENCES.... 47
APPENDICES
A. ANOVA & DUNCAN TEST TABLES.... 55
B. PICTURE OF BAKING MACHINE....85

# LIST OF TABLES

**TABLES**

**Table 1.1** Ingredients affecting in wafer sheet quality....................................14

**Table 3.1** Amount of water used in the preparation of wafer sheets ............26

**Table 3.2** Power law constants of the wafer batter samples at 22°C..............27

**Table A.1** ANOVA and Duncan Single Range Test for water loss of wafer sheets containing different types of flours in different combinations.................................................................................. 55

**Table A.2** ANOVA and Duncan Single Range Test for hardness of wafer sheets containing different types of flours in different combinations ...................................................................................57

**Table A.3** ANOVA and Duncan Single Range Test for fracturability of wafer sheets containing different types of flours in different combinations ...................................................................................59

**Table A.4** ANOVA for L* values of wafer sheets containing different types of flours in different combinations .............................................61

**Table A.5** ANOVA and Duncan Single Range Test for L* values of wafer sheets containing different types of flours in different combinations ...................................................................................62

**Table A.6** ANOVA for a* values of wafer sheets containing different types of flours in different combinations...................................................64

**Table A.7** ANOVA and Duncan Single Range Test for a* values of wafer sheets containing different types of flours in different combinations....................................................................................66

**Table A.8** ANOVA and Duncan Single Range Test for a* values of wafer sheets containing different types of flours in different combinations ...................................................................................68

**Table A.9** ANOVA for b* values of wafer sheets containing different types of flours in different combinations....................................................70

**Table A.10** ANOVA and Duncan Single Range Test for b* values of wafer sheets containing different types of flours in different combinations..................................................................................72

**Table A.11** ANOVA for total color difference values of wafer sheets containing different types of flours in different combinations ....74

**Table A.12** ANOVA and Duncan Single Range Test for total color difference values of wafer sheets containing different types of flours in different combinations................................................................. 76

**Table A.13** ANOVA and Duncan Single Range Test for color acceptability values of wafer sheets containing different types of flours in different combinations..................................................................78

**Table A.14** ANOVA and Duncan Single Range Test for texture acceptability values of wafer sheets containing different types of flours in different combinations ..................................................................80

**Table A.15** ANOVA and Duncan Single Range Test for taste acceptability values of wafer sheets containing different types of flours in different combinations..................................................................82

## LIST OF FIGURES

**FIGURES**

**Figure 3.1** Flow curves for wafer batter samples containing RF and BF at different ratios and control flours ........................................................ 28

**Figure 3.2** Flow curves for wafer batter samples containing RF and ChF in combination and control flours..........................................................28

**Figure 3.3** Flow curves for wafer batter samples containing different RF and CF different ratios and control flours ................................................ 29

**Figure 3.4** Weight loss of wafer sheets prepared by replacement of rice flour by different flour types at different ratios.……………………………………31

**Figure 3.5** Hardness of wafer sheets prepared using different flour types in different ratios and combinations..…..………………………………………32

**Figure 3.6** Fracturability of wafer sheets prepared using different flour types in different ratios and combinations.…………………………..…..……………34

**Figure 3.7** L* values of wafer sheets (at both upper and lower surfaces) containing different flour types in different ratios and combinations..………...............................................................……………35

**Figure 3.8** a* values of upper wafer sheets containing different flour types in different ratios and combinations………………….………..…………….……37

**Figure 3.9** a* values of lower wafer sheets containing different flour types in different ratios and combinations……….……………………….……….……38

**Figure 3.10** b* values of wafer sheets at both upper and lower surfaces containing different flour types in different ratios and combinations.………39

**Figure 3.11** ΔE* values of wafer sheets at both lower and upper surface containing different flour types in different ratios and combinations.............40

**Figure 3.12** Color acceptability scores of wafer sheets containing different flour types at different ratios and combinations ............................................ 41

**Figure 3.13** Texture acceptability scores of wafer sheets containing different flour types in different ratios and combinations ............................................ 42

**Figure 3.14** Taste acceptability scores of wafer sheets containing different flour types in different ratios and combinations…...............................……..43
**Figure B.1** Baking machine………………………………………...…….85

## LIST OF ABBREVIATIONS

| | |
|---|---|
| BF | Buckwheat flour |
| CF | Corn flour |
| ChF | Chestnut flour |
| RF | Rice flour |
| WF | Wheat flour |

# CHAPTER 1

# INTRODUCTION

## 1.1 Celiac Disease

Celiac disease, a disease caused by an immune disorder which is also known as gluten sensitive enteropathy, occurs in people who have a genetic problem with gluten when they eat it (Cureton and Fasano, 2009). Increasing numbers of scientists in the medical field acknowledge the existence of this autoimmune enteropathy that is the result of permanent gluten intolerance. As a matter of fact, this disease can affect various systems and is caused by the immune system responding to gluten when it is eaten by people who are genetically prone to this disease (Niewinski, 2008).

In countries with relatively healthy people, normally 0.3-1% of the population has celiac disease (Bai et al., 2007). In U.S., almost 1% of the population (1 out of 133 people) has celiac disease. Regrettably, only 17% of these 3 million Americans who are affected by this disease have been properly diagnosed. Celiac disease is transferred through DNA from parents to their children, making it a genetic disorder.  The symptoms of the disease are sometimes set off by intense emotional distress, surgery, pregnancy, infection, or other highly stressful situations (http://www.celiaccentral.org/Celiac-Disease/21/. Last visited: July, 2014).

The catalyst of celiac disease is the immune system's response to a protein present in some grains (especially in wheat, rye, and barley) known as gluten. If an individual has this disease and eats foods containing gluten, that person's immune system will react violently to it by destroying some of the small intestine's lining, particularly the villi, which are extremely small protrusions that resemble fingers. Because these protrusions are essential for absorbing nutrients to pass into the bloodstream, their loss ensures that the body will not absorb the nutrients it needs, no matter how much the person eats (http://www.cdd.com.au/pages/disease_info/coeliac_disease.html.Last visited: July, 2014). The only known cure for celiac disease is the complete lifelong gluten-free diet (Mendoza, 2005).

Of the permanent disorders, celiac disease is among the most frequently seen in the world. This disease can cause many medical problems and symptoms that were previously unrealized by medical professionals that can damage any part of the body, such as the common malabsorption syndrome (including loss of weight, chronic diarrhea, and abdominal distention). Because a large number of people with this disease are not correctly diagnosed due to the fact that celiac disease behaves differently from most other diseases, this disease may remain unchecked and cause other long-term illnesses, for example cancer, infertility or osteoporosis. There is a growing interest in the social dimension of celiac disease, since the burden of illness related to this condition is doubtless higher than previously thought. As a result of the increasing awareness of symptoms and complications caused by celiac disease, the level of interest in the social implications of this disease is increasing. Many times the effects of celiac disease can be detected in affected young children; however, the disease can wait to show itself until any age, even in elderly people (Catassi and Fasano, 2008).

Because celiac disease can manifest itself in many different kinds of health problems, it can be challenging to diagnose it correctly. A diagnosis can be obtained through an antibody blood test which can be run in conjunction with a genetic test. When results from these tests indicate celiac disease, usually an intestinal biopsy is done to confirm the results (http://www.celiaccentral.org/Celiac-Disease/21/. Last visited: July, 2014).

Celiac disease manifests itself in different ways in different people. Symptoms can not only be seen in the digestive organs but also in other organs. In the case of babies and young children, digestive symptoms such as the followings are more prevalent:

- abdominal bloating and pain
- chronic diarrhea
- vomiting
- constipation
- pale, foul-smelling, or fatty stool
- weight loss

Also, children with this disease are often irritable. For a child, being able to absorb necessary nutrients is essential for healthy growth and development. Malnutrition can cause multiple health problems including sickly babies, defective enamel on adult teeth, slow and stunted growth, and delayed puberty.

In the case of adults, who tend to have fewer digestive symptoms, the following symptoms are common:

- unusually low iron levels
- extreme tiredness
- pain in joints or bones
- osteoporosis or loss of bone
- arthritis
- seizures
- unusual prickling sensations in feet and hands
- anxiety or depression
- missed menstrual periods
- successive miscarriages or inability to conceive
- open sores in mouth
- dermatitis herpetiformis, a rash that causes itching

Although individuals having celiac disease may not show immediate signs of it, serious problems can develop with time such as disease of the liver, intestinal cancer, and effects of malnutrition resulting in a variety of problems such as osteoporosis, anemia, and miscarriage (http://digestive.niddk.nih.gov/ddiseases/pubs/celiac/ Last visited: July, 2014).

## 1.2 Flour Types

### 1.2.1 Wheat Flour

Approximately 10,000 years ago, when people started farming, people in the Middle East began eating cereal grains (including wheat) in large quantities (Figoni, 2008). Wheat is primarily important because people can grind wheat kernels into flour, semolina, and other products. Since these wheat products are used as the main ingredients of pasta and baked goods such as bread, wheat provides most of the humans on the planet with most of their nutrients (Šramková et al., 2009).

Varying with the kind of flour, with 68-76% (w/w) starch, 11-14% (w/w) moisture, 6-18% (w/w) protein, 2-3% (w/w) gums, 1-1.5% (w/w) lipids and about 0.5% (w/w) ash, wheat flour is a good source of complex carbohydrates. Flour's ability to give structure is mostly due to the presence of starch and gluten. When flour and water are combined, glutenin and gliadin, proteins present in flour, create gluten. Although they have a minor role in creating structure when compared with starch and gluten, pentosan gums are also important. It seems that gums help with structure by either working together with gluten or making their own structure (Figoni, 2008).

According to the texture of the wheat kernel, wheat flour may be considered soft or hard. Soft wheat kernels disintegrate more easily than hard kernels, which need more pressure. Soft wheat flour is less coarse than hard wheat flour. The wheat species *T. aestivum* produces hard wheat kernels used mostly in making bread if it contains the right amount of protein, which is 11-13%. If the protein level in the flour from this species is low (7-9%), the flour is softer and better for cakes and biscuits. Pancakes, crackers, waffles, wafers, and cookies are also produced using soft wheat flour. These foods look and taste better when they are produced with soft wheat flour instead of hard.

Although usually foods made with soft wheat flour are less dense than foods made with hard wheat flour, the foods made with soft wheat are softer and more tender when eaten, have better internal uniformity, and have better height and spread properties. These characteristics are likely due to the result of the low protein levels, low amount of water absorption, and the degree of fineness in soft wheat flour (Hoseney et al., 1988).

### 1.2.2 Gluten-free Flour Types

To maintain a healthy diet, individuals with celiac disease must receive nutrients from different flours. For this purpose, flours such as rice, corn, chestnut, chickpea, soy, soybean and sorghum flour and pseudocereals such as buckwheat and amaranth are used as alternatives**.**

#### 1.2.2.1 Rice Flour

Rice (a cereal grain which comes from the species *Oryza sativa*) is the second most important food in the world, the most important one being wheat. Rice has low protein level, high starch level, and no gluten-forming proteins. People usually eat rice as whole grains, but sometimes people rub off the outer part containing many important nutrients and grind it into flour or grits. They are very clean and white, and since they are low in oil have good storage properties (Manley, 2000).

People are starting to use rice flour more often for baked goods because it is a good substitute for wheat for those who cannot consume wheat. Both rice and corn are accepted as gluten-free cereal grains; however, rice is the more appropriate substitute in gluten-free products because it is white, bland, easily digestible, and hypoallergenic (Rosell and Collar, 2007). Rice has other properties that make it a top choice for gluten intolerant people including its easily digestible carbohydrates and its low level of sodium, protein and prolamins (Arendt et al., 2009).

Rice flour tastes quite bland. When used in place of wheat flour in biscuits, rice flour does not allow for as much rising of the dough and makes the final product softer. However, besides being used in Japanese rice crackers; rice flour is usually not used for making biscuits. Sometimes people use rice flour to make wafer batter thicker (Manley, 2000).

Even though there are many good properties that make rice flour suitable for usage, the proteins in rice are not as suitable for food processing as compared to proteins from other plants. Because rice proteins are hydrophobic, they do not dissolve easily in water. They cannot give dough the elasticity it needs to retain the carbon dioxide produced during proofing of yeast-leavened bread-like products. Because rice flour has only a small amount of prolamins, these cannot form a protein network like flour normally does when kneaded with water. That is why the rice dough cannot keep the carbon dioxide from escaping during proofing of the dough and the final product has lower specific volume and harder and more dense than regular wheat bread (Rosell and Collar, 2007).

Numerous products around the world such as cereals, breads, cakes, noodles and crackers, are made using rice flour, sometimes blending rice flour with chestnut, buckwheat, or other types of flours (Yeh, 2004).

#### 1.2.2.2 Corn Flour

Cultivated around the world, corn (maize) production is about 8 million tons a year. The biggest producers of corn include Indonesia, France, India, Argentina, Brazil, China and the United States. Many different varieties of corn are cultivated, including flint corn, flour corn, dent corn, popcorn, amylomaize, waxy corn and sweet corn. Corn kernels may be purple, red, or yellow. The kernels contain 82-93% endosperm, 10-11% germ, 5-6% pericarp and 0.8-1.0% tip cap (Singh et al., 2011).

Enwere (1998) states that corn has the highest percentage of oil among cereal grains except millet. Corn has also a high sulphur, sodium, chlorine, potassium, calorie and carbohydrate content. Although corn's protein has a low tryptophan and lysine content, it has a good amount of sulfur which means it has such amino acids as cysteine and methionine (Adebayo and Emmanuel, 2001).

Corn flour composed of the endosperm portion of the kernel and usually has a starch content of 75-87% and a protein content of 6-8% (Shukla and Cheryan, 2001).

#### 1.2.2.3 Buckwheat Flour

Grown in large quantities in North America, buckwheat is among the major crops from East Asia, and products made from it, including buckwheat bread, noodles, and pancakes, are widely consumed in Asia, Canada, the United States and Central Europe. Because of its nutritional value, it is used to make healthy foods and, buckwheat has been brought to the awareness of many countries (Takahama et al., 2011).

Because proteins that form gluten are not present in buckwheat (Francischi et al., 1994; Kreft and Kreft, 2000), Carroll and Hamilton (1975) have proposed that buckwheat can be used for treating people with celiac disease. Therefore, gluten-free foods can be made from buckwheat (Arendt et al., 2009).

The starch content of buckwheat flour, which varies according to the flour type, is 70-91% (w/w). Amylose makes up 25% of the starch, while amylopectin makes up the remaining 75%. When the buckwheat seeds and flour are baked or boiled, part of the starch turns resistant to hydrolysis. Because of this, buckwheat products may also be used for people with diabetes. In addition, the protein level of buckwheat flour is 10-20% (w/w). The protein found in buckwheat is rich in essential amino acids because it contains globulin, prolamin, glutelin, and albumin (Takahama et al., 2011).

Buckwheat flour also contains a generous amount of sodium, iron, calcium, magnesium and potassium, as well as a good amount of manganese, copper, and zinc. Compared to wheat flour, it contains twice as much lithium, manganese, sodium, magnesium, potassium, iron, copper and strontium, and about the same amount of the elements chromium, cobalt and lead. Overall, buckwheat contains more minerals than does wheat flour (Wei et al., 1995).

According to Steadman et al., (2001) there are many essential fatty acids and amino acids contained in buckwheat and Watanabe (1998) reports that it also contains vitamins B1 and B2. In addition, the anti-inflammatory flavanoid rutin, which produces hypotensive effects and strengthens blood vessels suffering from cerebral hemorrhage or other coronary diseases, is also present in buckwheat. According to a study by Tomotake et al., (2000) hamsters that ingested buckwheat protein experienced a decrease in cholesterol in their gallbladders, livers, and serum and a decrease in gallstones due to the different way cholesterol is metabolized. Another study by He et al., (1995), showed that buckwheat has a similar effect on humans produced by the presence of soluble fiber.

#### 1.2.2.4 Chestnut Flour

The chestnut, a member of the *Fagaceae* family, ripens in fall and winter and is usually eaten roasted or boiled. For extending its shelf life and consumption, starch and flour that are made from chestnuts can be used. These products are high in essential fatty acids and can be used in the production of gluten-free food for people with celiac disease. Chestnut flour can be used in a variety of baked goods as a partial substitute for corn, rice or wheat flour (Moreira et al., 2010a).

Normally chestnut flour is ground from lower quality and smaller chestnuts (Moreira et al., 2010b). The most common uses for chestnut flour is in making creams, purees, flakes, pasta, cakes, snacks and biscuits (Sacchetti et al., 2004). The chestnut flour has an average composition of 63.5±13.8% of starch, 22.9±9.2% of sugars, 6.2±0.7% of protein, 3.8±1.6% of fiber and 3.6±1.7% of fat (Demiate et al., 2001; Sacchetti et al., 2004).

Chestnut flour is also rich in essential amino acids and sucrose. However, dough made from chestnut flour is low in protein and does not have protein that can make elastic dough like gluten does (Borges et al., 2007). To help with the elasticity and produce a more desired form, there are some oils and hydrocolloids that can be added to the dough (Moreira et al., 2011). Adding these substances solves the problem of maintaining a gluten-free product without compromising its consistency and quality (Bárcenas and Rosell, 2006).

The amount of nutrition in foods could be increased by using chestnut flour in place of cereal flours. Even though using chestnut flour may result in less protein, the proteins have unique nutritional value such as the high percentage of albumin present in globulins, which are the primary storage proteins (approximately 20%). In addition, there is good amount of B group vitamins and vitamin E as well as a significant amount of dietary fiber present in chestnut flour (Sacchetti et al., 2004). Chestnut flour not only improves the nutritional value and healthiness of products, but also adds some different value to the dough. For example, the thickening, stabilizing, texturing, and emulsifying of the dough can be aided by the rich fiber content, and the flavor and color of the food can be changed by the sugar present in the chestnut flour (Demirkesen, 2013).

### 1.3 Gluten-free Product Development

Because celiac disease is a lifelong condition that makes the body sensitive to rye, wheat and barley due to amino acids found in the prolamin fraction of the grains; in order to remain healthy, affected individuals must strictly follow a gluten-free diet, which means they cannot eat the proteins from the offending grains. People on the gluten-free diet must be careful about what grains they eat. Because they cannot eat anything with rye, wheat or barley in it, they must eat only products produced with grains which are gluten-free such as corn, rice, millet, sorghum, amaranth, quinoa, chestnut and buckwheat. The majority of breads, baked goods and pasta products are made from wheat, and a large percentage of breakfast cereals are made from grains containing gluten. Therefore, substitutes without gluten must be consumed by individuals who have celiac disease (Thompson, 2009).

The definition of gluten-free food, according to the codex standard is a food that does not contain any kind of barley, oats, wheat (including all members of the *Triticum* species, for example, kamut, spelt and durum wheat) or rye or any of their cross breed varieties even if these have gone through a gluten-removing process. Also, the gluten level in the product must be 20 mg/kg or less (Codex Standard 118, 1979).

In recent years, gluten-free foods, especially breads, cakes and biscuits have been commonly investigated by many researchers. Numerous studies have been conducted especially on gluten-free bread.

Gallagher et al. (2003) were investigated the properties of crumbs and crusts of gluten-free breads by using seven dairy powders. They found that powders with high protein content result in breads with a lower volume but with an increased crumb and crust hardness.

Examinations of the results of combining hydrocolloids with dough in the absence of gluten, especially in bread quality and dough rheology, were carried out by Lazaridou et al. (2007). According to their oscillatory and creep measurements, the elasticity and resistance to deformation of gluten-free dough formulations improved with hydrocolloids xanthan, CMC, pectin, agarose and β-glucan in decreasing order.

Marco and Rosell (2008) studied gluten-free bread quality by adding structuring agents, such as HPMC. They found that the use of HPMC improved the volume of the bread which was closer to the wheat bread structure when the soybean flour was used.

The rheological properties of gluten-free bread dough were examined by Demirkesen et al. (2010a). Their measurements showed that in order to get the desired physical properties in dough formulation, addition of emulsifiers and gums were necessary. In another study of Demirkesen et al. (2013), the effects of different tigernut flour/rice flour ratios on quality of gluten-free bread formulations baked in infrared-microwave combination and conventional ovens were investigated. They found that both tigernut/rice flour ratio and oven type were significant factors in the quality parameters of gluten-free breads.

Sensory, textural, and rheological characteristics of bread made from rice and buckwheat flour were investigated by Torbica et al. (2010). According to this study, gluten-free bread containing rice and buckwheat flour did not require the addition of the hydrocolloids such as xanthan, guar gum and HPMC for the development of dough structure.

There are also studies about other types of gluten-free products in addition to bread. Rice cakes prepared with different kinds of gums and baked in different ovens were examined by Turabi et al. (2010) to analyze their macro and micro-structures quantitatively. They found that the usage of xanthan and xanthan–guar gum blend resulted in more porous cakes. In addition to this, compared to the cakes baked in infrared-microwave combination oven, there were more deformed starches in conventionally baked ones. In the other study of Turabi et al. (2008) rheological properties of rice cake batter and quality characteristics of rice cakes prepared using different gums with or without an emulsifier blend were investigated. They found that all gums except HPMC increased the emulsion stability of cake batter. In addition to this, the highest volume and porosity were obtained in cakes containing xanthan and emulsifier blend. The effect of xanthan gum on the quality of cakes containing no gluten was studied by Preichardt et al. (2011). According to their results xanthan gum improved the quality of gluten-free cakes by making them softer and retarding their staling.

Schober et al. (2003) evaluated the effects of fat powders and combinations of gluten-free flour on quality of biscuits. They found that rice-corn-potato-soya flour blend in ratio of 70:10:10:10 was most similar to wheat flour in terms of water activity, moisture, texture, diameter, thickness and color for biscuits and hardness and stickiness for biscuit dough. In addition to this flour blend also showed the best overall acceptability in sensory testing.

### 1.4 Wafer

A particular type of thin, crispy biscuit known as wafer is made by spreading flavored cream between wafer sheets. Some of the ingredients of these wafer sheets are water, flour, and small amounts of oil, salt, and sugar, which are combined to make a liquid batter (TSE, 1989).

It is thought that wafers were invented by monks who were accustomed to using iron plates which usually bore religious symbols or the symbol of their order to cook their holy bread. The dough was placed between these plates, producing thin disc-like bread. The people of Holland are accredited with creating the modern wafer in the mid-19$^{th}$ century. They used special hinged tongs to make the wafers. Following World War I, wafer ovens were constructed. However, mass manufacturing of wafers did not begin until the 1950's.

Special equipment is necessary to make this unique kind of biscuit called wafer. The heated metal plates used in baking wafers resemble book leaves with hinges at one side and often have patterns engraved in them. The wafer sheets baked between them are usually thin and bear the patterns of the plates. The wafers commonly found in markets that sell biscuits are typically made by spreading caramel or cream between the large rigid flat wafer sheets and then using wires or saws to cut the sheets into smaller pieces. The wafers may be smothered in or molded with chocolate (Manley, 2000).

Producing wafers with a good shelf-life period is very important. Customers tend to prefer brittle wafers, not leathery or soggy wafers. The shelf-life is affected by several factors including the characteristics of the ingredients (especially flour) and the method used in producing the wafer. Getting the right consistency of wafer batter is quite complex. Even the temperature of the water, the sequence of adding ingredients and the time and speed of mixing have an important effect on the final product. After the batter is mixed, it is poured onto a hot plate, and the top hot plate is placed over it. At this point, the appropriate viscosity of the batter and correct temperature of the plates are very important (Navarrete et al., 2004).

To make high-quality wafers, the quality of the flour, water, and other ingredients must be carefully monitored, as well as the proportions used of these ingredients. In addition, the amount of time the batter is mixed, the temperature of the batter and baking plates, and baking time must also be carefully monitored (Dogan, 2006).

### 1.4.1 Wafer Sheet Quality Parameters

Quality is one of the most important parameter for both manufacturers and consumers. In order to make high quality wafer sheets with desired hardness, fracturability, color, flavor and longer shelf life, raw materials should be chosen carefully since the quality of the flour, water, and other ingredients affects the wafer sheet quality.

In addition to quality of raw materials, control of process conditions is also important for the quality of the end product. In batter preparation firstly, it is important to have a homogenous wafer batter which is free of lumps. Therefore, mixing time and speed of mixer are important process parameters for wafer batter. In addition to batter preparation, baking is also important process to get typical porous, fragile, and crisp structure of the wafer sheet. Important parameters of baking process are baking time, baking temperature, adjustment of baking plates, state of the baking plates, state of the closing system and adjustment of heating system.

### 1.4.2 Ingredients Used in Wafer Sheet Production

Tiefenbacher (2002) list the ingredients affecting wafer quality (Table 1.1). The main ingredients in wafer are flour, water, salt, leavening agent, oil and emulsifier.

**Table 1.1** Ingredients affecting in wafer sheet quality, derived from Tiefenbacher, 2002

| Ingredient | Specification | Comments | Influence on wafer |
|---|---|---|---|
| Wheat flour | Protein below 10%, moisture below 14.5% | Low absorption Use low shear mixer not to develop gluten | Provides bulk and structure |
| Starch, native | Potato, tapioca preferable to corn, wheat | Increases dry matter Reduces gluten problems | Increased stability, more homogenous structure |
| Water | Potable, Preferable below 60°F | Dissolve water soluble components, disperse flour | Weight+stability decrease; water hardness increases wafer hardness slightly |
| Baking Soda | Food grade Sodium bicarbonate | Improves spread in baking mould | Less weight and stability More color |
| Sugar | Sucrose, Granular | Dissolve sugar completely | Improves taste, texture; Increases wafer color + residues on baking moulds |
| Oil/Fat | Coconut, palm kernel; partially hardened oils; No di-, polyunsaturates | Reduces viscosity; Add in liquid form or powder | Improves release, texture; if too high: cloudiness, incomplete structure details |
| Lecithin | Lecithin (liquid); or carrier bound powder, deoiled powder | Reduces viscosity; mix with oil; If powder add before flour | Improves release, texture; increases residues on baking plates, color |

#### 1.4.2.1 Flour

Because the strength that gluten provides to flour is essential for producing high quality wafers, it is important to choose the suitable flour. There should be an optimum amount of gluten to make the wafer strong: too little will make it weak and fragile but too much will make it flinty and hard. Producers of wafer sheets prefer soft wheat flour ground for biscuits. However, a study performed by Wade (1988) found that 22 different kinds of flour (among them cake and bread flour) from both hard and soft wheat with protein levels between 8.1% and 10.9% could be used to make good wafer sheets. Flour typically used for bread with higher protein levels was reported to be not useful for making good wafer sheets.

For good-quality wafer sheets, attention must also be given to the degree of fineness of granulation. Finer flour produces a lighter, friable, soft sheet, while course flour produces poor quality sheets (Dogan, 2006).

#### 1.4.2.2 Water

Another important ingredient is water, which causes the batter to be pumpable and aids in mixing of ingredients into the batter. There should be enough water in the batter for mixing and for lowering the viscosity so that the batter can spread by itself to cover the plates (Kobs, 2001).

The flour-to-water ratio must be carefully monitored to obtain a good sheet texture. If there is too little water, the sheet does not turn out well, but rather it is too heavy and thick and undercooked. Also, because the water evaporates during the baking process, water also acts like leavening agent (Wade, 1988).

The amount of mineral content in the water affects the hardness and fragility of the wafer. Hard water makes the wafers harder and more fragile. According to Tiefenbacher (2002), water between the soft and medium levels is the best for making wafers.

#### 1.4.2.3 Salt

The importance of salt in baked goods is related to its ability to round out the flavors and make the overall flavor better. Also, it has an effect on how the dough is formed, particularly when yeast is involved, because it affects fermentation and lean dough development. Salt is used in wafers for better taste. Usually the salt concentration is between 0-0.75 parts for every 100 units of flour (Tiefenbacher, 2002).

#### 1.4.2.4 Leavening Agent

The final pH of wafer is influenced by the presence of sodium bicarbonate, which also affects how well the wafer turns color as it is baked. The best wafers are produced when the pH level is between 6.8 and 7.4. If the wafers will be used with chocolate, the pH level should be toward the higher end of this range to produce the best overall flavor (Manley, 2000). The ideal ratio of sodium bicarbonate to flour should be between 0.1-0.4 units per 100 units of flour (Tiefenbacher, 2002).

#### 1.4.2.5 Oil and Emulsifier

To satisfy the need for release agents, oil and an emulsifier (commonly lecithin) are used. Fats keep wafers sticking on the plates. Some fats mix in better than other fats, so generally liquid vegetable oils such as coconut oil, cotton seed oil and sunflower seed oil are used (Manley, 2000). Lecithin, which is combined with oil in wafer batter, changes the color of the food and leaves more residues behind on baking plates (Tiefenbacher, 2002).

## 1.5 Objective of the Study

For celiac disease patients, it is important to consume gluten-free food products that are suitable for their diet. For this purpose gluten-free foods have commonly started to find place in the market shelves in recent years. Although gluten-free foods such as breads, cakes or biscuits are investigated by many researchers, there is no search about gluten-free wafers in the literature. Therefore, main aim of this study was to determine a gluten-free wafer sheet formulation by using different gluten-free flours at different ratios and combination.

It is common to use mainly rice flour in gluten-free products. However, using only rice flour results poor flavor and low nutritional value in gluten-free products. Therefore, in order to improve the quality and nutritional values of gluten-free foods, in this study, in addition to rice flour, corn flour, chestnut flour, and buckwheat flour were chosen as gluten-free flours. These flours have many advantages when used in the gluten-free foods since they can meet nutritional requirements of celiac patients. Corn, buckwheat and chestnut flours are rich in essential amino acids and minerals. Using different gluten-free flours will also contribute to variety of celiac patients' diets. It was aimed to investigate rheological properties of batter having different formulations and color, textural and sensory properties of wafer sheet since they are important in acceptability of product.

# CHAPTER 2

# MATERIALS AND METHOD

## 2.1 Materials

For wafer sheet batter preparation, rice flour (Gamsan Gıda İmalat San. ve Dış Tic. Ltd. Şti., Istanbul, Turkey) having 14% moisture, 6% protein (N×5.95), 0.75% ash, wheat flour having 14.5% moisture, 7% protein, 0.55% ash, water (Kalabak, Eskişehir, Turkey), salt, sodium bicarbonate, coconut oil and lecithin were obtained from Eti Food Industry and Co. Inc. (Eskişehir, Turkey). Corn flour (Bağdat Baharat, Ankara, Turkey) and Buckwheat flour (Ekoloji Market, Istanbul, Turkey) were bought from local markets. Chestnut flour was supplied by Kafkas Pasta Şekerleme San.&Tic. A.Ş. (Karacabey, Bursa, Turkey).

## 2.2 Methods

### 2.2.1 Batter Preparation

Wafer sheet containing only rice flour was used as a control since it is commonly used in gluten-free product development. Wheat flour wafer sheet was also prepared to compare the quality of gluten-free formulations with that of wheat containing one. In rice flour containing batter, 20,40,60% of rice flour was replaced by corn, buckwheat or chestnut flours to obtain gluten-free wafer sheets.

In all the formulations, the batters were composed of 100% flour or flour blends, 0.5% salt, 0.4% sodium bicarbonate, 1% coconut oil and 0.5% lecithin (on flour weight basis). The amount of water used in batter formulations were adjusted depending on the viscosity of the batter since the time of flow of batter is directly proportional to viscosity. In all samples the amount of water added to provide the time of flow to be 21±1 sec was determined by flow cup viscometer with 100 ml capacity (TQC, Capelle aan den Ijssel, The Netherlands).

During preparation of the wafer sheet batter, firstly, water was added into a laboratory type wafer mixer with a 5 L capacity (Hobart Corporation, Troy, Ohio, USA). Salt and sodium bicarbonate were fully dispersed in water for 10s. Then, flour or flour blends were added to the mixture. Finally, blend of coconut oil and lecithin were added and final mixture was mixed for 4 min with mixer. The batter temperature was kept constant at 22±1°C throughout the experiments.

**2.2.2 Baking**

Before baking, the batter was held at room temperature for 10 min to allow air bubbles to rise to the top. This aeration process is important to prevent change in batter density during production which affects final weight of the product. Samples were baked using laboratory type wafer baking machine with dimensions of 290mm*210mm*5mm (Franz HAAS, Vienna, Austria) (Figure B.1). According to the study of Dogan (2006), baking temperature above 170°C increases fragility and gives a dark color. Therefore, the temperature of the upper and lower plates was kept constant at 165°C. A 125±3 g portion of the batter was poured on the center of the surface of the lower plate. Then, the upper plate was closed and lid was locked. Depending on the final moisture content of wafer sheet, which is in the range of 1-2%, baking time was adjusted to range of 5-6 min for gluten free wafer sheets.
Moisture content of the wafer sheet was measured by moisture analyser (Sartorius, Goettingen, Germany). In all measurements, 3 g of samples taken from the center of the wafer sheets were used.

### 2.2.3 Rheological Analyses of Wafer Sheet Batter

The rheological measurements were conducted using Malvern rheometer (Kinexus, Worcestershire, UK).All measurements were done at 22°C, using cone and plate geometry (40 mm diameter and 4° cone angle).The batter samples were placed between the plates and the edges were carefully trimmed with a spatula. The flow experiments were conducted under steady-shear conditions with shear rate ranging from 20 to 200 1/s. For the relaxation of the residual stresses, the batter was rested at room temperature for 10 min before testing. Throughout the experiments, shear rate versus shear stress and shear rate versus apparent viscosity data were collected. All the rheological experiments were performed twice and their average values were reported in the study.

### 2.2.4 Analyses of Wafer Sheet

Weight loss, moisture content, color analysis, texture profile analysis and sensory analysis were performed in wafer sheet.

#### 2.2.4.1 Weight Loss

Weight of batter sample ($W_{batter}$) and its weight after baking ($W_{sheet}$) were measured. Then, the percentage weight loss (WL %) of the wafer sheet during baking was calculated using Equation (2.1);

$$WL(\%) = \left[\frac{W_{batter} - W_{sheet}}{W_{batter}}\right] \times 100 \quad (2.1)$$

where, W denotes weight (g).

#### 2.2.4.2 Color

The color of the wafer sheet was measured by using Hunterlab Spectrophotometer (Colorflex, Broomfield, Colorado, USA). Three measurements were taken from different sections of upper and also lower surface of wafer sheets.

In color measurement, CIE $L^*$, $a^*$, $b^*$ color scale was used where the $L^*$ value indicates lightness/darkness, the $a^*$ value represents the degree of redness/greenness and the $b*$ value represents the degree of blueness/yellowness. Total color difference ($\Delta E*$) was calculated from the following equation (2.2);

$$\Delta E* = \left[(L^*-L^*_{ref})^2 + (a^*-a^*_{ref})^2 + (b^*-b^*_{ref})^2\right]^{1/2} \qquad (2.2)$$

where, $L^*_{ref}$ , $a^*_{ref}$ , $b^*_{ref}$ represent the $L*$, $a*$, $b*$ values of the wafer sheet prepared using only rice flour.

(For upper surface, $L^*_{ref} = -0.57, a^*_{ref} = 23.96, b^*_{ref} = 75.17$)

(For lower surface, $L^*_{ref} = 0.31, a^*_{ref} = 23.2, b^*_{ref} = 75.12$)

**2.2.4.3 Texture Profile Analysis**

Texture of wafer sheet samples were measured by using a twin column frame Texture Analyzer (Stable Micro Systems TA HD plus, Surrey, UK). Three point bend probe was attached to the instrument set to; compression force mode; trigger force 5.0 g; pre-test speed 1.0 mm/s; test speed 2.0 mm/s; post-test speed 10.0 mm/s; and rupture distance 10 mm. Load cell of 30 N were used. Samples having dimensions of 27 mm×36 mm in hardness and 53 mm×94 mm in fracturability were assembled horizontally on the base of the equipment. Fracturability of the wafer sheets were quantified by measuring force (g force) required to break them. Measurements were done in duplicate.

**2.2.4.4 Sensory Analysis**

Sensory analysis of wafer sheet was performed by hedonic ranking test by 10 semi-trained panellists (Resurreccion, 2008). 5-point ranking scale was used in the tests. Ranking scale was defined from 1 to 5 which were Like extremely (=5), Like moderately (=4), Neither like or dislike (=3), Dislike moderately (=2), Dislike extremely (=1).

Sheets containing flour blends were evaluated in terms of acceptability. One sample prepared with each kind of flour blends (80% rice+20% chestnut, 60% rice+40% buckwheat, 40% rice+60% corn, 100% rice, 100% wheat) were chosen according to quality parameters of wafer sheets, to compare their acceptability with that of control sheets in terms of color, texture and taste.

### 2.2.5 Statistical Analysis

Analysis of variance (ANOVA) was performed to determine the significant differences between the effects of flour types and percent replacement of rice flour ($p \leq 0.05$). If significant difference was found, means were compared by Duncan's multiple comparison test (SAS 9.1 for Windows, NC, USA).

# CHAPTER 3

# RESULTS AND DISCUSSION

In this part, effects of different gluten-free wafer sheets formulations containing only rice flour, rice-corn flour blends, rice-chestnut flour blends and rice-buckwheat flour blends prepared by replacing 20%, 40% and 60% of rice flour on rheological properties and quality parameters (weight loss, hardness, fracturability, color and sensory properties) were investigated. For comparison, wafer sheets having only rice flour and only wheat flour were used.

Samples having 60% rice and 40% chestnut flours and 40% rice and 60% chestnut flours could not be analyzed since they were stuck to the plates during baking without reaching the desired moisture content. According to Manley (2000) problem of sticking to one of the plates could be related to amount of sugar and moisture content of the sheet and the surface condition of the plates which result in failing to release of wafer sheet when the plates are opened. High amount of sugar in chestnut flour is the main reason of wafers sticking to the plates.

## 3.1 Effects of Different Flour Types on Rheological Properties of Wafer Batters

The amount of water used in the experiments for obtaining the desired viscosity can be seen in Table 3.1.

When the amount of water used in the only wheat flour (WF) and only rice flour (RF) containing batter preparation were compared, it was observed that sample with wheat flour required more water in order to get the desired viscosity. It can be explained by the composition of flours. The ability of gluten found in wheat flour to absorb water and hydrophobic characteristics of protein in rice flour were the main reasons in the difference of the amount of water (Table 3.1).

Partial replacement of rice flour by buckwheat flour (BF) or chestnut flour (ChF) increased the required amount of water in preparation of batter due to higher fiber content of these flours.

**Table 3.1** Amount of water used in the preparation of wafer sheets

| **Flours (100 g)** | **Water amount (g)** |
|---|---|
| 100% RF | 110.0 |
| 100% WF | 141.0 |
| 80%20% RF:ChF | 135.0 |
| 80%:20% RF:CF | 110.5 |
| 60%:40% RF:CF | 112.5 |
| 40%:60% RF:CF | 115.0 |
| 80%:20% RF:BF | 130.0 |
| 60%:40% RF:BF | 150.0 |
| 40%:60% RF:BF | 179.5 |

Data of shear stress (τ) versus shear rate (γ) data were fitted well to the Power Law model for all wafer batter formulations at 22ºC (Eq. (3.1)):

$$\tau = K(\dot{\gamma})^n \tag{3.1}$$

where τ is the shear stress (Pa), γ is the shear rate ($s^{-1}$), K is the consistency index ($Pa.s^n$) and n is flow behavior index.

Table 3.2 shows the Power Law parameters of wafer batter samples. According to Table 3.2, flow behavior indexes ranging from 0.56 to 0.86 showed that all batter formulations showed shear thinning (pseudoplastic) behavior. For the shear thinning materials, as the shear stress increases the viscosity decreases because of the disturbance of interactions between the components (Malkin and Isayev, 2006).

**Table 3.2** Power law constants of the wafer batter samples at 22°C

| Formulation | K (Pa.s$^n$) | n | $R^2$ |
|---|---|---|---|
| 80:20 RF:CF | 4.11 | 0.71 | 0.999 |
| 60:40 RF:CF | 4.33 | 0.67 | 0.996 |
| 40:60 RF:CF | 8.03 | 0.50 | 0.920 |
| 80:20 RF:BF | 2.03 | 0.86 | 0.999 |
| 60:40 RF:BF | 2.75 | 0.74 | 0.999 |
| 40:60 RF:BF | 2.77 | 0.56 | 0.997 |
| 80:20 RF:ChF | 6.21 | 0.61 | 0.999 |
| 100 RF | 3.21 | 0.74 | 0.999 |
| 100 WF | 2.11 | 0.75 | 0.999 |

The flow curves of wafer batter samples containing different flours and flour blends are given in Figure 3.1-3.3.

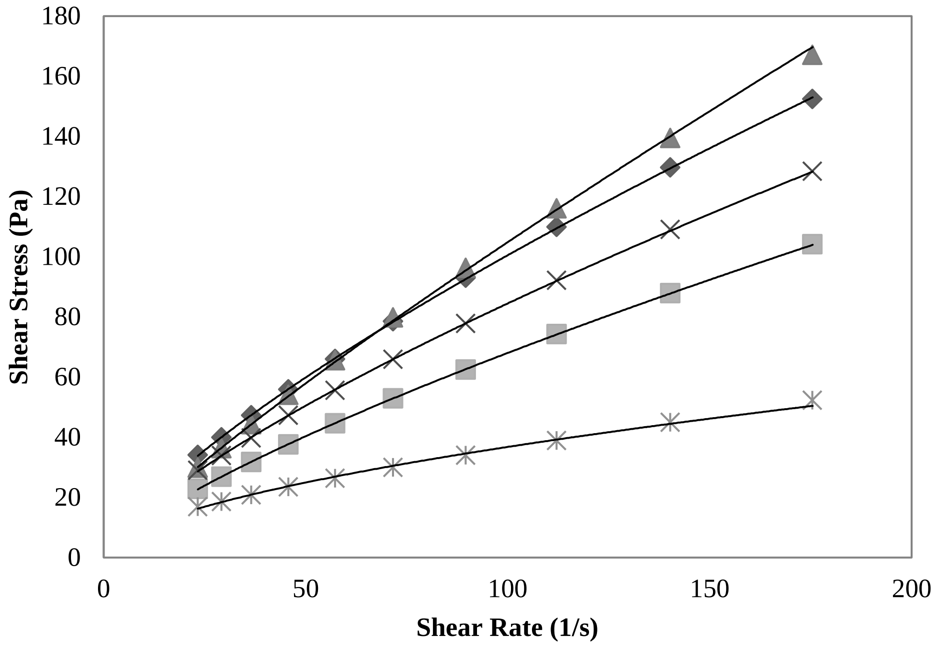


**Figure 3.1** Flow curves for wafer batter samples containing RF and BF at different ratios and control flours. ( ■ ): 100 WF, ( ◆ ): 100 RF, ( ▲ ): 80:20 RF:BF, ( X ): 60:40 RF:BF, ( *) : 40:60 RF:BF, —— : Power-law Model

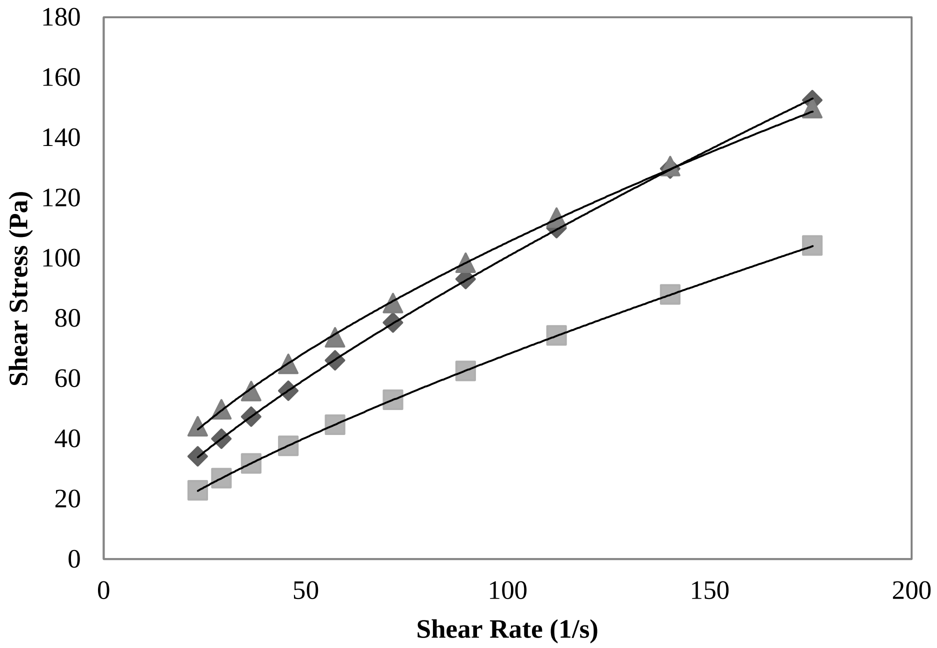


**Figure 3.2** Flow curves for wafer batter samples containing RF and ChF in combination and control flours. ( ■ ): 100 WF,( ◆ ): 100 RF, ( ▲ ): 80:20 RF:ChF:, —— : Power-law Model

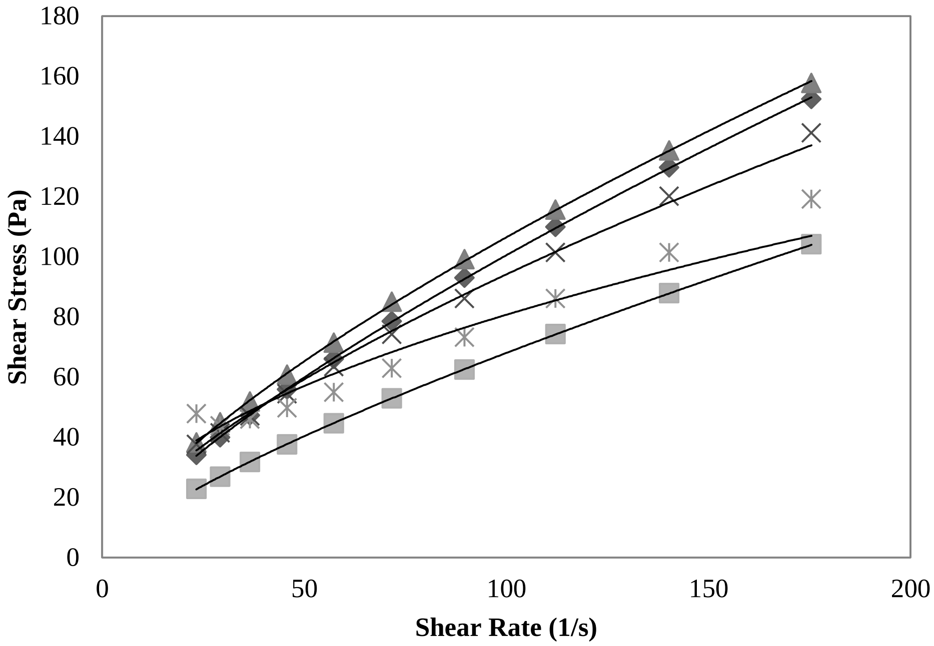


**Figure 3.3** Flow curves for wafer batter samples containing RF and CF at different ratios and control flours. (■): 100 WF, (◆): 100 RF, (▲): 80:20 RF:CF, ( X ): 60:40 RF:CF, ( * ): 40:60 RF:CF, —: Power-law Model

In general, higher consistency index values were obtained in wafer batter samples containing corn or chestnut flour. However, batter containing only wheat flour was the formulation having lower consistency index value. Among different gluten-free batter formulations, the highest consistency index and apparent viscosity values were obtained for sample containing rice:corn blend at ratio of 40:60 (Table 3.2). It was observed that as the ratio of rice flour increased in the rice-corn flour blends, the viscosity of batter decreased. Rice flour apparently dilutes the strengthening influence of corn flour, increasing the available free water in the batter system. This free water could increase flow, and end up with a lower viscosity value (Mukprasirt et al., 2000). It was also observed that chestnut containing sample had higher consistency index compared to samples having buckwheat-rice flour blend, only rice and only wheat flour (Table 3.2). The consistency index values of batter containing rice and chestnut flours at a ratio of 80:20 was even higher than that of rice and corn flour containing sample at a ratio of 80:20. High fiber content of chestnut flour is one of the main reasons affecting rheological parameters. Since the entanglement of fibers causes more resistance to flow, it results in increase in the apparent viscosity values (Demirkesen et al., 2010b). In addition, through the hydrogen bonding available hydroxyl groups in fiber structure can bind more water. With this mechanism, the amount of available water is reduced for the plasticizing effects (Nelson, 2001). Only rice flour, buckwheat-rice flour blend and only wheat flour samples followed corn flour samples, respectively in the decreasing order. The samples containing buckwheat-rice flour blend and only wheat flour had very similar flow curves with similar consistency index values. Among these samples buckwheat sample (60:40 RF:BF) and the control samples (both rice and wheat flour samples) had the closest values of consistency and flow behavior index.

## 3.2 Effects of Different Flour Types on Weight Loss of Wafer Sheets

The effects of partial replacement of rice flour by different gluten-free flours on weight loss of wafer sheets are presented in Figure 3.4. It was found that wafer formulations containing different flour blends with different ratios showed different behavior. According to ANOVA results (Table A.1) wafer sheets containing only rice flour and rice-corn flour blends in which rice flour was higher in amount (sample numbers 1, 2 and 3) were not significantly different. This may be due to the hydrophobic characteristics of rice proteins. Since the final moisture content of wafer sheets were in the range of 1-2%, weight loss of batters during baking was directly correlated with the amount of water added in preparation of batter (Table 3.1 and Figure 3.4). The ANOVA results showing the difference between weight loss of different types of batters can also be applicable to discuss the difference between amount of water added for obtaining the desired viscosity. Among different types of flour blends only weight loss of rice-corn flour blend at a ratio of 40:60 and rice-buckwheat flour blend at a ratio of 80:20 were not significantly different. All the other flour blends showed significantly different weight loss behavior. The weight loss result of wafer sheet sample with rice-buckwheat flour blend at a ratio of 40:60 was the closest one to the sample with wheat flour.

The release of moisture during baking depends on the overall compositions. Therefore, it was expected to observe different behavior in weight loss during baking of wafer sheets having different formulations.

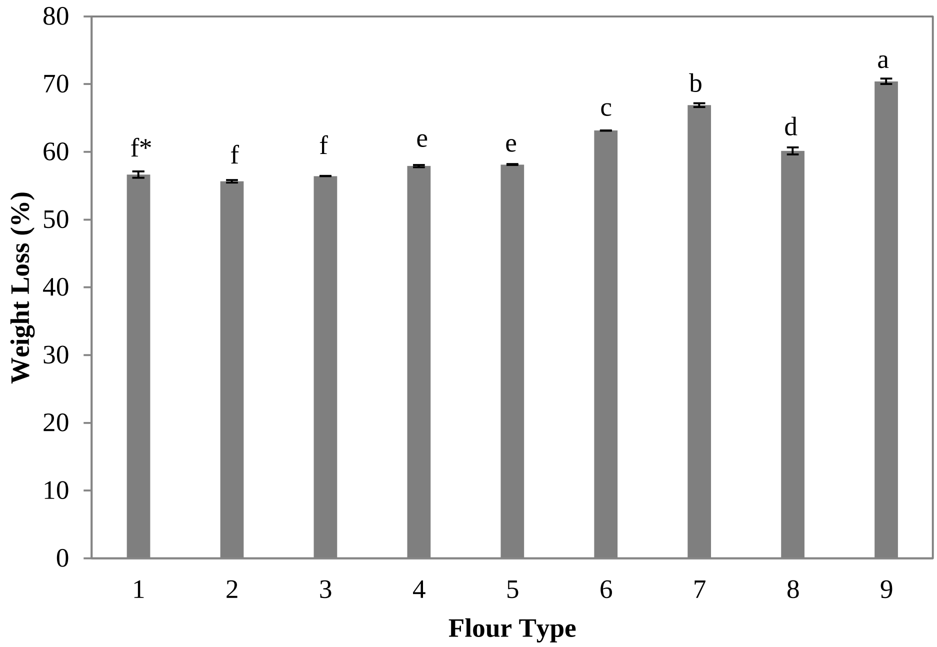


**Figure 3.4** Weight loss of wafer sheets prepared by replacement of rice flour by different flour types at different ratios. 1. RF; 2. RF:CF 80:20; 3. RF:CF 60:40; 4. RF:CF 40:60; 5. RF:BF 80:20; 6. RF:BF 60:40; 7. RF:BF 40:60; 8. RF:ChF 80:20; 9. WF. *Bars with different letters are significantly different.

## 3.3 Effects of Different Flour Types on Texture Properties of Wafer Sheets

### 3.3.1 Hardness

The effect of replacement of rice flour by different flours at different ratios on hardness of the wafer sheet samples were presented in Figure 3.5. According to this figure, wafer samples prepared by the combination of corn and rice flours had the highest hardness value. The hardness of these samples was not statistically different from each other. Samples containing chestnut, buckwheat and/or wheat flour had statistically lower hardness values than the other group (samples containing rice and corn). This might be due to the higher fiber content of chestnut and buckwheat flours and gluten content of wheat flour which cause higher water binding capacity.

Besides this, in the study of Yıldız (2010) it was found that the amount of water in the batter was important in affecting the final hardness of the product. It was indicated that the less amount of water used in the batter leading the harder final product. This agreed with the result of the experiments. The hardness of the samples which had higher amount of water in the batters such as samples containing chestnut, buckwheat and wheat flour, were significantly lower than the samples containing rice and corn (Table 3.1).

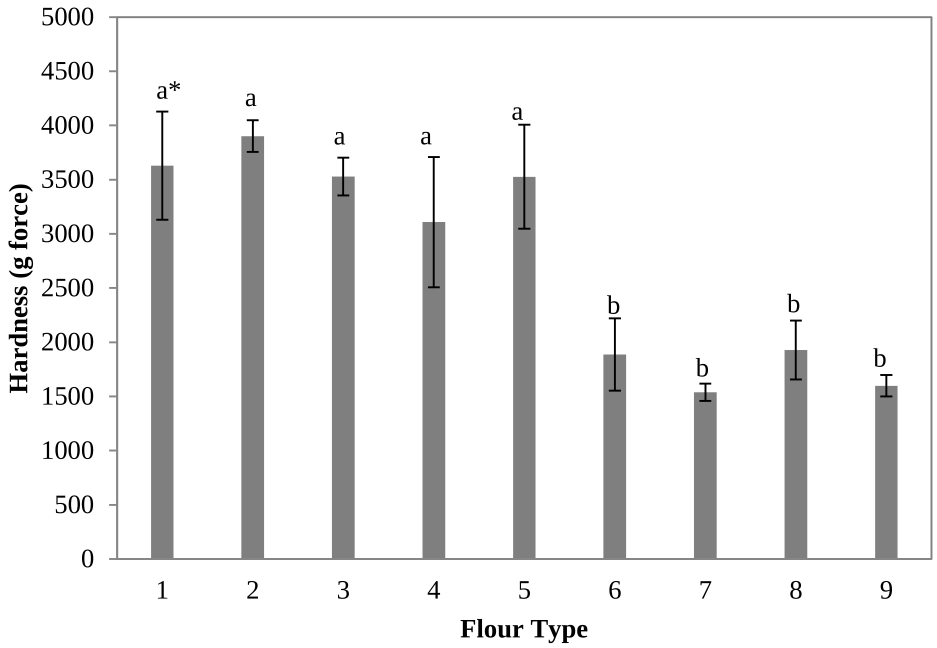


**Figure 3.5** Hardness of wafer sheets prepared using different flour types at different ratios and combinations: 1. RF; 2. RF:CF 80:20; 3. RF:CF 60:40; 4. RF:CF 40:60; 5. RF:BF 80:20; 6. RF:BF 60:40; 7. RF:BF 40:60; 8. RF:ChF 80:20; 9. WF. Bars indicate standard error of the replicates. *Bars with different letters are significantly different.

When the results of rheological analyses and texture analyses were compared, it was observed that for samples with low consistency values for instance

100% wheat flour sample and sample containing rice and buckwheat flour blend (RF:BF-60:40) had also low hardness values. Samples having higher hardness values which were prepared using only rice flour or rice and corn flour combination had also higher consistency index.

### 3.3.2 Fracturability

The effects of different flours on fracturability of wafer sheets are presented at Figure 3.6. According to this figure, samples containing corn flour significantly had higher fracturability values than the other samples. It was also observed that samples containing buckwheat flour were not significantly different than the wheat flour containing sample.

High values of fracturability of wafer sheet are not desirable in the production. The higher values of fracturability values end up with more problems in the cutting stage of the wafer sheets. According to these, samples containing corn flour is not suitable for wafer sheet production with its high fracturability value.

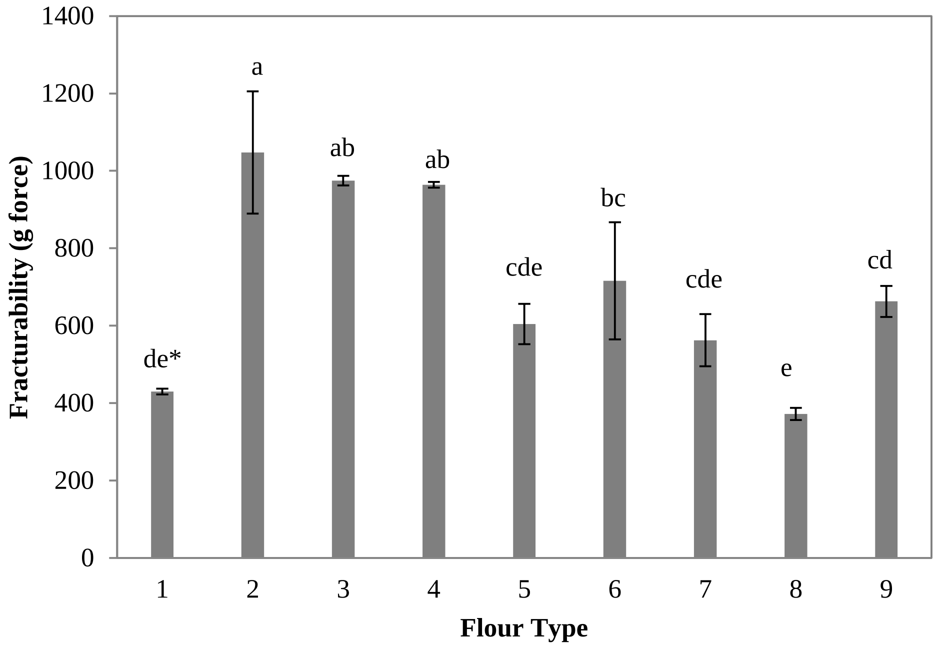


**Figure 3.6** Fracturability of wafer sheets prepared using different flour types at different ratios and combinations: 1. RF; 2. RF:CF 80:20; 3. RF:CF 60:40; 4. RF:CF 40:60; 5. RF:BF 80:20; 6. RF:BF 60:40; 7. RF:BF 40:60; 8. RF:ChF 80:20; 9. WF. *Bars with different letters are significantly different.

## 3.4 Effects of Different Flour Types on Color of Wafer Sheets

In this study, the color of wafer sheets containing different flour blends were investigated by using L*, a* and b*. Then, total color of samples was calculated by using Equation (2.2).

### 3.4.1 L* Parameter

In determination of color, L* value indicates lightness/darkness of the samples. According to ANOVA Table A.4, it was found that there was no significant difference between L* values of upper and lower surface of wafer sheets ($p>0.05$). Therefore, average L* values were calculated by considering the data obtained for both upper and lower surfaces of wafer sheets in comparison of the effect of different flour types on color of wafer sheets. According to ANOVA Table A.5, it was found that L* values of wafer sheets containing only rice flour and only wheat flour were significantly higher than the others ($p \leq 0.05$). This was related to their lighter appearance. As shown in the Figure 3.7, the values of L* in the case of all ratios of buckwheat flour blends and nearly all ratios of corn flour blends (expect 80% rice +20% corn) were not significantly different. Among all type of flour blends, wafer sheet containing chestnut-rice flour blend had significantly darker appearance, which may be due to higher sugar content of chestnut flour resulting in browning.

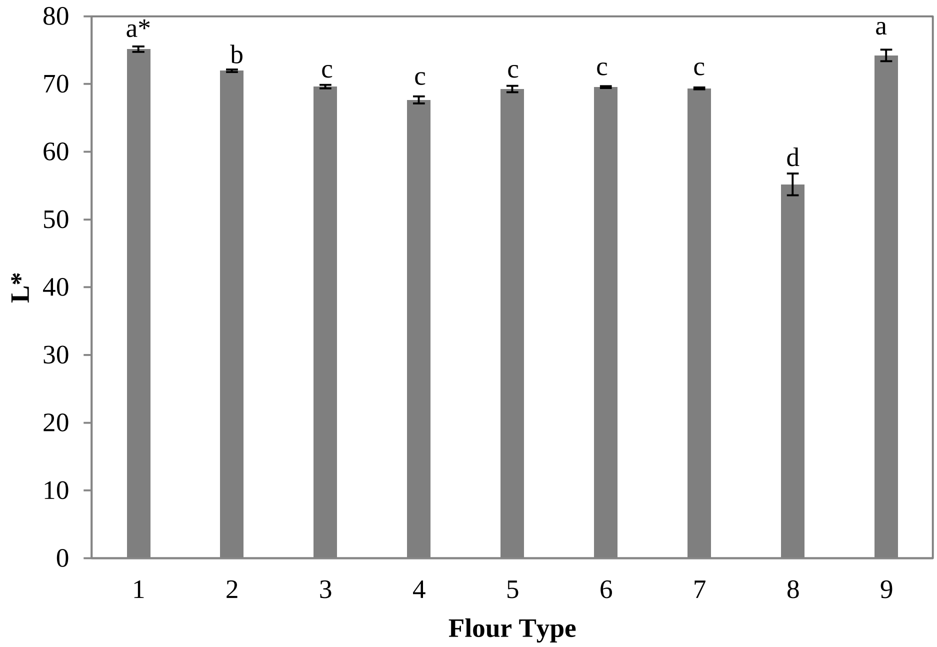


**Figure 3.7** L* values of wafer sheets (at both upper and lower surfaces) containing different flour types at different ratios and combinations: 1. RF; 2. RF:CF 80:20; 3. RF:CF 60:40; 4. RF:CF 40:60; 5. RF:BF 80:20; 6. RF:BF 60:40; 7. RF:BF 40:60; 8. RF:ChF 80:20; 9. WF. *Bars with different letters are significantly different.

### 3.4.2 a* Parameter

In determination of color, a* value indicates redness/greenness of the samples. According to ANOVA Table A.6, there was a significant difference between upper and lower surfaces of the wafer sheet samples ($p \leq 0.05$). It was found that the lower surface of all samples had higher a* values than upper surface. This may be because of the contact time of batter with the hot surface. Wafer batter was firstly poured to lower surface of the wafer sheet machine; the baking process of lower surface of wafer sheet had already started till lid was closed. Since there was a difference between a* values of upper and lower surfaces, two separate statistical analysis were made for a* values. According to ANOVA Table A.7 and A.8, in both lower and upper surfaces of wafer sheet samples containing rice-chestnut flour blend had higher values of a*. This may be because of the high sugar content of the chestnut flour which leads to browning of wafer sheets through Maillard and caramelization reactions during the baking process (Sacchetti et al., 2004; Gómez et al., 2008). As shown in Figure 3.8 and 3.9, after rice-chestnut flour blend, in both upper and lower surfaces of wafer sheets, the highest a* values were observed in samples containing rice and corn flour blends. Increasing the amount of corn flour in the formulation increased a* value. This may be due to the natural color of corn flour affecting the baked products. It was also found that the control wafer sheets containing only rice flour and wheat flour had the lowest a* values.

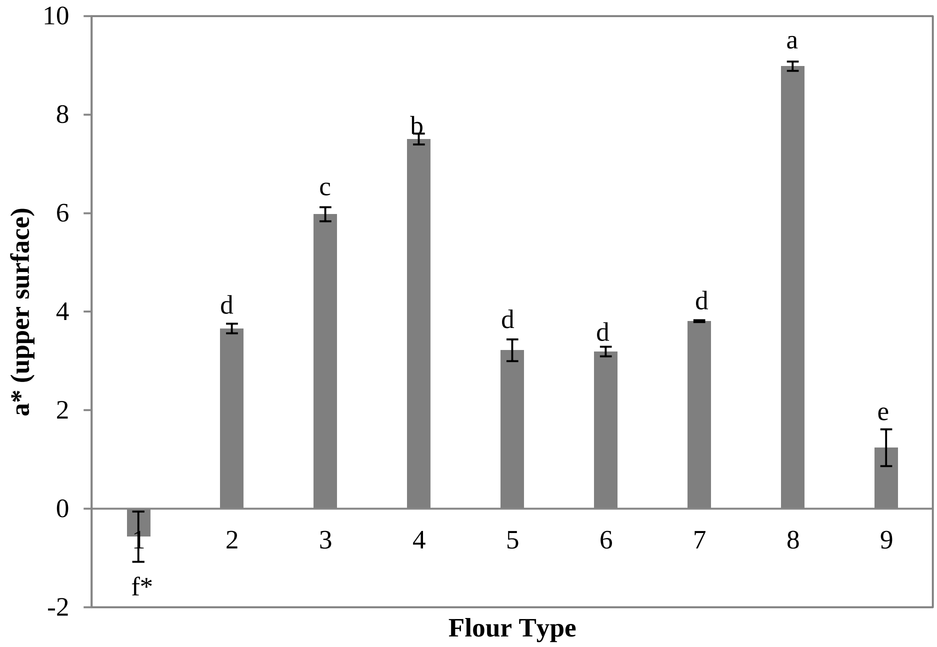


**Figure 3.8** a* values of upper surface of wafer sheets containing different flour types at different ratios and combinations: 1. RF; 2. RF:CF 80:20; 3. RF:CF 60:40; 4. RF:CF 40:60; 5. RF:BF 80:20; 6. RF:BF 60:40; 7. RF:BF 40:60; 8. RF:ChF 80:20; 9. WF. *Bars with different letters are significantly different.

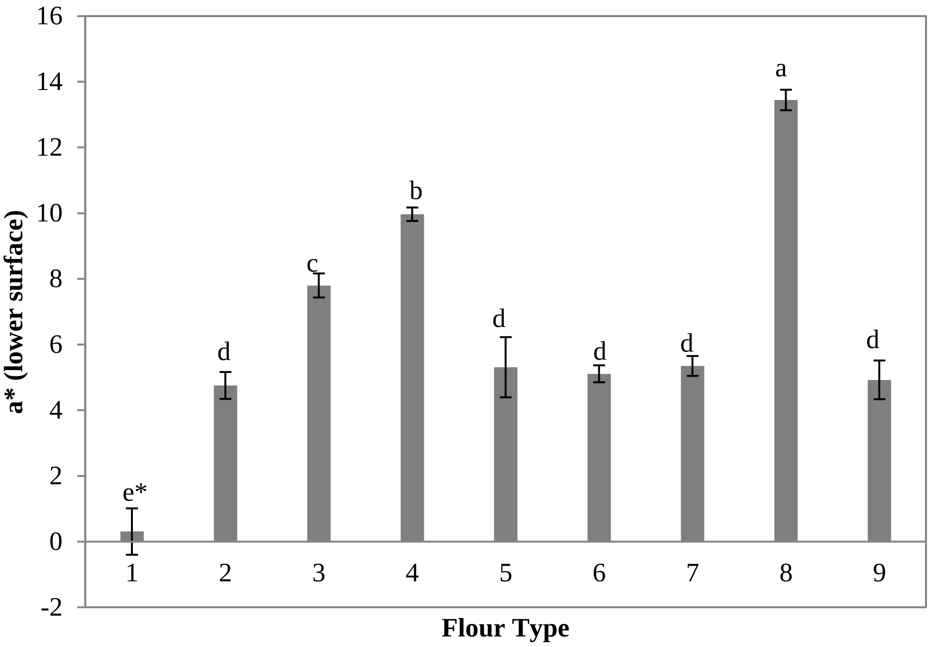


**Figure 3.9** a* values of lower surface of wafer sheets containing different flour types at different ratios and combinations: 1. RF; 2. RF:CF 80:20; 3. RF:CF 60:40; 4. RF:CF 40:60; 5. RF:BF 80:20; 6. RF:BF 60:40; 7. RF:BF 40:60; 8. RF:ChF 80:20; 9. WF. *Bars with different letters are significantly different.

### 3.4.3 b* Parameter

In determination of color, b* value indicates blueness/yellowness of the samples. According to ANOVA Table A.9, it was found that there was no significant difference between b* values of upper and lower surface of wafer sheets ($p>0.05$). Therefore, b* values of both upper and lower surfaces were used in comparison. As shown in the Figure 3.10 wafer sheets containing rice-corn sheets had the highest value of b* due to corn flour's natural color. In addition, samples containing rice-chestnut flour blends had also high values of b* due to yellow color of chestnut flour as in the case of corn flour. According to ANOVA Table A.10, there were significant differences between the samples containing different flour blends ($p\leq0.05$). As shown in the Figure 3.10, samples having buckwheat, rice and wheat flours had lower b* values as compared to the other flour blends.

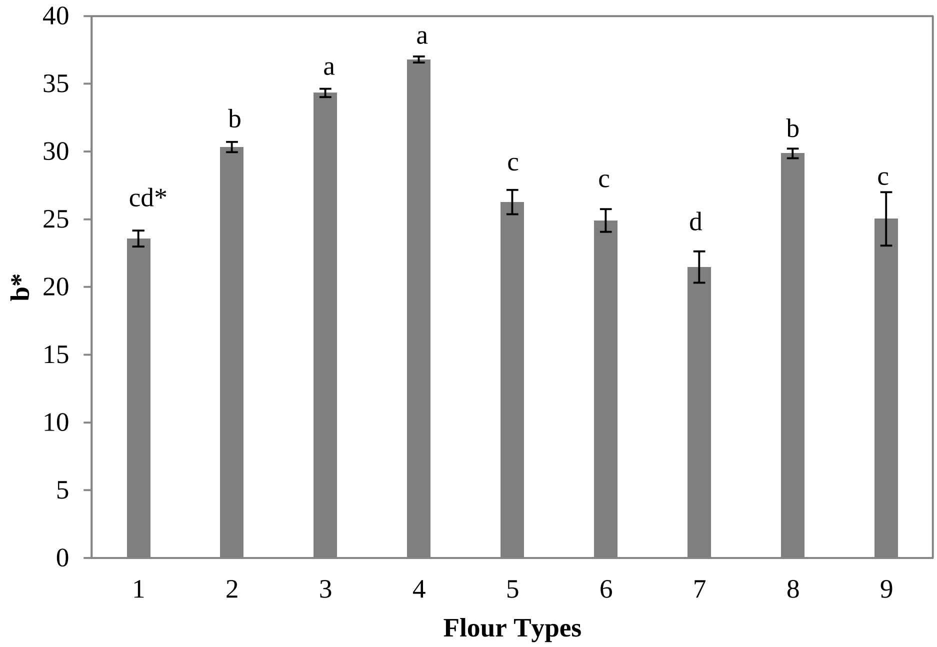


**Figure 3.10** b* values of wafer sheets at both upper and lower surfaces containing different flour types at different ratios and combinations:1. RF; 2. RF:CF 80:20; 3. RF:CF 60:40; 4. RF:CF 40:60; 5. RF:BF 80:20; 6. RF:BF 60:40; 7. RF:BF 40:60;  8. RF:ChF 80:20; 9. WF. *Bars with different letters are significantly different.

### 3.4.4 Total Color Difference (∆E*)

Total color difference was measured by using the color values of wafer sheet containing only rice flour as reference. According to ANOVA Table A.11, it was found that there was no significant difference between upper and lower surface of wafer sheets ($p>0.05$) in terms of total color change. Therefore, ∆E* values of both upper and lower surfaces of wafer sheets were used together to understand the effect of different flour types. According to ANOVA, there were significant differences between different flour blends in terms of total color difference (Table A.12). Only the samples containing rice and buckwheat flour in all ratios and sample having rice and corn flour blend at a ratio of 20:80 were not significantly different. As shown in the Figure 3.11, sample having rice-chestnut flour had much higher ∆E* value than the other samples. The main reason of color change in this sample was Maillard reaction because of high sugar content of chestnut flour. Total color differences of wafer sheet samples prepared with wheat flour and combination of rice and buckwheat flours at a ratio of 60:40 were statistically the same.

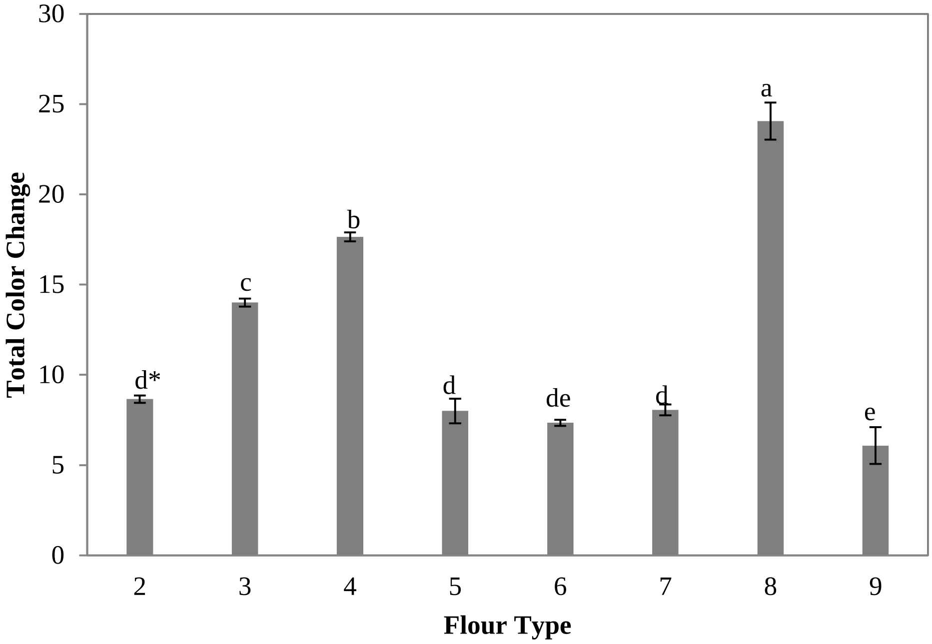


**Figure 3.11** ΔE* values of wafer sheets at both lower and upper surfaces containing different flour types at different ratios and combinations: 2. RF:CF 80:20; 3. RF:CF 60:40; 4. RF:CF 40:60; 5. RF:BF 80:20; 6. RF:BF 60:40; 7. RF:BF 40:60; 8. RF:ChF 80:20; 9. WF. *Bars with different letters are significantly different.

### 3.5 Effects of Different Flour Types on Sensory Analysis of Wafer Sheets

For measuring the food acceptability, the sensory evaluations were performed according to ranking tests. In a ranking test, higher scores represent a food with higher acceptability (Resurreccion, 2008). The effect of different flour combinations at different ratios on acceptability of color, texture and taste of wafer sheets were investigated by sensory analysis.

Beside control samples, one of sample from each type of flour blends was chosen according to texture and rheological analyses results. Samples with the similar results with control samples were used in sensory analyses which were 60:40 RF:BF, 40:60 RF:CF and 80:20 RF:ChF.

### 3.5.1 Color

In the sensory analysis of wafer sheets, the highest scores in color acceptability were obtained in the samples containing wheat or rice flour. According to ANOVA Table A.13, there was no significant difference between these samples in terms of color acceptance. According to Figure 3.12, there was no significant difference between the samples containing buckwheat and chestnut flour in terms of color acceptability.

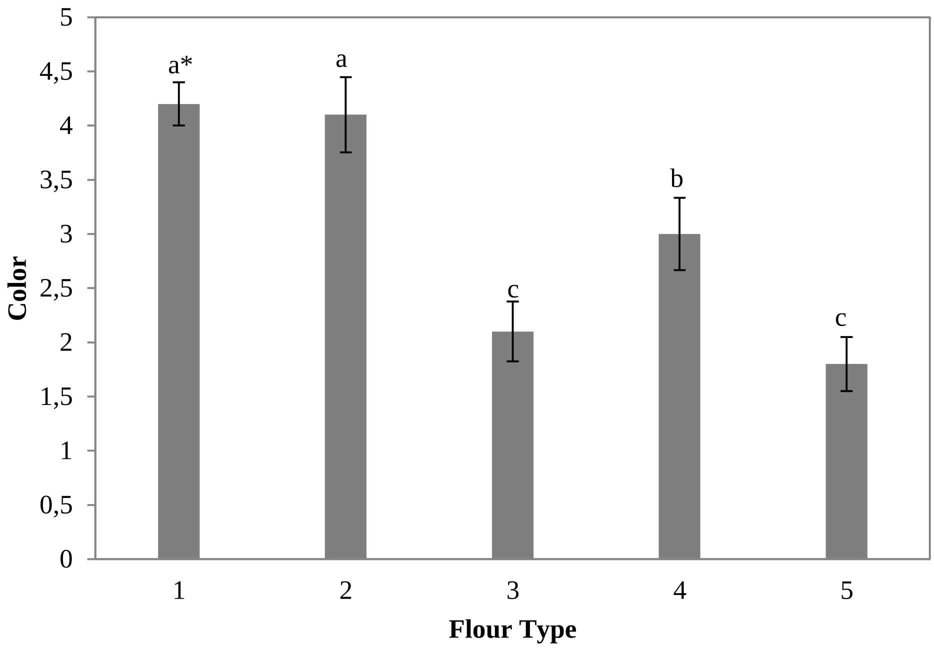


**Figure 3.12** Color acceptability scores of wafer sheets containing different flour types at different ratios and combinations: 1. WF; 2. RF; 3. RF:BF 60:40; 4. RF:CF 40:60; 5. RF:ChF 80:20. *Bars with different letters are significantly different.

### 3.5.2 Texture

In the sensory analysis of wafer sheets, the highest score in the texture acceptability was obtained by sample containing wheat flour. According to ANOVA Table A.14, there was no significant difference in texture acceptability of wafer sheet made using wheat flour and sample containing rice and buckwheat flours at a ratio of 60:40 (Figure 3.13). This result is similar to the hardness and fracturability results where there was no significant difference between samples with wheat flour and rice:buckwheat flours blend at a ratio of 60:40 (Figure 3.5 and 3.6).

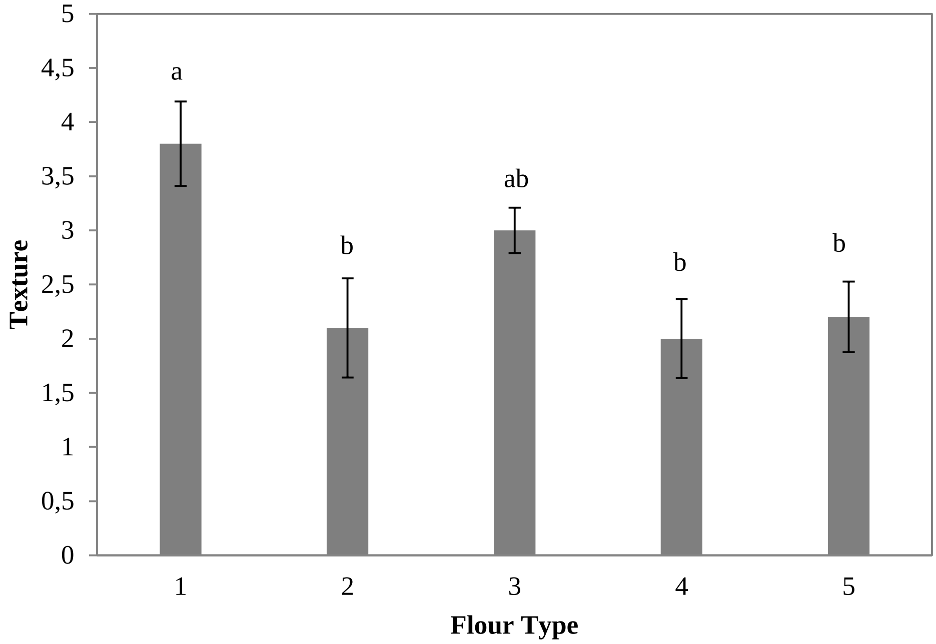


**Figure 3.13** Texture acceptability scores of wafer sheets containing different flour types at different ratios and combinations: 1. WF; 2. RF; 3. RF:BF 60:40; 4. RF:CF 40:60; 5. RF:ChF 80:20. *Bars with different letters are significantly different.

### 3.5.3 Taste

In the sensory analysis of wafer sheets the most acceptable sample in terms of taste was again wheat flour containing sample (Figure 3.14). There was no significant difference in the taste acceptability between the samples containing rice, buckwheat, corn and chestnut flours.

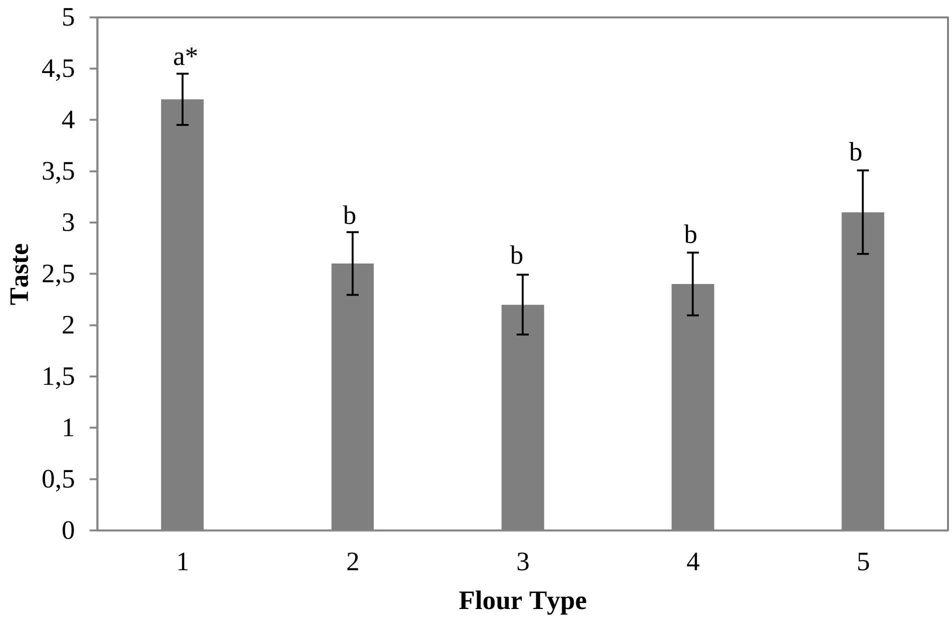


**Figure 3.14** Taste acceptability scores of wafer sheets containing different flour types at different ratios and combinations: 1. WF; 2. RF ;3. RF:BF 60:40; 4. RF:CF 40:60; 5. RF:ChF 80:20. *Bars with different letters are significantly different.

# CHAPTER 4

# CONCLUSION AND RECOMMENDATIONS

All flour blends and 100% rice and 100% wheat flour formulations showed shear thinning behavior and they all obeyed Power law model. Among all samples, consistency and flow behavior indices of rice and buckwheat flour containing sample at a ratio of 60:40 were the most similar to those of control samples (both rice and wheat flour samples).

When the texture profile of wafer sheets were examined in terms of hardness, it was seen that samples containing only rice flour and all the samples with corn flours had harder texture as compared to the other samples. Buckwheat-rice flour samples and chestnut-rice flour sample were similar to the wheat flour containing sample in terms of hardness. In terms of fracturability, all samples with corn flour had the highest values, which is not desirable in wafer sheet production because of problems arising in the cutting stage of the sheets. For fracturability parameter, the buckwheat-rice flour samples were the closest one to the wheat flour containing sample. When texture results were considered, the best alternative flour to wheat flour for gluten-free wafer sheet production was buckwheat-rice flour blend.

In the color analyses of wafer sheets, the effects of natural color of the flours were clearly observed in the final product. Samples containing corn flour and sample having chestnut flour were different than other samples by their yellowness and redness values, respectively. Other samples had similar color.

When the sensory analyses of wafer sheets were examined, sample prepared with rice and buckwheat flour at a ratio of 60:40 was similar to the wheat flour containing sample in terms of texture acceptability. In acceptability of color, samples with wheat flour and rice flour had the highest scores. In the taste analysis, as in the other cases wheat flour had the highest score.

It can be concluded that for gluten-free wafer sheet production, buckwheat-rice flour blends could be used as an alternative to wheat flour. Although color acceptability of wafer sheets containing rice and buckwheat flours at a ratio of 60:40 was lower, with its texture properties, it was the closest alternative to wheat flour containing sample.

As future study, different flour blends like chestnut-buckwheat flours or other gluten-free flour blends could be investigated. Different types of gluten-free starch like potato starch could be studied to improve structure and texture of the wafer sheets. Shelf life of the gluten-free wafer sheets could also be examined.

# REFERENCES


Adebayo, A.O., and Emmanuel, F. 2001. The protein quality of some corn-based Nigeria diets. J. Mgt. Technol., 3, 122–127.

Arendt, E.K., Renzetti, S., Dal Bello, F., 2009. Dough microstructure and textural aspects of gluten-free yeast bread and biscuits. In: Gluten-free Food Science and Technology, (Eds.) Gallagher, E., Wiley-Blackwell, Oxford, UK, pp. 107-129.

Bai, J., Zeballos, E., Fried, M., Corazza, G.R., Schuppan, D., Farthing, M.J.G., Catassi, C., Greco, L., Cohen, H., Krabshuis, J.H., 2007. World Gastroenterology Organization Practice Guidelines: Celiac Disease.

Bárcenas, M.E., Rosell, C.M., 2006. Different approaches for improving the quality and extending the shelf life of the partially baked bread: low temperatures and HPMC addition. Journal of Food Engineering, 72(1), 92–99.

Borges, O.P., Carvalho, J.S., Correia, P.R., Silva, A.P., 2007. Lipid and fatty acid profiles of Castanea sativa Mill. Chestnuts of 17 native Portuguese cultivars.Journal of Food Composition and Analysis, 20(2), 80–89.

Carroll, K.K. and Hamilton R. M. G., 1975. Nutritional perspectives and atherosclerosis.  Journal of Food Science, 40:18-22.

Catassi, C., and Fasano, A., 2008. Celiac disease. In: Gluten-free Cereal Products and Beverages, (Eds.) Arendt, E. K. and Dal Bello F., Academic Press, Oxford, UK, pp. 1-22.

Centre for Digestive Disease, 2009. Coeliac disease. From http://www.cdd.com.au/pages/disease_info/coeliac_disease.html last visited: July, 2014.

Codex standard for foods for special dietary use for persons intolerant to gluten, 1979. Codex Standard, 118, 1-3.

Cureton, P., and Fasano, A., 2009. The increasing incidence of celiac disease and the range of gluten-free products in the market place. In: Gluten-free Food Science and Technology, (Eds.) Gallagher, E., Wiley-Blackwell, Oxford, UK, pp. 1-15.

Demiate, I.M., Oetterer,M., Wosiacki, G., 2001. Characterization of chestnut (Castanea sativa, Mill) starch for industrial utilization. Braz. Arch. Biol. Technol., 44, 69–78.

Demirkesen, I., Mert, B., Sumnu G., Sahin, S., 2010a. Rheological properties of gluten-free bread formulations. Journal of Food Engineering, 96(2), 295–303.

Demirkesen, I., Mert, B., Sumnu G., Sahin, S., 2010b. Utilization of chestnut flour in gluten-free bread formulations. Journal of Food Engineering, 101(3), 329-336.

Demirkesen, I., 2013. Development of gluten-free bread formulations for baking in infrared-microwave combination oven. PhD Thesis, METU, Ankara.

Demirkesen, I., Sumnu, G., Sahin, S., 2013. Quality of gluten-free bread formulations baked in different ovens. Food and Bioprocess Technology, 6(3), 746-753.

Dogan, I.S., 2006. Factors affecting wafer sheet quality. International Journal of Food Science and Technology, 41, 569-576.

Enwere, J. 1998. Foods of Plant Origin. Afro-Orbis Publications Ltd, Nsukka, Nigeria, pp. 40-48.

Figoni, P.I., 2008. How Baking Works: Exploring the Fundamentals of Baking Science. Wiley, Oxford, UK, pp. 65-86.

Francischi, M. L. P., Salgado, J. M., Leitão, R. F. F., 1994. Chemical, nutritional and technological characteristics of buckwheat and non-prolamine buckwheat flours in comparison of wheat flour. Plant Foods for Human Nutrition, 46(4), 323-329.

Gallagher, E., Gormley, T.R., Arendt, E.K., 2003. Crust and crumb characteristics of gluten-free breads. Journal of Food Engineering, 56(2-3), 153–161.

Gómez, M., Oliete, B., Caballero, P. A., Ronda, F., Blanco, C. A., 2008. Effect of nut paste enrichment on wheat dough rheology and bread volume. Food Science Technology International, 14, 57–65.

He, J., Klag, M.J., Whelton, P.K., Mo, J.P., Chen, J.Y., Quian, M.C., Mo, P.S., He, G.Q., 1995. Oats and buckwheat intakes and cardiovascular disease risk factors in an ethnic minority of China. The American Journal of Clinical Nutrition, 61(2), 366-372.

Hoseney, R.C., Wade, P., and Finley, J.W., 1988. Soft wheat products. In: Wheat: Chemistry and Technology Volume 2, (Eds.) Pomeranz, Y., American Association of Cereal Chemists, Inc., Minnesota, USA, pp. 407-456.

Kobs, L., 2001. "B" is for baking cookies. From, http://www.foodproductdesign.com/articles/2001/10/147b148------is-for-baking-cookies.aspx last visited: July, 2014.

Kreft, M. & Kreft, S., 2000. Localization and morphology of buckwheat embryo. Fagopyrum, 17, 15-19.

Lazaridou, A., Duta, D., Papageorgiou, M., Belc, N., Biliaderis, C.G., 2007. Effects of hydrocolloids on dough rheology and bread quality parameters in gluten-free formulations. Journal of Food Engineering, 79(3), 1033–1047.

Malkin, A. Y. and Isayev, A. I., 2006. Pressure corrections. In: Rheology: concepts, methods, and applications (1st ed.). ChemTac Publishing, Toronto, pp. 253-320.

Manley, D., 2000. Technology of biscuits, crackers and cookies (3rd ed.). Woodhead Publishing Limited, Cambridge, England, pp. 290-306.

Marco, C., and Rosell, C.M., 2008. Breadmaking performance of protein enriched, gluten-free breads. European Food Research and Technology, 227(4), 1205-1213.

Mendoza, N., 2005. Coeliac disease: an overview of the diagnosis, treatment and management. Nutrition Bulletin, 30(3), 231–236.

Moreira, R., Chenlo, F., Torres, M.D., and Prieto, D.M., 2010a. Influence of the particle size on the rheological behaviour of chestnut flour doughs. Journal of Food Engineering, 100(2), 270-277.

Moreira, R., Chenlo, F., Torres, M.D., Prieto, D.M., 2010b. Water adsorption and desorption isotherms of chestnut and wheat flours. Industrial Crops and Products, 32(3), 252-257.

Moreira, R., Chenlo, F., Torres, M.D., 2011. Rheology of commercial chestnut flour doughs incorporated with gelling agents. Food Hydrocolloids, 25(5), 1361-1371.

Mukprasirt, A., Herald, T. J., & Flores, R. A., 2000. Rheological characterization of rice flour-based batters. Journal of Food Science, 65, 1194–1197.

National Digestive Diseases Information Clearinghouse, 2008. Celiac disease. From http://digestive.niddk.nih.gov/ddiseases/pubs/celiac/ last visited: July, 2014.

National Foundation for Celiac Awareness, 2014. What is celiac disease? From http://www.celiaccentral.org/Celiac-Disease/21/ last visited: July, 2014.

Navarrete, N.M.,Moraga, G., Talens, P.,& Chiralt, A., 2004. Water sorption and the plasticization effect in wafers. International Journal of Food Science and Technology, 39, 555–562.

Nelson, A. L., 2001. High Fiber Ingredients. (1st eds.). Eagen Press Handbook Series, AACC, Minnesota. pp. 44-61.

Niewinski, M.M., 2008. Advances in celiac disease and gluten-free diet. Journal of the American Dietetic Association, 108(4), 661-672.

Preichardt, L.D., Vendruscolo, C.T., Gularte, M.A. and Moreira, A.S., 2011. The role of xanthan gum in the quality of gluten-free cakes: improved bakery products for coeliac patients. International Journal of Food Science and Technology, 46(12), 2591–2597.

Resurreccion, A. V. A., 2008. Consumer sensory testing for food product development. In: Developing New Food Products for a Changing Marketplace, (Eds.), Brody, Aaron L., Lord, John B. ( 2nd ed.), CRC Press Taylor and Francis Group, FL, USA, pp. 5–25.

Rosell, C.M., and Collar, C., 2007. Rice-based products. In: Handbook of Food Products Manufacturing, (Eds.) Hui, Y.H., John Wiley & Sons, Inc., Hoboken, New Jersey, pp. 523-534.

Sacchetti, G., Pinnavaia, G.G., Guidolin, E., Dalla Rosa, M., 2004. Effects of extrusion temperature and feed composition on the functional, physical and sensory properties of chestnut and rice flour-based snack-like products. Food Research International, 37(5), 527-534.

Schober, T.J., O'Brien, C.M., McCarthy, D., Darnedde, A., Arendt, E.K., 2003. Influence of gluten-free flour mixes and fat powders on the quality of gluten-free biscuits. European Food Research and Technology, 216(5), 369-376.

Shukla, R., and Cheryan, M., 2001. Zein: the industrial protein from corn. Industrial Crops and Products, 13(3), 171–192.

Singh, N., Singh, S., and Shevkani, K., 2011. Maize: Composition, bioactive constituents, and unleavened bread. In: Flour and Breads and Their

Fortification in Health and Disease Prevention, (Eds.) Preedy, V.R., Watson, R.R., Patel, V.B., Elsevier, Oxford, UK, pp. 89-99.

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

Steadman, K., Burgoon, M., Lewis, B., Edwardson, S., Obendorf, R., 2001. Minerals, phytic acid, tannin and rutin in buckwheat seed milling fractions. Journal of the Science of Food and Agriculture, 81(11), 1094-1100.

Takahama, U., Tanaka, M., Hirota, S., 2011. Buckwheat flour and bread. In: Flour and Breads and Their Fortification in Health and Disease Prevention, (Eds.) Preedy, V.R., Watson, R.R., Patel, V.B., Elsevier, Oxford, UK, pp. 141-151.

Thompson, T., 2009. The nutritional quality of gluten-free foods. In: Gluten-free Food Science and Technology, (Eds.) Gallagher, E., Wiley-Blackwell, Oxford, UK, pp. 42-51.

Tiefenbacher, K. F., 2002. Haas Waffelmaschinen: Handbook of Wafer Technologie. Franz Haas Waffelmaschinen GmbH, Leobendorf, Austria.

Tomotake, H., Shimaoka, I., Kayashita, J., Yokoyama, F., Nakajoh, M., Kato, N., 2000. Buckwheat protein product suppresses gallstone formation and plasma cholesterol more strongly than soy protein isolate in hamsters. Journal of Nutrition, 130(7), 1670-1674.

Torbica, A., Hadnadev, M., Dapčević, T., 2010. Rheological, textural and sensory properties of gluten-free bread formulations based on rice and buckwheat flour. Food Hydrocolloids, 24(6-7), 626–632.

TSE, 1989. Wafer Standards TS 7474. Türk Standartları Enstitüsü, Ankara.

Turabi, E., Sumnu G., & Sahin, S., 2008. Rheological properties and quality of rice cakes formulated with different gums and an emulsifier blend. Food Hydrocolloids, 22(2), 305-312.

Turabi, E., Sumnu G., Sahin, S., 2010. Quantitative analysis of macro and micro-structure of gluten-free rice cakes containing different types of gums baked in different ovens. Food Hydrocolloids, 24(8), 755–762.

Wade, P., 1988. Biscuits, cookies and crackers. Vol. 1. The principles of the craft. Elsevier, New York, pp. 139-150.

Watanabe, M., 1998. Catechins as antioxidants form buckwheat (fagopyrum esculentum moench) groats. Journal of Agricultural and Food Chemistry, 46(3), 839-845.

Wei, Y., Zhang, G., Li, Z., 1995. Study on nutritive and physico-chemical properties of buckwheat flour. Nahrung, 39(1), 48-54.

Yeh, A.,2004. Preparation and applications of rice flour. In: Rice Chemistry and Technology, (Eds.) Champagne, E., American Association of Cereal Chemists, Inc., Minnesota, U.S.A., pp. 495-539.

Yıldız, O., 2010. The effects of formulation, baking and storage periods on the quality of gluten-free cake. PhD Thesis, Yuzuncu Yıl University, Van.

## APPENDIX A

## ANOVA & DUNCAN TEST TABLES

**Table A.1** ANOVA and Duncan Single Range Test for water loss of wafer sheets containing different types of flours in different combinations.

**Samples:** 1. Rice flour; 2. Rice flour: Corn flour 80:20; 3. Rice flour: Corn flour 60:40; 4. Rice flour: Corn flour 40:60; 5. Rice flour: Buckwheat flour 80:20; 6. Rice flour: Buckwheat flour 60:40; 7. Rice flour: Buckwheat flour 40:60; 8. Rice flour: Chestnut flour 80:20; 9. Wheat Flour

**1-Way ANOVA**

The SAS System

The GLM Procedure

Class Level Information

| Class | Levels | Values |
|---|---|---|
| X | 9 | 1 2 3 4 5 6 7 8 9 |

Number of Observations Read 18

Number of Observations Used 18

Dependent Variable: Y

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 8 | 426.6762524 | 53.3345316 | 293.47 | <.0001 |
| Error | 9 | 1.6356160 | 0.1817351 | | |
| Corrected Total | 17 | 428.3118684 | | | |

| R-Square | Coeff Var | Root MSE | Y Mean |
|---|---|---|---|
| 0.996181 | 0.703560 | 0.426304 | 60.59244 |

| Source | DF | Type I SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 4 | 426.6762524 | 53.3345316 | 293.47 | <.0001 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 4 | 426.6762524 | 53.3345316 | 293.47 | <.0001 |

Duncan's Multiple Range Test for Y

| | |
|---|---|
| Alpha | 0.05 |
| Error Degrees of Freedom | 9 |
| Error Mean Square | 0.181735 |

| Duncan Grouping | Mean | N | X |
|---|---|---|---|
| A | 70.4000 | 2 | 9 |
| B | 66.9000 | 2 | 7 |
| C | 63.1480 | 2 | 6 |
| D | 60.1200 | 2 | 8 |
| E | 58.1320 | 2 | 5 |
| E | 57.9160 | 2 | 4 |
| F | 56.6400 | 2 | 1 |
| F | 56.4160 | 2 | 3 |
| F | 55.6600 | 2 | 2 |

**Table A.2** ANOVA and Duncan Single Range Test for hardness of wafer sheets containing different types of flours in different combinations.

**Samples:** 1. Rice flour; 2. Rice flour: Corn flour 80:20; 3. Rice flour: Corn flour 60:40; 4. Rice flour: Corn flour 40:60; 5. Rice flour: Buckwheat flour 80:20; 6. Rice flour: Buckwheat flour 60:40; 7. Rice flour: Buckwheat flour 40:60; 8. Rice flour: Chestnut flour 80:20; 9. Wheat Flour

**1-Way ANOVA**

The SAS System

The GLM Procedure

Class Level Information

| Class | Levels | Values |
|---|---|---|
| X | 9 | 1 2 3 4 5 6 7 8 9 |

Number of Observations Read 45

Number of Observations Used 45

Dependent Variable: Y

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 8 | 38234148.35 | 4779268.54 | 7.87 | <.0001 |
| Error | 36 | 21867901.93 | 607441.72 | | |
| Corrected Total | 44 | 60102050.28 | | | |

| R-Square | Coeff Var | Root MSE | Y Mean |
|---|---|---|---|
| 0.636154 | 28.46495 | 779.3855 | 2738.054 |

| Source | DF | Type I SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 8 | 38234148.35 | 4779268.54 | 7.87 | <.0001 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 8 | 38234148.35 | 4779268.54 | 7.87 | <.0001 |

Duncan's Multiple Range Test for Y

| | |
|---|---|
| Alpha | 0.05 |
| Error Degrees of Freedom | 36 |
| Error Mean Square | 607441.7 |

| Duncan Grouping | Mean | N | X |
|---|---|---|---|
| A | 3901.4 | 5 | 2 |
| A | 3628.0 | 5 | 1 |
| A | 3527.2 | 5 | 3 |
| A | 3526.7 | 5 | 5 |
| A | 3108.1 | 5 | 4 |
| B | 1928.4 | 5 | 8 |
| B | 1886.2 | 5 | 6 |
| B | 1597.7 | 5 | 9 |
| B | 1538.7 | 5 | 7 |

**Table A.3** ANOVA and Duncan Single Range Test for fracturability of wafer sheets containing different types of flours in different combinations.

**Samples:** 1. Rice flour; 2. Rice flour: Corn flour 80:20; 3. Rice flour: Corn flour 60:40; 4. Rice flour: Corn flour 40:60; 5. Rice flour: Buckwheat flour 80:20; 6. Rice flour: Buckwheat flour 60:40; 7. Rice flour: Buckwheat flour 40:60; 8. Rice flour: Chestnut flour 80:20; 9. Wheat Flour

**1-Way ANOVA**

The SAS System

The GLM Procedure

Class Level Information

| Class | Levels | Values |
|---|---|---|
| X | 9 | 1 2 3 4 5 6 7 8 9 |

Number of Observations Read 18

Number of Observations Used 18

Dependent Variable: Y

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 8 | 951815.446 | 118976.931 | 9.37 | 0.0015 |
| Error | 9 | 114333.705 | 12703.745 | | |
| Corrected Total | 17 | 1066149.152 | | | |

| R-Square | Coeff Var | Root MSE | Y Mean |
|---|---|---|---|
| 0.892760 | 16.01560 | 112.7109 | 703.7569 |

| Source | DF | Type I SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 8 | 951815.4464 | 118976.9308 | 9.37 | 0.0015 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 8 | 951815.4464 | 4779268.54 | 9.37 | 0.0015 |

Duncan's Multiple Range Test for Y

| | |
|---|---|
| Alpha | 0.05 |
| Error Degrees of Freedom | 9 |
| Error Mean Square | 12703.75 |

| Duncan Grouping | Mean | N | X |
|---|---|---|---|
| A | 1047.5 | 2 | 2 |
| AB | 974.6 | 2 | 3 |
| AB | 964.0 | 2 | 4 |
| BC | 715.7 | 2 | 6 |
| CD | 662.7 | 2 | 9 |
| CDE | 604.6 | 2 | 5 |
| CDE | 562.9 | 2 | 7 |
| DE | 430.0 | 2 | 1 |
| E | 371.8 | 2 | 8 |

**Table A.4** ANOVA for L* values of wafer sheets containing different types of flours in different combinations.

**Samples:** 1. Upper sheets 2. Lower sheets

**1-Way ANOVA**

The SAS System

The GLM Procedure

Class Level Information

| Class | Levels | Values |
|---|---|---|
| X | 2 | 1 2 |

Number of Observations Read 54

Number of Observations Used 54

Dependent Variable: Y

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 1 | 10.755741 | 10.755741 | 0.33 | 0.5707 |
| Error | 52 | 1717.485393 | 33.028565 | | |
| Corrected Total | 53 | 1728.241133 | | | |

| R-Square | Coeff Var | Root MSE | Y Mean |
|---|---|---|---|
| 0.006224 | 8.316467 | 5.747048 | 69.10444 |

| Source | DF | Type I SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 1 | 10.75574074 | 10.75574074 | 0.33 | 0.5707 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 1 | 10.75574074 | 10.75574074 | 0.33 | 0.5707 |

**Table A.5** ANOVA and Duncan Single Range Test for L* values of wafer sheets containing different types of flours in different combinations.

**Samples:** 1. Rice flour; 2. Rice flour: Corn flour 80:20; 3. Rice flour: Corn flour 60:40; 4. Rice flour: Corn flour 40:60; 5. Rice flour: Buckwheat flour 80:20; 6. Rice flour: Buckwheat flour 60:40; 7. Rice flour: Buckwheat flour 40:60; 8. Rice flour: Chestnut flour 80:20; 9. Wheat Flour *both upper and lower sheets

**1-Way ANOVA**

The SAS System

The GLM Procedure

Class Level Information

| Class | Levels | Values |
|---|---|---|
| X | 9 | 1 2 3 4 5 6 7 8 9 |

Number of Observations Read 54

Number of Observations Used 54

Dependent Variable: Y

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 8 | 1604.268867 | 200.533608 | 72.79 | <.0001 |
| Error | 45 | 123.972267 | 2.754939 | | |
| Corrected Total | 53 | 1728.241133 | | | |

| R-Square | Coeff Var | Root MSE | Y Mean |
|---|---|---|---|
| 0.928267 | 2.401873 | 1.659801 | 69.10444 |

| Source | DF | Type I SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 8 | 1604.268867 | 200.533608 | 72.79 | <.0001 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 8 | 1604.268867 | 200.533608 | 72.79 | <.0001 |

Duncan's Multiple Range Test for Y

| | |
|---|---|
| Alpha | 0.05 |
| Error Degrees of Freedom | 45 |
| Error Mean Square | 2.754939 |

| Duncan Grouping | Mean | N | X |
|---|---|---|---|
| A | 75.1450 | 6 | 1 |
| A | 74.2167 | 6 | 9 |
| B | 71.9567 | 6 | 2 |
| C | 69.6150 | 6 | 3 |
| C | 69.5467 | 6 | 6 |
| C | 69.3500 | 6 | 7 |
| C | 69.2750 | 6 | 5 |
| C | 67.6583 | 6 | 4 |
| D | 55.1767 | 6 | 8 |

**Table A.6** ANOVA for a* values of wafer sheets containing different types of flours in different combinations.

**Samples:** 1. Upper sheets 2. Lower sheets

**1-Way ANOVA**

The SAS System

The GLM Procedure

Class Level Information

| Class | Levels | Values |
|---|---|---|
| X | 2 | 1 2 |

Number of Observations Read 54

Number of Observations Used 54

Dependent Variable: Y

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 1 | 63.6352667 | 63.6352667 | 6.02 | 0.0176 |
| Error | 52 | 549.9594667 | 10.5761436 | | |
| Corrected Total | 53 | 613.5947333 | | | |

| R-Square | Coeff Var | Root MSE | Y Mean |
|---|---|---|---|
| 0.103709 | 62.03664 | 3.252098 | 5.242222 |

| Source | DF | Type I SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 1 | 63.63526667 | 63.63526667 | 6.02 | 0.0176 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 8 | 63.63526667 | 63.63526667 | 6.02 | 0.0176 |

Duncan's Multiple Range Test for Y

| | |
|---|---|
| Alpha | 0.05 |
| Error Degrees of Freedom | 52 |
| Error Mean Square | 10.57614 |

| Duncan Grouping | Mean | N | X |
|---|---|---|---|
| A | 6.3278 | 27 | 2 |
| B | 4.1567 | 27 | 1 |

**Table A.7** ANOVA and Duncan Single Range Test for a* values of wafer sheets containing different types of flours in different combinations.

**Samples:** 1. Rice flour; 2. Rice flour: Corn flour 80:20; 3. Rice flour: Corn flour 60:40; 4. Rice flour: Corn flour 40:60; 5. Rice flour: Buckwheat flour 80:20; 6. Rice flour: Buckwheat flour 60:40; 7. Rice flour: Buckwheat flour 40:60; 8. Rice flour: Chestnut flour 80:20; 9. Wheat Flour *upper sheets

**1-Way ANOVA**

The SAS System

The GLM Procedure

Class Level Information

| Class | Levels | Values |
|---|---|---|
| X | 9 | 1 2 3 4 5 6 7 8 9 |

Number of Observations Read 27

Number of Observations Used 27

Dependent Variable: Y

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 8 | 212.3896667 | 26.5487083 | 157.22 | <.0001 |
| Error | 18 | 3.0396000 | 0.1688667 | | |
| Corrected Total | 26 | 215.4292667 | | | |

| R-Square | Coeff Var | Root MSE | Y Mean |
|---|---|---|---|
| 0.985890 | 9.992989 | 0.410934 | 4.112222 |

| Source | DF | Type I SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 8 | 212.3896667 | 26.5487083 | 157.22 | <.0001 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 8 | 212.3896667 | 26.5487083 | 157.22 | <.0001 |

Duncan's Multiple Range Test for Y

| | |
|---|---|
| Alpha | 0.05 |
| Error Degrees of Freedom | 18 |
| Error Mean Square | 0.168867 |

| Duncan Grouping | Mean | N | X |
|---|---|---|---|
| A | 8.9833 | 3 | 8 |
| B | 7.5033 | 3 | 4 |
| C | 5.9767 | 3 | 3 |
| D | 3.8100 | 3 | 7 |
| D | 3.6567 | 3 | 2 |
| D | 3.2167 | 3 | 5 |
| D | 3.1900 | 3 | 6 |
| E | 1.2400 | 3 | 9 |
| F | -0.5667 | 3 | 1 |

**Table A.8** ANOVA and Duncan Single Range Test for a* values of wafer sheets containing different types of flours in different combinations.

**Samples:** 1. Rice flour; 2. Rice flour: Corn flour 80:20; 3. Rice flour: Corn flour 60:40; 4. Rice flour: Corn flour 40:60; 5. Rice flour: Buckwheat flour 80:20; 6. Rice flour: Buckwheat flour 60:40; 7. Rice flour: Buckwheat flour 40:60; 8. Rice flour: Chestnut flour 80:20; 9. Wheat Flour *lower sheets

**1-Way ANOVA**

The SAS System

The GLM Procedure

Class Level Information

| Class | Levels | Values |
|---|---|---|
| X | 9 | 1 2 3 4 5 6 7 8 9 |

Number of Observations Read 27

Number of Observations Used 27

Dependent Variable: Y

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 8 | 330.6952667 | 41.3369083 | 54.08 | <.0001 |
| Error | 18 | 13.7576000 | 0.7643111 | | |
| Corrected Total | 26 | 344.4528667 | | | |

| R-Square | Coeff Var | Root MSE | Y Mean |
|---|---|---|---|
| 0.960060 | 13.81605 | 0.874249 | 6.327778 |

| Source | DF | Type I SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 8 | 330.6952667 | 41.3369083 | 54.08 | <.0001 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 8 | 330.6952667 | 41.3369083 | 54.08 | <.0001 |

Duncan's Multiple Range Test for Y

| | |
|---|---|
| Alpha | 0.05 |
| Error Degrees of Freedom | 18 |
| Error Mean Square | 0.764311 |

| Duncan Grouping | Mean | N | X |
|---|---|---|---|
| A | 13.4433 | 3 | 8 |
| B | 9.9667 | 3 | 4 |
| C | 7.7967 | 3 | 3 |
| D | 5.3467 | 3 | 7 |
| D | 5.3067 | 3 | 5 |
| D | 5.1067 | 3 | 6 |
| D | 4.9233 | 3 | 9 |
| D | 4.7533 | 3 | 2 |
| E | 0.3067 | 3 | 1 |

**Table A.9** ANOVA for b* values of wafer sheets containing different types of flours in different combinations.

**Samples:** 1. Upper sheets 2. Lower sheets

**1-Way ANOVA**

The SAS System

The GLM Procedure

Class Level Information

| Class | Levels | Values |
|---|---|---|
| X | 2 | 1 2 |

Number of Observations Read 54

Number of Observations Used 54

Dependent Variable: Y

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 1 | 9.779267 | 9.779267 | 0.34 | 0.5595 |
| Error | 52 | 1474.124415 | 28.348546 | | |
| Corrected Total | 53 | 1483.903681 | | | |

| R-Square | Coeff Var | Root MSE | Y Mean |
|---|---|---|---|
| 0.006590 | 18.97382 | 5.324335 | 28.06148 |

| Source | DF | Type I SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 1 | 9.77926667 | 9.77926667 | 0.34 | 0.5595 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 1 | 9.77926667 | 9.77926667 | 0.34 | 0.5595 |

Duncan's Multiple Range Test for Y

| | |
|---|---|
| Alpha | 0.05 |
| Error Degrees of Freedom | 52 |
| Error Mean Square | 28.34855 |

| Duncan Grouping | Mean | N | X |
|---|---|---|---|
| A | 28.487 | 27 | 1 |
| A | 27.636 | 27 | 2 |

**Table A.10** ANOVA and Duncan Single Range Test for b* values of wafer sheets containing different types of flours in different combinations.

**Samples:** 1. Rice flour; 2. Rice flour: Corn flour 80:20; 3. Rice flour: Corn flour 60:40; 4. Rice flour: Corn flour 40:60; 5. Rice flour: Buckwheat flour 80:20; 6. Rice flour: Buckwheat flour 60:40; 7. Rice flour: Buckwheat flour 40:60; 8. Rice flour: Chestnut flour 80:20; 9. Wheat Flour *both upper and lower sheets

**1-Way ANOVA**

The SAS System

The GLM Procedure

Class Level Information

| Class | Levels | Values |
|---|---|---|
| X | 9 | 1 2 3 4 5 6 7 8 9 |

Number of Observations Read 54

Number of Observations Used 54

Dependent Variable: Y

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 8 | 1258.770381 | 157.346298 | 31.45 | <.0001 |
| Error | 45 | 225.133300 | 5.002962 | | |
| Corrected Total | 53 | 1483.903681 | | | |

| R-Square | Coeff Var | Root MSE | Y Mean |
|---|---|---|---|
| 0.848283 | 7.970820 | 2.236730 | 28.06148 |

| Source | DF | Type I SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 8 | 1258.770381 | 157.346298 | 31.45 | <.0001 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 8 | 1258.770381 | 157.346298 | 31.45 | <.0001 |

Duncan's Multiple Range Test for Y

| | |
|---|---|
| Alpha | 0.05 |
| Error Degrees of Freedom | 45 |
| Error Mean Square | 5.002962 |

| Duncan Grouping | Mean | N | X |
|---|---|---|---|
| A | 36.787 | 6 | 4 |
| A | 34.332 | 6 | 3 |
| B | 30.330 | 6 | 2 |
| B | 29.858 | 6 | 8 |
| C | 26.270 | 6 | 5 |
| C | 25.028 | 6 | 9 |
| C | 24.902 | 6 | 6 |
| CD | 23.582 | 6 | 1 |
| D | 21.465 | 6 | 7 |

**Table A.11** ANOVA for total color difference values of wafer sheets containing different types of flours in different combinations.

**Samples:** 1. Upper sheets 2. Lower sheets

**1-Way ANOVA**

The SAS System

The GLM Procedure

Class Level Information

| Class | Levels | Values |
|---|---|---|
| X | 2 | 1 2 |

Number of Observations Read 48

Number of Observations Used 48

Dependent Variable: Y

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 1 | 0.008008 | 0.008008 | 0.00 | 0.9885 |
| Error | 46 | 1764.907117 | 38.367546 | | |
| Corrected Total | 47 | 1764.915125 | | | |

| R-Square | Coeff Var | Root MSE | Y Mean |
|---|---|---|---|
| 0.000005 | 52.81172 | 6.194154 | 11.72875 |

| Source | DF | Type I SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 1 | 0.00800833 | 0.00800833 | 0.00 | 0.9885 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 1 | 0.00800833 | 0.00800833 | 0.00 | 0.9885 |

Duncan's Multiple Range Test for Y

| | |
|---|---|
| Alpha | 0.05 |
| Error Degrees of Freedom | 46 |
| Error Mean Square | 38.36755 |

| Duncan Grouping | Mean | N | X |
|---|---|---|---|
| A | 11.742 | 27 | 2 |
| A | 11.742 | 27 | 1 |

**Table A.12** ANOVA and Duncan Single Range Test for total color difference values of wafer sheets containing different types of flours in different combinations.

**Samples:** 2. Rice flour: Corn flour 80:20; 3. Rice flour: Corn flour 60:40; 4. Rice flour: Corn flour 40:60; 5. Rice flour: Buckwheat flour 80:20; 6. Rice flour: Buckwheat flour 60:40; 7. Rice flour: Buckwheat flour 40:60; 8. Rice flour: Chestnut flour 80:20; 9. Wheat Flour *both upper and lower sheets

**1-Way ANOVA**

The SAS System

The GLM Procedure

Class Level Information

| Class | Levels | Values |
|---|---|---|
| X | 9 | 2 3 4 5 6 7 8 9 |

Number of Observations Read 48

Number of Observations Used 48

Dependent Variable: Y

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 7 | 1679.778733 | 239.968390 | 113.11 | <.0001 |
| Error | 40 | 84.861033 | 2.121526 | | |
| Corrected Total | 47 | 1764.639767 | | | |

| R-Square | Coeff Var | Root MSE | Y Mean |
|---|---|---|---|
| 0.951910 | 12.41639 | 1.456546 | 11.73083 |

| Source | DF | Type I SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 7 | 1679.778733 | 239.968390 | 113.11 | <.0001 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 7 | 1679.778733 | 239.968390 | 113.11 | <.0001 |

Duncan's Multiple Range Test for Y

| | |
|---|---|
| Alpha | 0.05 |
| Error Degrees of Freedom | 40 |
| Error Mean Square | 2.121526 |

| Duncan Grouping | Mean | N | X |
|---|---|---|---|
| A | 24.0517 | 6 | 8 |
| B | 17.6467 | 6 | 4 |
| C | 14.0050 | 6 | 3 |
| D | 8.6550 | 6 | 2 |
| D | 8.0617 | 6 | 7 |
| D | 8.0000 | 6 | 5 |
| DE | 7.3450 | 6 | 6 |
| E | 6.0817 | 6 | 9 |

**Table A.13** ANOVA and Duncan Single Range Test for color acceptability values of wafer sheets containing different types of flours in different combinations.

**Samples:** 1. WF; 2.RF; 3. RF:CF 40:60; 4. RF:ChF 80:20; 5. RF:BF 60:40

**1-Way ANOVA**

The SAS System

The GLM Procedure

Class Level Information

| Class | Levels | Values |
|---|---|---|
| X | 9 | 1 2 3 4 5 |

Number of Observations Read 50

Number of Observations Used 50

Dependent Variable: Y

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 4 | 48.92000000 | 12.23000000 | 14.87 | <.0001 |
| Error | 45 | 37.00000000 | 0.82222222 | | |
| Corrected Total | 49 | 85.92000000 | | | |

| R-Square | Coeff Var | Root MSE | Y Mean |
|---|---|---|---|
| 0.569367 | 29.82779 | 0.906765 | 3.040000 |

| Source | DF | Type I SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 4 | 48.92000000 | 12.23000000 | 14.87 | <.0001 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 4 | 48.92000000 | 12.23000000 | 14.87 | <.0001 |

Duncan's Multiple Range Test for Y

| | |
|---|---|
| Alpha | 0.05 |
| Error Degrees of Freedom | 45 |
| Error Mean Square | 0.822222 |

| Duncan Grouping | Mean | N | X |
|---|---|---|---|
| A | 4.2000 | 10 | 1 |
| A | 4.1000 | 10 | 2 |
| B | 3.0000 | 10 | 4 |
| C | 2.1000 | 10 | 3 |
| C | 1.8000 | 10 | 5 |

**Table A.14** ANOVA and Duncan Single Range Test for texture acceptability values of wafer sheets containing different types of flours in different combinations.

**Samples:** 1. WF; 2.RF; 3. RF:CF 40:60; 4. RF:ChF 80:20; 5. RF:BF 60:40

**1-Way ANOVA**

The SAS System

The GLM Procedure

Class Level Information

| Class | Levels | Values |
|---|---|---|
| X | 9 | 1 2 3 4 5 |

Number of Observations Read 50

Number of Observations Used 50

Dependent Variable: Y

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 4 | 48.92000000 | 12.23000000 | 14.87 | <.0001 |
| Error | 45 | 37.00000000 | 0.82222222 | | |
| Corrected Total | 49 | 85.92000000 | | | |

| R-Square | Coeff Var | Root MSE | Y Mean |
|---|---|---|---|
| 0.569367 | 29.82779 | 0.906765 | 3.040000 |

| Source | DF | Type I SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 4 | 48.92000000 | 12.23000000 | 14.87 | <.0001 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 4 | 48.92000000 | 12.23000000 | 14.87 | <.0001 |

Duncan's Multiple Range Test for Y

| | |
|---|---|
| Alpha | 0.05 |
| Error Degrees of Freedom | 45 |
| Error Mean Square | 0.822222 |

| Duncan Grouping | Mean | N | X |
|---|---|---|---|
| A | 4.2000 | 10 | 1 |
| A | 4.1000 | 10 | 3 |
| B | 3.0000 | 10 | 2 |
| C | 2.1000 | 10 | 5 |
| C | 1.8000 | 10 | 4 |

**Table A.15** ANOVA and Duncan Single Range Test for taste acceptability values of wafer sheets containing different types of flours in different combinations.

**Samples:** 1. WF; 2.RF; 3. RF:CF 40:60; 4. RF:ChF 80:20; 5. RF:BF 60:40

**1-Way ANOVA**

The SAS System

The GLM Procedure

Class Level Information

| Class | Levels | Values |
|---|---|---|
| X | 9 | 1 2 3 4 5 |

Number of Observations Read 50

Number of Observations Used 50

Dependent Variable: Y

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 4 | 25.60000000 | 6.40000000 | 6.41 | 0.0004 |
| Error | 45 | 44.90000000 | 0.99777778 | | |
| Corrected Total | 49 | 70.50000000 | | | |

| R-Square | Coeff Var | Root MSE | Y Mean |
|---|---|---|---|
| 0.363121 | 34.44442 | 0.998888 | 2.900000 |

| Source | DF | Type I SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 4 | 25.60000000 | 6.40000000 | 6.41 | 0.0004 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| X | 4 | 25.60000000 | 6.40000000 | 6.41 | 0.0004 |

Duncan's Multiple Range Test for Y

| | |
|---|---|
| Alpha | 0.05 |
| Error Degrees of Freedom | 45 |
| Error Mean Square | 0.997778 |

| Duncan Grouping | Mean | N | X |
|---|---|---|---|
| A | 4.2000 | 10 | 1 |
| B | 3.1000 | 10 | 5 |
| B | 2.6000 | 10 | 2 |
| B | 2.4000 | 10 | 4 |
| B | 2.2000 | 10 | 3 |

## APPENDIX B

## PICTURE OF BAKING MACHINE

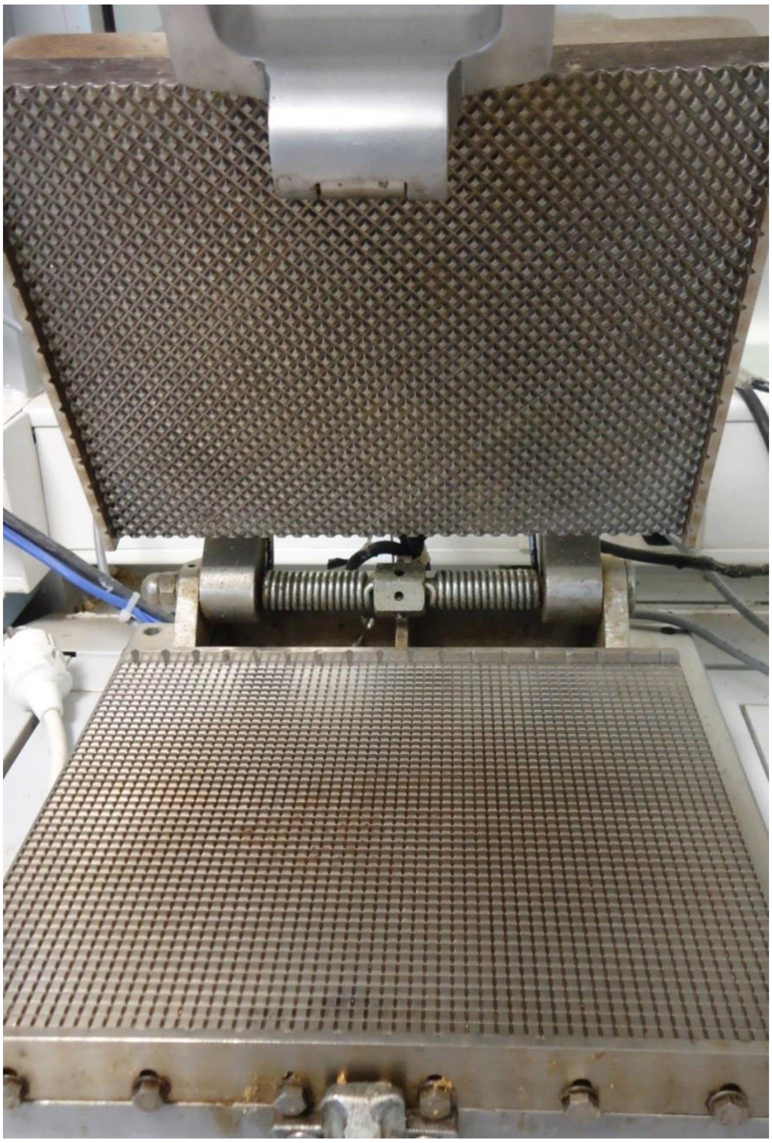

**Figure B.1** Baking machine (Franz HAAS, Vienna, Austria)