“EVALUATION OF THE EFFECTS OF LEGUME FLOUR INCORPORATION INTO WAFER SHEETS

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ABSTRACT

EVALUATION OF THE EFFECTS OF LEGUME FLOUR INCORPORATION INTO WAFER SHEETS

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Changing consumer demands have directed food industry into development of alternative food products in terms of nutrition, authenticity, innovation and functionality.

The main objective of this study was to develop wafer sheets by partial replacement of wheat flour by bean, carob, chickpea and lentil flours. In this regard, firstly nutritional components of the flours were analyzed. Wheat flour was replaced by 10%, 20% and 30% legume flour and its effects on specific gravity and rheology of the batters were studied. In addition, the effects of these flours on wafer sheet quality in terms of weight loss, hardness, color and sorption behavior were investigated. Only wheat flour containing samples were used as the control.

Legume flour addition did not affect specific gravity of the batters. From rheological analyses, all batters were found to obey Power law with shear thinning behavior. Added flour type affected both consistency coefficient and flow behavior index, whereas legume flour content only affected flow behavior index. Lentil flour added samples had the lowest consistency coefficient and the highest flow behavior index. Increasing legume flour content decreased weight loss of wafer sheets upon baking. Lentil flour added samples gave the same weight loss as the control wafer. Hardness values increased when legume flour was added and increased further by increasing legume flour concentration. Carob flour, chickpea flour and 10% lentil flour containing samples had the same hardness values to the control. Color of 10% chickpea and 10% lentil flour samples were the same as the control wafer. Sorption analyses of the wafers indicated localized sorption and similar properties of water in multilayers to those of bulk water. The parameters of sorption implied that lentil and chickpea flour replacement maintained the same monolayer moisture content as the control wafer. It was concluded that wafer sheets with 10% lentil flour replacement had the highest quality.

Keywords: Wafer, alternative food, legume flour, rheology, sorption

ÖZ

GOFRET YAPRAĞINDA BAKLAGİL UNU KULLANIMI ETKİLERİNİN DEĞERLENDİRİLMESİ

Tufan, Büşra
Yüksek Lisans, Gıda Mühendisliği Bölümü
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Tüketici taleplerinin değişmesi, gıda endüstrisini besleyicilik, özgünlük, inovasyon ve fonksiyonellik açısından alternatif gıda ürünlerinin geliştirilmesine yöneltmiştir.

Bu çalışmada temel olarak buğday ununun kuru fasulye, keçiboynuzu, nohut ve mercimek unlarının kısmi ikamesiyle gofret yaprağı geliştirilmesi amaçlanmıştır. Bu bağlamda, ilk olarak unların besin ögesi analizleri yapılmıştır. Buğday unu, %10, %20 ve %30 oranında baklagil unları ile ikame edilmiştir. Alternatif unların hamurun özgül ağırlığı ve reolojisi üzerindeki etkisi incelenmiştir. Ayrıca söz konusu unların, gofret yaprağının ağırlık kaybı, sertlik, renk ve sorpsiyon davranışı gibi kalite özelliklerine etkileri araştırılmıştır. Kontrol olarak sadece buğday unu içeren örnekler kullanılmıştır.

Baklagil unu ikamesi, hamurların özgül ağırlığını etkilememiştir. Reolojik analizlerden, tüm hamurların Power yasasına uydukları ve kayma ile incelen davranış gösterdikleri görülmüştür. Eklenen un çeşidi hem kıvam indeksi hem de akış davranışı indeksini etkilerken; miktarı sadece akış davranışı indeksini etkilemiştir. Mercimek unu ikameli örnekler en düşük kıvam indeksi ve en yüksek akış davranış indeksine sahip olmuştur. Artan baklagil unu içeriği, pişirme sonrasında gofret yapraklarının ağırlık kaybını azaltmıştır. Yalnız %10 mercimek unu ikame edilmiş örnekler kontrol gofretininkinden daha yüksek ağırlık kaybı değerlerine sahip olmuştur. Sertlik değerleri baklagil un ilavesi ile artmış, eklenen miktarın artması ile daha da artış göstermiştir. Keçiboynuzu unu, nohut unu ve %10 mercimek unu ikameli örnekler kontrole en yakın tekstürü vermiştir. Kontrole en yakın renk değerine sahip örnekler, %10 nohut unu ve %10 mercimek unu ikameli örnekler olmuştur. Gofretlerin sorpsiyon analizleri, lokalize sorpsiyon olduğunu ve multimoleküler su katmanlarının özelliklerinin yığın suya benzer olduğunu göstermiştir. Sorpsiyon parametreleri, %10 mercimek unu ile %10 ve %20 nohut unu ikameli örneklerin kontrolün monomoleküler su içeriği ile aynı olduğunu göstermiştir. Sonuç olarak %10 mercimek unu ikameli gofret yaprakları en yüksek kaliteye sahip bulunmuştur.

Anahtar kelimeler: Gofret, alternatif gıda, baklagil unu, reoloji, sorpsiyon

To My Beloved Family

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LIST OF ABBREVIATIONS

ANOVA: Analysis of Variance

B: Bean

CA: Carob

CAGR: Compound Annual Growth Rate

CH: Chickpea

FMCG: Fast-Moving Consumer Goods

GAB Model: Guggenheim-Anderson-de Boer Model

L: Lentil

RH: Relative Humidity

WHC: Water Holding Capacity

CHAPTER 1

INTRODUCTION

1.1 Fast-Moving Consumer Goods Market

Fast-Moving Consumer Goods (FMCG) are the goods that are relatively low in price, easily purchased and consumed in frequent intervals (Dibb, Simkin, Pride, & Ferrel, 2006). Food and beverages, household items, clothing, personal hygiene, pet care products and tobacco are the major subgroups of the FMCGs. Food and beverages categories include the bakeries, vegetables and fruits, meat and dairy products, functional and healthy foods, frozen food, confectionary and snacks, seasonings, alcoholic and non-alcoholic beverages (Statista, n.d.).

Among the FMCG products, snack foods constitute an important part of the daily nutrition of individuals and poses a profit-generating sector. According to a global marketing research firm Nielsen, between 2013 and 2014, $ 374 billion was spent on snack foods globally. While America has the biggest share with $ 167 billion, sales are growing more rapidly in developing regions such as Asia-Pacific by 4%, Latin America by 9% and Middle East by 5%. Another result is that confectionaries and sweets have the biggest share in snack sales globally as well in Europe and Middle East. The percentage of respondents of Nielsen's study, who mention that they eat chocolate in 30 days, is 64%. However, savory snacks is the fastest-growing class among all categories. The reason behind this fact is suggested to be the replacement of the meals by such snacks. It indicates that although the consumers still opt for sweets mostly, preferences are shifted towards a more health-focused direction. One third of the respondents give importance to the lowness in calories (30%), salt (34%) and sugar (34%). Natural ingredients are attributed to the highest importance by 45% and moderate importance by 32%. One-third of the participants prefer nutritional ingredients such as whole grain (29%), high protein (31%) and fiber (37%) foods. Snacks are consumed by 76% of the participants to suppress the hunger and by 45% for the meal replacement (Nielsen, 2014).

Awareness of the consumers about the food nutrition and health as well as the change in daily routines brought healthy snacks to the forefront. In 2016, healthy snacks market reached to $ 21.1 billion with expected Compound Annual Growth Rate (CAGR) by 5.1%. Specifically, adult consumers seem to prefer healthy snacks for on-the-go consumption while the middle-aged and young consumers for the healthier diet habits. Nutrition is the other factor determining the consumer preference. Hence; product diversity, nutrition, taste and affordability have become the focus of the healthy snack manufacturers (Grand View Research, 2017).

Healthy snack food trends cover the use of pulses (lentil, chickpea, bean, pea), vegetables (spinach, kale, sweet potato), grain formulations (ancient, whole, multi) in the U.S. Globally, crackers and salty snacks with alternative ingredients has grown by 5.2% in 2016. The two prominent segments in this category are the snacks based on vegetables (non-potato) and pulses. Among pulse-based snacks, those based on chickpea is the fastest growing segment (Research and Markets, 2017).

Overall, by 2021, the snack food market is predicted to rise to $ 620 billion globally. Increasing awareness of people on health and nutrition, the restrictions by government authorities, changing lifestyles and searching for convenient food, innovative and different taste pursuits and seek for the organic or functional foods seem to expand the healthy snack food sector in the upcoming years (Research and Markets, 2015).

1.2 Wafer

Wafer is a special type of light, thin and crispy product produced by rapid baking after stacking a liquid batter between two hot plates. 'Wafer' term is used for a product range of plain wafers, hollow wafers, sugar cones, wafer sticks, waffles. However, only the plain wafers would be considered under the scope of this study.

Wafers are thought to be stemming from the thin holy breads baked between two metallic plates by the monks as religious symbols. However, the first wafers in today's sense were produced in mid-19th century in Netherlands. The first ovens were operated after World War I, and automatized after 1950s (Manley,2011).

According to the report of a market research company Technavio, market trends will be based on three areas: gluten free and organic wafer products, new flavors and emerging markets. Innovative packaging poses another important demand of the market for the shelf life and attractiveness, also protection against damage on the shape, moisture transmission and radiation. The study suggests that wafer market achieved $ 44.06 billion in 2016 and will reach to $ 55 billion value by 2021 with 4.43% CAGR increase (Technavio, 2017).

Wafers are rarely consumed as they are rather tasteless and serve as a carrier for another material. They are generally sold by sandwiching between caramel or cream, being enrobed by chocolate and being embedded in moulded chocolate. In a few countries, wafers are sold for culinary use such as serving with butter, cheese or ice cream (Manley,2011).

Wafer production differs from other baking processes in terms of the structure of the batter and the baking equipment. Wafer semi-products should be handled carefully from the initial mixing of batter till packaging of the finished products.

Wafer batter is a liquid like batter with moisture content of 63-66%. This is required for the uniform spreading of batter on the baking plates and resulting in uniform texture and color of the wafer sheet (Tiefenbacher, 1998). Wafer batter is obtained by mixing all the materials in water. The mixing should be a rapid stirring instead of action like kneading as in the other types of bakery products. The purpose of the stirring is to disperse all the materials without forming gluten strands, otherwise batter depositors would be blocked or the spreading of the batter on the baking plate would be difficult. For this reason; short time stirring with higher shear rate with cold water is required (Townsend, 1990).

Following the mixing for 2.5-6.0 min, the batter is screened in order to discard the lumps and air bubbles, then pumped into the wafer oven. Wafer oven has a distinctive design from the other baking ovens. It is generally composed of a set of plate pairs fixed from one side to a chain. The set of plates are continuously circulated in a chamber where they are heated by electric heaters or gas flames individually. After deposition of the wafer batter through the small holes of the depositor onto the baking plates, immediately the upper plate is overlapped onto the bottom plate and the two plates are latched. This enables the formed steam to spread the batter evenly to the corners as well as expel of excess batter and steam throughout the small vents placed at the edges of the plates. Each plate pair is filled with batter successively and upon baking at the end of the cycle, upper plate is opened and produced wafer sheet is removed automatically. Generally 60, 45 or 30 plate paired ovens are used in industrial scale with baking time varying from 1.5 to 3.0 min (Manley,2011). Baking temperatures are usually kept between 140-205 °C (Tiefenbacher, 1998). Since the batter exposes to the lower plate more, bottom plate temperature should be lower than the temperature of upper plate for uniformity of baking and final color.

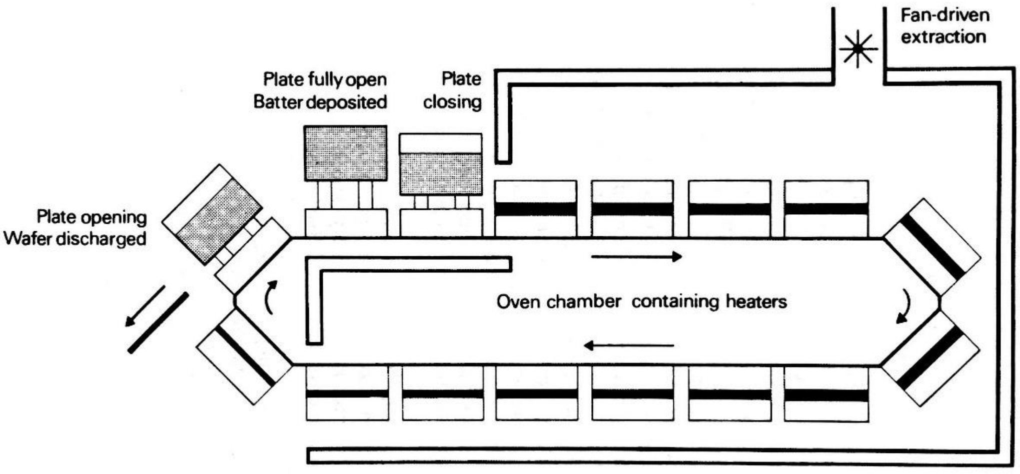

Figure 1.1 Wafer oven (Townsend, 1990)

Wafer sheets are highly prone to moisture absorption from the surroundings. This causes an increase in the wafer size following the baking. Especially for the wafers to be used in moulded chocolate or enrobed with chocolate, this uncontrolled swelling could cause crack in chocolate. By conditioning, wafer is encouraged to pick up moisture and complete the swelling before the enrobing (Townsend, 1990). In usual conditioning practice, wafer sheets are conditioned by passing through a chamber at 35-60°C and 60-90% humidity for 16-20 min.

The next step in production is cream or caramel sandwiching, chocolate enrobing or placement of wafer in molded chocolate. 'Wafer book' is built by the placement of creamed wafer sheets on top of another. After cooling at 10-12 °C with bone dry air, wafer books are cut and packaged by itself or after combined with chocolate. The wafer composition of the final product, is about 30% (w/w) (Manley, 2011). To keep the wafer crispy during the shelf life, moisture level of the cream ingredients should be lower than certain levels. Also, use of anhydrous fats, well-roasted nuts, fat-based flavors and low moist rework is important (Tiefenbacher, 1998).

The basic recipes for a typical wafer batter consist of water, flour, oil, emulsifier and leavening agents. However, different formulations could be handled according to the product and process specification, raw material availability or costs (Table 1.1).

Table 1.1 Typical wafer formulations (adapted from Manley, 2011)

	1	2	3	4	5
Flour	100	100	100	100	100
Sugar	3.5	1.7	-	-	-
Oil or fat	2.7	5.3	-	2.4	-
Skimmed milk powder	3.1	1.7	-	-	2.5
Dried egg powder	0.33	2.9	-	-	-
Salt	0.18	0.18	-	0.23	0.75
Soda	0.29	0.29	-	0.32	0.25
Ammonium Bicarbonate	0.83	-	0.89	-	-
Yeast (for 1hr. fermentation	-	-	0.63	-	-
Lecithin powder*	-	-	2.05	0.95	-
Lecithin (fluid)	0.05	0.05	-	-	-
Water	145	133	145	147	150

*Lecithin powder is a mixture of 50/50 lecithin/milk powder. Ideally, fluid lecithin should be added to oil prior to mixing. The typical solids content of the batter is between 33 and 48% with most at about 35%.

Wafer quality is affected by many parameters such as raw material quality, amount of water used in the recipe, parameters of batter mixing (mixing rate, mixing time, batter holding time) and baking parameters (temperature and time) and environmental conditions. Sheet weight, thickness, color, texture, moisture content, bending of sheet, stickiness to the plates; batter density and viscosity were studied in order to determine the quality of wafer sheets (Dogan, 2006).

Lightness and delicacy are significant characteristics of wafer sheet. Heavy weight means hard texture which is not accepted by the consumer. Also, heavy sheets might be under baked and this causes insufficient crispiness.

All wafer sheets should be complete and uniform, shortages at the corners and inequalities should be avoided (Manley,2011).

Textural properties of wafer have key importance in the consumer eye. These properties could be categorized into two: how the wafer snaps in the first bite and how it dissolves in the mouth thereafter. Different analytical methods could be applied to measure these properties. Wafer mechanical strength and the force required to break the wafer into two could be determined by three point bend test by a texture analyzer or other audio- methods comprising the frequencies transmitted via loudspeakers during the action of chewing and resulting in resonance patterns. (Beckett, Livings and Schroeder,1994).

Lightness and bright color of wafer sheet as well as homogeneity of color are important parameters affecting consumer preference (Doğan, 2006). These properties are influenced by the ingredients, baking temperature, time and depositing pattern.

Batter viscosity should be strictly controlled for the production side and the quality of the final product. Low viscosity value of the batter is required in order to spread the batter over the plate. In this respect, the ratio and the specification of the critical ingredients such as flour, water, oil/fat or emulsifier are important in the recipe. Stirring of batter for short time, relatively high shear rates during mixing, lower mixing temperatures and controlled batter holding time are significant factors to control the viscosity. Endogenous α-amylase content of the batter is critical since during the batter holding time prior to baking, α-amylase degrades the starch, causing a slackening of the batter especially in warm conditions (IARC Working Group on the Evaluation of Carcinogenic Risks to Humans, 2010).

Major ingredients used in wafer sheet production, their required specifications and the effects on wafer quality are summarized in Table 1.2.

Table 1.2 Main ingredients in wafer batter and their required quality specifications (adapted from Tiefenbacher, 2002)

Ingredient	Specification	Comments	Influence on Wafer	% on Flour Basis
Wheat flour	Protein below 10%, moisture below 14.5%	Low absorption	Provides bulk and structure	100
Starch, native	Potato, tapioca preferable to corn, wheat	Increases dry matter Reduces gluten problems	Increased stability, more homogenous structure	0-8
Water	Potable, Preferable below 15°C	Dissolve water soluble components, disperse flour	Weight+ stability decrease; water hardness increases wafer hardness slightly	125-155
Baking Soda	Food grade Sodium Bicarbonate (E500)	Improves spread in baking mould	Less weight and stability More color	0.1-0.4
Sugar	Sucrose, Granular	Dissolve sugar completely	Improves taste, texture; Increases wafer color + residues on baking moulds	0-3
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	0.5-6
Lecithin	Soy 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	0.2-2

1.3 Product Development

Compared to other cereal based industrial food products, studies on wafers are limited. Dogan (2006) investigated the parameters that affect quality of both wafer batters and sheets. It was found that water and gluten content had no effect on density, but water content and holding time affected viscosity. Color of wafers were influenced by water content and baking temperature. Above 160% water content (on flour basis), wafer had higher lightness values. Baking temperature and water content were optimized for the best texture values. Below 145% (on flour basis) water level and 150°C baking temperature, wafers gave hard texture; whereas above 160% (on flour basis) water level and 180°C baking temperature wafers were too fragile. Overall, wafers with 155-165% water level (on flour basis) in batter, baked at 170°C for 116-118 s were found to be acceptable.

In another study, Barron (1977) studied the expansion behavior of wafers coated with chocolate and its effect on cracking of chocolate. Linear expansion in wafer length according to varying relative humidities were determined. Time for cracking was measured with respect to chocolate type and thickness, relative humidity of the environment, initial moisture content of the wafer, number and width of the holes in coating. On a normal ambient interval of relative humidity (43.7-75.5%), increase in wafer length was 0.42% for 1% increase in moisture content. The increase in moisture content from 2% to 5.5% by conditioning before enrobing resulted in doubling the crack time. Therefore, it was concluded that proper conditioning and even distribution of the holes in coating might suppress the cracking.

Oliver and Sahi (1995) investigated the effect of wheat cultivar type on rheological properties of wafer batter. Soft milled wheat resulted in more viscous rheological properties which was favored for wafer production, whereas hard milled flours showed higher elastic properties. Significant differences were found in elastic modulus (G′), viscous modulus (G″) and viscosities from different wheat types. The batters with higher gluten hydration time (time for the resistance against power input to reach the maximum) implied that gluten proteins resulted in weak batter. Gluten hydration time was found to be correlated with phase angle i.e. ratio of G''/G'. It was concluded that soft milled flours are better for wafers.

According to a study conducted by Meral and Doğan (2004), composite wafer products (wafers with cream) were analyzed in terms of quality parameters and investigated according to the standard of TSE (Turkish Standards Institution). Sugar, protein and fat content; as well as dry matter, ash, acid insoluble ash and extractable fat acidity were determined. It was found that chemical composition of wafers differed according to the company significantly. In addition, quality of the wafers produced by the same company showed variation.

In another study Hempel, Jacob and Rohm (2007), evaluated the effect of inulin addition as a prebiotic and different flour type on quality characteristics of wafer crackers. Wheat, rye, spelt wheat flour and also combination of wheat flour: rye flour and wheat flour: spelt wheat flour (1:1) were used. Inulin syrup produced from Jerusalem artichoke was used in two forms: freeze dried directly or freeze dried after ultrafiltration. Rheological properties of batter were analyzed and for wafer sheets, moisture content, water activity, color, texture and sensorial attributes were determined. Flour type influenced batter viscosity: rye flour increased batter viscosity while spelt wheat flour showed the opposite effect. Spelt wheat increased water activity, indicating lower water binding capacity. Flour type did not affect wafer color however ultrafiltered freeze-dried Jerusalem artichoke showed lower lightness due to less participation in non-enzymatic browning caused by decreased reducing sugars. Spelt wheat flour increased firmness like ultrafiltered freeze-dried Jerusalem artichoke did. Sensory quality scores decreased by increasing rye and spelt wheat flour as well as ultrafiltered freeze-dried Jerusalem artichoke. It was concluded that wheat flour might be partially substituted by rye flour or spelt wheat flour.

As a recent study Mert, Sahin and Sumnu (2015), studied developing gluten free wafer sheets by substituting rice flour by buckwheat, corn, and chestnut flour at

20%, 40% and 60%. Batters containing only rice flour and wheat flour were used as the control. Rheological properties of the batters were studied and batters were found to obey Power law model. Rice / buckwheat flour containing samples at a ratio of 60/40 was the most similar sample to the wheat flour control sample in terms of flow behavior index and consistency index. In terms of texture, rice flour control sample and all corn flour containing samples gave the hardest texture. Color of the wafers represented the natural color of the flours.

The rareness of the studies in the literature brought about the need for product development in wafers. For this reason, legume flours (bean, carob, chickpea and lentil) were used for their highly nutritional content. These flours could also be an alternative as the integration of savory flavors into mostly sweet- dominated wafer products. Combined with savory creams and fillings, these wafers could also serve for replacement of meals.

The influences of these flours to processing convenience and product quality are important for the utilization. Therefore, replacement of wheat flour was done at 10%, 20% and 30%. The effects of this replacement on wafer batters and wafer sheets were studied.

Pulse consumption increased by 10% between 1989-1999 reaching to 5.9 kg consumption per capita. This increase is expected to be sharper if the governmental bodies and producers extend the studies on utilization of legumes in food products (Schneider, 2002).

1.4 Wafer Ingredients

1.4.1 Flour

1.4.1.1 Wheat Flour

Wheat flour is claimed to be the most important food crop in the world. Global wheat production is estimated to have reached to 754.8 million tons (FAO, 2017). Although more than two dozen of species are characterized by the name of *Triticum*, only four types (*T. monococcum* L., *T. turgidum* L., *T. timopheevii* Zhuk., and *T. aestivum* L. em Theil.) are commonly cultivated (Morris & Rose, 1996). Since wheat flour, semolina and many other products that are obtained by milling of the wheat grain are the main ingredient for most types of bread and other bakery products and pastas; wheat constitutes the main nutritional source of humankind. Therefore, providing such staple food source nutritionally balanced, many nutritional deficiency diseases affecting large communities would be diminished (Šramková, Gregová, & Šturdík, 2009).

As the seeds of the wheat plant, wheat kernel has three parts: the bran, the endosperm and the germ.

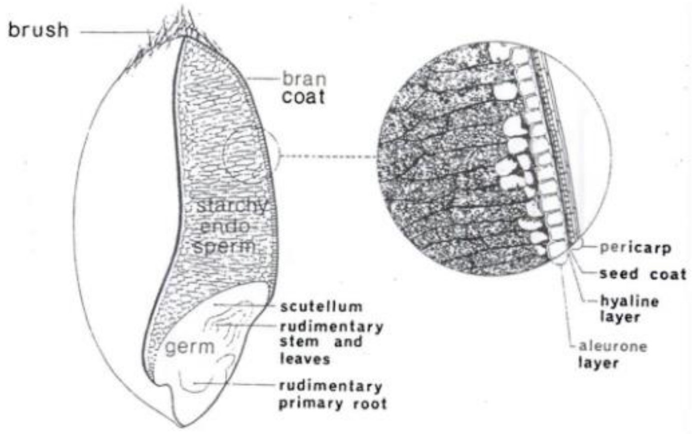

Figure 1.2 Wheat grain cut lengthwise through crease

The kernel is composed of 2-3% germ, 80-85% starchy endosperm and 10-13% bran by weight (on dry basis) (Belderok, Mesdag, & Donner, 2000).

Bran comprises many layers that protect the endosperm and the germ. It has high fiber content around 53% mostly insoluble fiber. Bran is also a rich source of protein and Vitamin B (Šramková et al., 2009). Bran is generally removed during processing of the wheat into the flour. It could be purchased separately and used in bakery products for fiber and flavor enrichment as well as appearance.

Germ consists of high protein content (25%), minerals, fat, vitamin B and E. Under suitable conditions, it undergoes germination to the new plant. It is also removed during processing of kernel.

Wheat flour is mainly the ground form of wheat endosperm. It is composed of 68-76% starch, 11-14% moisture, 6-18% proteins, 2-3% gums, 1-1.5% lipids and 0.6% ash (Figoni, 2008).

Many plants store carbohydrate in the form of starch. Starch is a water insoluble complex polymer with higher molecular weight. Starch in food systems have crucial functions such as thickening and gelling, improving stability, moisture absorption, softening and tenderizing the food and also glazing.

Among the other proteins; glutenin and gliadin are two important structure building proteins in wheat flour. Upon being mixed with water, glutenin and gliadin proteins in wheat flour form gluten network. Gluten network is strengthened by mixing even kneading, and it provides a strong, cohesive and elastic structure. This structure is highly favored for bread and cracker type products (Figoni, 2008). Since wafer is a light and crispy product, strong gluten matrix that is higher protein containing flour is unwanted. Wafer batter has a liquid form, in contrast to the dough. Therefore, the use of medium protein level of flour (9.5%) is important. Higher protein content could result in dense and hard texture while lower protein content could cause fragile wafer sheets.

Hygroscopic nature of flour particles makes them absorb water highly and this property is related to the components of flour. Besides proteins, pentosan gum is important due to its high-water absorption potential. Pentosan could uptake 10 times of its own weight (Bushuk, 1998).

In the milling step of flour production, starch is physically damaged to an extent. Damaged starch is an important parameter for water holding properties of the flour. In a high-water medium, proteins absorb water about 200% of their weight, undamaged starch absorbs 33% of its weight and damaged starch absorbs as much as its weight. For wafer batters, low water holding potential of the flour is required. In this regard, low starch damage resulting from the milling of soft wheat kernels is important (Manley, 2011).

Moisture and ash content of the flour are other critical parameters for the utility of flour in production and for the storage. Moisture content of flour above 14.5% might create a risk for spoilage and reduces the shelf life of the flour. Higher ash content means the higher bran extraction which is rich in terms of minerals. This causes darker flour color and an increase in water adsorption (Tiefenbacher, 1998).

Distribution of flour particle size constitutes an important factor on wafer sheet quality. Fine particles would enable light and soft texture while coarse particle would result in dense and non-uniform sheets (Dogan, 2006).

Wheat flour has important functions for baked goods. Besides being a bulking material, it contributes to structure provision, liquid absorption, enhancement of flavor and color and addition of nutritional value. Wheat flour is a good source of minerals, vitamins, protein and wheat starch. However, fiber content of white flour is low due to absence of fiber-rich bran. Also wheat proteins are nutritionally incomplete unlike egg or milk proteins (Figoni, 2008). Cereal proteins are poor in terms of certain amino acids such as lysine, tryptophan and threonine. These amino acids limit the availability of other proteins. In this respect, consumption of cereals with other protein sources is essential (Šramková et al., 2009).

1.4.1.2 Legume Flours

Legumes are claimed to be the firstly cultivated plants by humanity. Traces of some legumes in Turkey belonging to Neolithic age (7000 to 8000 years B.C.), depicts the role of the legumes in human life for 10.000 years. Being the base of the foods in the region, legumes were spread to the rest of the world and diversified (Schuster-gajzágó, 2009). Having about 1300 species, legumes are classified under the family Leguminosae. They are prominently cultivated and marketed for their seeds. Lentil, bean, broad bean, pea, soybean, pigeon pea, cowpea, peanut and chickpea are among the mostly common species (Annor, Ma, & Boye, 2014).

Legumes are an important source of nutrition due to their high content of protein, vitamins, minerals, fibers, starch and contribute greatly to the protection of health. Therefore, together with their comparably lower prices, legumes are indispensable dietary part of the majority of people around the world.

Legumes are a valuable protein source with 17-40% protein content similar to that of meat (18-25%) (Bojňanská, Frančáková, Líšková, & Tokár, 2012). Their total dietary fiber content could be up to 30% on d.m. and they could be regarded as fiber themselves. Unavailable oligosaccharides in legumes function as a probiotic for the intestinal system. They are also utilized in food systems for their rich B vitamins (especially vitamin B1, B2 and B3), minerals (iron, manganese, calcium, zinc and phosphorus) (Rysová, Ouhrabková, Gabrovská, Paulí, & Winterová, 2010) also antioxidants and polyphenols (Han, Janz, & Gerlat, 2010).

Although legumes are an important source of protein, the amino acid composition of them is not complementary. Legume proteins are rich in terms of essential amino acid lysine but deficient in terms of sulphur-containing amino acids such as methionine, cystine and tryptophan as compared to cereals. Therefore mutual consumption of legumes with cereals are important in terms of complementary amino acid complementation (Duranti, 2006).

Apart from the nutritional aspects, legumes have been studied for the possible functional properties for the food products such as water holding, water retention and swelling capacity, foaming capacity and stability, emulsifying capacity and stability and oil absorption (Arab, Helmy, & Bareh, 2010; Butt & Batool, 2010).

Legumes have also important nutraceutical properties and several studies were carried out for their health benefits (De la Hera, Ruiz-París, Oliete, & Gómez, 2012; Duranti, 2006). Continuous consumption of legumes accompanied by low fat diet inhibits the cardiovascular diseases due to high fiber content together with low glycaemic index (GI) and minor elements (Anderson & Gustafson, 1988; Kushi, Meyer, & Jacobs, 1999; Siddiq, Ravi, Harte, & Dolan, 2010). Low GI value and insoluble dietary fiber content are also suggested to control the glycaemia in diabetics, and prohibits insulin resistance (Ma et al., 2011; Rizkalla, Bellisle, & Slama, 2002). Lowering cholesterol absorption and inhibition of fermentation in gastrointestinal systems are attributed characteristics to the legumes for preventing especially colon cancer (Geil & Anderson, 1994; Leterme, 2002; Mathers, 2002). Satiety feeling brought about by legume consumption is believed to help individuals to maintain their body weight and to prevent obesity

(Karlström et al., 1987). Legumes are also claimed to be advantageous for bone health (Alekel et al., 2000).

Legumes are processed for the final products to obtain edible food, to diminish anti-nutritional components, to extend shelf life, to inactivate the microorganisms and to enhance digestibility and nutrition. Final products of the legumes could be seeds, flour or cooked meal. The processing steps into flour include husking (hulling), winnowing, soaking, germinating, milling, sieving and canning; some of the steps being optional (Subuola, Widodo, & Kehinde, 2012).

In this nutritional and nutraceutical aspects, legume and cereal combination have arisen attention in product development in recent years. Several studies have been carried out about the addition of legume to cereal based products in flour form that of chickpea and soybean in cakes (Hemeda & Mohamed, 2010), lentil and bean in wheat dough (Kohajdová, Karovičová, & Magala, 2013), lentil and chickpea in bread (Bojňanská et al., 2012), faba bean and cowpea in cakes (Abou-Zaid, Ramadan, & Al-Asklany, 2011), bean, chickpea grass pea and pea in pasta, tempeh and bread (Rysová et al., 2010); navy bean, pinto bean and lentil in spaghetti (Bahnassey & Khan, 1986); pea, lentil and chickpea in bread (Dalgetty & Baik, 2006); pigeon pea in biscuit (Tiwari, Brennan, Jaganmohan, Surabi, & Alagusundaram, 2011), soybean in cake (Ronda, Oliete, Gómez, Caballero, & Pando, 2011) and carob bean in cake (Berk, Şumnu, & Şahin, 2017).

1.4.1.2.1 Bean Flour

Common bean (*Phaseolus* vulgaris) is one of the oldest grain of the New World. It has a wide range of morphological varieties, cultivation methods, adapted environmental conditions. It is consumed as immature or mature seeds or as vegetables with pods (Broughton et al., 2003).

Bean is believed to be originally cultivated in Mesoamerica and Southwest America and spread to the rest of the world. It then became one of the staple food of human diet, especially a rich protein source for undeveloped and developed countries. It constitutes more than 50% of the legumes consumed. Like many other legumes, beans have a critical role in nitrogen fixation. It is also known as French bean, kidney bean, snap bean, runner bean or green bean (Dalla Via et al., 2013).

According to the FAOSTAT (2018) data, Myanmar, India, Brazil, USA, China were the most important bean cultivators on production basis between 2011-2016. In this 5-year period, world bean production increased by 11.7% from 2011 to 2016, reaching to 26.8 million tons in 2016 (FAOSTAT, 2018).

Common bean is named as “poor man’s meat” due to its high protein content of about 20-25%. It constitutes an important part of the diet especially in South America and Africa (Dalla Via et al., 2013). However, major protein in bean, phaseolin, has low sulphur-containing amino acids like methionine. In this respect, combined intake of beans with cereals is required. Bean also poses as a crucial source of magnesium, iron, manganese, phosphorus and in a lower extent calcium, copper and zinc (Broughton et al., 2003).

Nutritional composition of small white bean type is depicted in Table 1.3.

Table 1.3 Chemical composition of small white bean (per 100 g of dry matter, adapted from Kohajdová et al., 2013).

Components	Composition (% d.m.)
Protein (N ×6.25)	30.53
Fat	2.92
Carbohydrates	38.63
Fiber	24.02
Ash	3.90

Many researchers have been interested in enrichment of food products with bean flour types for the nutritional enhancement and functional properties. These studies include the diverse types of beans in food categories such as common bean flour in tortilla (Anton, Ross, Lukow, Fulcher, & Arntfield, 2008), pasta (Gallegos-Infante et al., 2010; Giménez et al., 2012), gluten free pasta (Giuberti, Gallo, Cerioli, Fortunati, & Masoero, 2014), spaghetti (Bahnassey, Khan, & Harrold, 1986; Duszkiewicz-Reinhard, Khan, Dick, & Holm, 1988), baked roll (Kohajdová, Karovi, & Magala, 2011), cookie (Zucco, Borsuk, & Arntfield, 2011), bread (Lorimer, Zabika, Horte, Stchiw, & Uebersax, 1991; Rizzello, Calasso, Campanella, De Angelis, & Gobbetti, 2014), snack (Anton, Gary Fulcher, & Arntfield, 2009), beef sausage (Dzudie, Scher, & Hardy, 2002), lupin, triticale-soya-lupin flour in bread (Dervas, Doxastakis, Hadjisavva-Zinoviadi, & Triantafillakos, 1999; Doxastakis, Zafiriadis, Irakli, Marlani, & Tananaki, 2002) and faba bean and cowpea in gluten free cake (Abou-Zaid et al., 2011). These studies suggested varying results in terms of consumer acceptance and functionality improvement based on the bean type and ratio as well as on the nature of the food product.

1.4.1.2.2 Carob Flour

Carob plant (*Ceratonia siliqua* L.) belongs to Leguminosae family. It originated from Mediterranean region and was spread to Greece, Italy, South Africa, Spain and Portugal. Today some species are cultivated also in North and South America in climates similar to that of Mediterranean. Carob is an important food source especially in Mediterranean cuisine, also used as animal feed. Carob molasses and syrup is widely consumed. (Batlle & Tous, 1997).

Global carob production decreased by 19% between 2011-2016 at 159000 tons level. Cultivation area dropped to 66000 ha during this period. Top 5 carob producing countries are Portugal, Spain, Italy, Morocco and Turkey (FAOSTAT, 2018).

Carob fruit is composed of two parts as seed and pulp. Seed constitutes the 10% of the fruit by weight and contains mostly galactomannans. Seed is an important raw material in food industry. Locust bean gum which is derived from carob seed is used as thickener and stabilizer. Besides being a raw material for food industry, it is also used in pharmaceutical, textile industry (Bouzouita et al., 2007).

De-seeded carob pulp is known as 'kibble'. It has high sugar content composed of sucrose, fructose and glucose. Carob kibble is a nutritious human and animal food especially in terms of fibers and polyphenols. It is also a rich source of potassium, calcium, phosphorus and magnesium. Anticarcinogen and antidiabetic effects of carob consumption as well as the effects on cholesterol lowering have been reported. In addition to these nutritional and health benefits of carob, it is a functional food material that is used for cocoa and sugar replacement and shelf life extension (Nasar-Abbas et al., 2016).

Table 1.4 Chemical composition of carob kibble (adapted from Nasar-Abbas et al., 2016)

Components	Composition (%)
Protein (N ×6.25)	2-7
Fat	0.5-1
Total sugars	45-52
Fiber	< 40
Ash	2-3
Total polyphenols	1.4-2.0

Carob could be consumed directly after drying, in the form of molasses and syrup, gum or flour. There are several studies in literature investigating the use of carob flour in food products such as bread (Miñarro, Albanell, Aguilar, Guamis, & Capellas, 2012; Salinas, Carbas, Brites, & Puppo, 2015; Smith, Bean, Herald, & Aramouni, 2012; Tsatsaragkou, Gounaropoulos, & Mandala, 2014; Turfani, Narducci, Durazzo, Galli, & Carcea, 2017), cake (Berk et al., 2017), biscuit

(Šebečić, Vedrina-Dragojević, Vitali, Hečimović, & Dragičević, 2007) and pasta (Biernacka, Dziki, Gawlik-Dziki, Różyło, & Siastała, 2017; Sęczyk, Świeca, & Gawlik-Dziki, 2016).

1.4.1.2.3 Chickpea Flour

As an ancient crop in Near East, chickpea (*Cicer* arietinum) is thought to be grown firstly in Palestine in 8000 B.C. and cultivated in Egypt. Egyptians used the chickpea flour in bread to increase the weight. Greeks consumed it in roasted, dried or fresh forms while Romans boiled it and placed in soups (Alcock, 2006). It was brought to New World in the 16th century A.D. by Spanish and Portuguese (Redden & Berger, 2007).

Chickpea is commonly used in many cuisines in different forms. To illustrate, it is used in a very popular meal *dhal*, grounded into flour namely *besan*, which is used in baked products *roti* or *chapatti* in India. In Turkey, a snack called *leblebi*, a roasted form, and chickpea meal is very common. *Hummus* is a favored dish in Arabic countries, prepared from mashed chickpea. Also, there exists varying sorts of chickpea consumption from green vegetable to dried or milled form around the world (Yadav, Longnecker, et al., 2007).

Between 2011-2016; India, Australia, Myanmar, Turkey and Pakistan performed the highest chickpea production. With fluctuations during this period, chickpea production remains at the 11-13 million tons level having similar fluctuations in cultivation area too. Since 1966, production amount increased by 116%, while harvested area remaining almost the same, indicating an increase in yield (FAOSTAT, 2018).

Chickpea plays an important role in nutrition of the many parts of the world as well as in the diets of vegetarians. It is a rich source of carbohydrates especially fibers and proteins. Apart from methionine and cysteine, it has a balanced essential amino acid composition. Chickpea, has higher lipid content compared to other legumes (except soybean and groundnut) mainly polyunsaturated lipids which are beneficial in prevention of cardiovascular diseases. In terms of macronutrient minerals namely phosphorus and magnesium, chickpea can provide an important part of the required daily intake. It is also a rich source of copper and manganese, and to a lesser degree iron and zinc. Chickpea contains water- soluble vitamins such as B-complex vitamins and vitamin C, as well as lipid- soluble vitamins namely vitamin A, vitamin E and vitamin K (Wood & Grusak, 2007). Average nutritional composition of chickpea is shown in Table 1.5.

Table 1.5 Chemical composition of chickpea (per 100 g of dry matter, adapted from Silva-Cristobal, Osorio-Díaz, Tovar, & Bello-Pérez, 2010).

Components	Composition (% d.m.)
Protein (N ×6.25)	23.56
Fat	5.18
Carbohydrates	46.43
Fiber	20.78
Ash	4.05

Due to recommendations of health organizations on the consumption of vegetable proteins, like other legumes chickpea utilization is encouraged to produce more value- added products. Especially for developing countries, where legumes are staple food, they could be involved in solutions against malnutrition. In this concept, chickpea usage in different food products has been studied Some of them might be listed as chickpea utilization in bread (Dalgetty & Baik, 2006; Fenn, Lukow, Humphreys, Fields, & Boye, 2010; Youssef, Salem, & Abdel-Rahman, 1976), pasta (Arab et al., 2010; Osorio-Díaz, Agama-Acevedo, Mendoza-Vinalay, Tovar, & Bello-Pérez, 2008; Sabanis, Makri, & Doxastakis, 2006), toast bread (Hefnawy, El-Shourbagy, & Ramadan, 2012), cake (Gómez, Oliete, Rosell, Pando, & Fernández, 2008; Hemeda & Mohamed, 2010), cracker and biscuit

(Bose & Shams-Ud-Din, 2010; Kohajdová et al., 2011), snacks (Debnath, Bhat, & Rastogi, 2003; Meng, Threinen, Hansen, & Driedger, 2010), sausage (Verma, Ledward, & Lawrie, 1984) and fried dessert (Bhat & Bhattacharya, 2001).

1.4.1.2.4 Lentil Flour

Lentil (*Lens* culinaris) is an ancient food source. Its history is claimed to go back to 7500-9200 B.C., Syria. It is thought that lentil agriculture passed to Greece and Rome from Middle East. The traces in the stomachs of predynastic bodies in Egypt implied that it was a staple food source in Mediterranean region (Alcock, 2006). Wild species were then spread to Central Europe and South Asia. Lentil has an important role in dishes around the world. It is used in meals, soups and purees mostly and, as flour, it is incorporated into infant food, cake and bread. Lentil is consumed traditionally together with rice, barley and wheat (Yadav, McNeil, & Stevenson, 2007).

World lentil production increased by 40% from 2011 to 2016, reaching to 6.3 million tons in 2016 (with fluctuations each year). Cultivation area rose from 4.2 to 5.5 million ha in this interval with Canada, India, Turkey, Australia and Nepal being the top five producers. As well, the production has increased by 600% from 1966 to 2016 (FAOSTAT, 2018). Lentil is one of the main food sources in South Asia and Middle East, West Asia, Europe, America and Sub-Saharan Africa due to its nutritional value and relatively low prices (Kumar, Barpete, Kumar, Gupta, & Sarker, 2013).

As already mentioned, lentil is a nutritious food source, with high content of proteins, fibers, vitamins, minerals and antioxidants. The chemical composition of lentil Urbano, Porres, Frias, and Vidal-Valverde (2007) is presented in Table 1.6.

Table 1.6 Chemical composition of lentil (per 100 g of dry matter, adapted from Urbano, Porres, Frias, and Vidal-Valverde, 2007).

Components	Range
Total nitrogen	3.72-4.88
Protein (N ×6.25)	20.6-31.4
Non-protein nitrogen	0.49-1.049
Fat	0.7-4.3
Carbohydrates	43.4-69.9
Fiber	5.0-26.9
Ash	2.2-4.2

However, there also exist non-nutritional components lowering the bioavailability of beneficial components in lentils such as trypsin inhibitors, phytic acid, tannins, protease inhibitors, α-galactosidase and other oligosaccharides. The negative effects of these compounds can be eliminated during processing and cooking of lentils (N. Wang, Hatcher, Toews, & Gawalko, 2009). Besides being rich in terms of essential amino acids, lentil has favorable fiber (hemicellulose, cellulose, pectic substances, lignin); minerals (K, P, Ca, Mg, Na, Fe, Zn, Cu, Mn) as well as vitamins (Retinol, B vitamins, vitamin C and vitamin H) considering other legumes are low in vitamin C, retinol and carotene (Urbano et al., 2007).

Lentil has been widely studied by several researchers and industry in seeking for more use of this low-price and highly nutritive crop in products. Some of these studies are the utilization of lentil in cake (De la Hera et al., 2012), in bread (Bojňanská et al., 2012; Dalgetty & Baik, 2006; Sadowska, Fornal, Vidal-Valverde, & Frias, 1999), in yogurt (Agil et al., 2013; Zare, Boye, Orsat, Champagne, & Simpson, 2011), in pasta (Bahnassey & Khan, 1986), in meal (Hettiaratchi, Ekanayake, & Welihinda, 2009). These studies have suggested important results on batter/dough as well as on properties of final products depending on the percentage in the recipe, origin of the lentils and the process parameters.

1.4.2 Water

Water is the main ingredient together with flour in wafer production. Water is important for the hydration, solubility and uniform dispersion of ingredients. Wafer batter has a unique formulation high in water when compared to the doughs. In the formulation, water content has a key importance in terms of the appropriate viscosity. Generally, water content of batter varies between 1.25-1.6 on flour basis. The spreadability of the batter on baking plates and uniform wafer texture are affected by the batter viscosity. In order to prevent gluten formation, cold water usage is advised. Water hardness should be lower than 2 mmol/L (11 ^{0}dH), hard water results in harder wafer texture. Water content should be at the optimum level for also lowering scraps (Tiefenbacher, 2017). It acts also as catalyst for the reactions taking place during processing. Microbiology, dissolved chemicals and physical appearance of water is of great importance in terms of food safety. Potable water should be used in manufacturing which is delivered by public supply or the water treatment systems in the facilities (Manley, 2011).

1.4.3 Fats/Oils and Emulsifier

Contrary to general use of oils, fats and emulsifiers for viscosity adjustment and dissolving two immiscible substances by decreasing surface tension; their use in wafer production is primarily as releasing agents. Wafer batter has already low viscosity and fat/oil content; therefore, there would be no need for emulsifying. Fats/oils together with emulsifier provide a good release of the baked sheets from the oven plates, eliminate sticking and scraps. Use of fats and stable oils, especially vegetable fat (hydrogenated) are recommended for wafer batters. Lecithin obtained from soy, rapeseed, corn, sunflower is generally preferred in wafer batters. Besides releasing from plate, lecithin facilitates steam venting. In this study, anhydrous vegetable fat (palm, rapeseed, cottonseed) as well as soy lecithin were used (Tiefenbacher, 1998).

1.4.4 Leavening Agents

Leavening in bakery products could be achieved by 3 ways: chemical leavening (chemical leaveners), physical leavening (aeration or whipping) and biological leavening (yeast, fermentation). Chemical leavening is widely applied due to safety, controllability and convenience. Sodium bicarbonate and ammonium bicarbonate are the mostly used salts for this purpose either by themselves or in combination. Release of the leavening gas, carbon dioxide, is induced by heat (Tiefenbacher, 1998). Wafer has a structure of gas cells dispersed in a dry gelatinized matrix. Leavening provides the spreading of the batter within the gaps of oven plates. Uniform distribution, size and form of gas cells through the wafer sheets is of great importance in terms of the microstructure and textural attributes (Sundara, 2012). Therefore, it is advised the comprehensive consideration of gassing process for both the process control and the product quality.

1.4.5 Other Ingredients

Wafer sheets have various forms and purposes of use. In addition to the above-mentioned main ingredients, researchers utilize several other ingredients in order to diversify the product scale. Therefore, alternative ingredients such as enzymes, salts, food colors, flavors, fibers, cocoa are used in wafer production.

1.5 Objective of the Study

Perception of food consumption has been driven by changing factors recently such as awareness of consumers on health, governmental restrictions, busy daily routines. These changes have led the industry to seek new solutions. Besides suppression of hunger; meeting consumer demands in terms of health, innovation, taste convenience and affordability are of the highest priority. Great importance is attributed to veganism, organic food, authenticity, clean food, calorie control and food intolerances. Therefore, product diversity is of great importance. Increasing number of studies has been carried out on developing new food formulations.

Considering the consumer habits on snack consumption and development of snack food market, the integration of above mentioned demands into snack foods would gain advantages for both the consumers and the industry. Wafer subsector achieves increasing revenue each year and wafer has taken its indispensable role in daily diet. However, the studies on wafers are too limited in literature. Existing studies rarely focused on product development. Additionally, there was no research on legume flour incorporation into wafer batter at varying ratios.

With this study, it was aimed to develop wafer sheets with increased nutritional quality in terms of protein and fiber through replacement of wheat flour by bean, carob, chickpea and lentil flour at different concentrations. The effect of legume flour type and content on specific gravity and rheology of wafer batters and weight loss, hardness, color and sorption isotherm of wafer sheets were also investigated.

CHAPTER 2

MATERIALS AND METHODS

2.1 Materials

Wheat flour was purchased from local market (Erişler, İstanbul), lentil flour and carob flour were purchased from Havancızade (Istanbul, Turkey). Bean flour and chickpea flour are supplied from Bafa Un (Sivas, Turkey).

Hydrogenated vegetable oil (palm, rapeseed and cottonseed oil) were purchased from AAK (Tekirdağ, Turkey). Soy lecithin was procured from Lipoid GmbH (Ludwigshafen, Germany). Sodium bicarbonate was purchased from (Pakmaya, Kocaeli, Turkey).

Sodium hydroxide, lithium chloride, magnesium chloride, magnesium nitrate, potassium iodide, sodium chloride, potassium chloride, barium chloride and potassium sulphate salts used in the sorption studies were purchased from Sigma Aldrich Chemical Co. (St. Louis, MO, USA).

Total dietary fiber assay kit (TDF-100A, Sigma Aldrich Chemical Co., St. Louis, MO, USA) was used for the determination of insoluble and soluble fiber contents of the flours.

2.2 Methods

2.2.1 Preparation of the Wafer Batter

Control wafer batter was composed of 182% water, 1% vegetable oil, 0.52% sodium bicarbonate and 0.5% lecithin on 100g wheat flour basis. The formulations of batters are given at Table 2.1 - 2.3. For alternative flour formulations, 10%, 20% and 30% of wheat flour was replaced by lentil, chickpea, bean and carob flours. For bean flour (10%, 20% and 30%) as well as carob flour (20% and 30%) formulations, additional water was required in order to provide the same wafer consistency in all formulations (Table 2.2-2.3) (Mert et al., 2015).

Table 2.1 Formulation of batters prepared by 10%, 20% and 30% replacement of reference wheat flour by chickpea flour or lentil flour

	Legume Flour Concentration (Chickpea, Lentil)			
Ingredient	0% (Control)	10%	20%	30%
Water (g)	64.080	64.080	64.080	64.080
Wheat Flour (g)	35.209	31.688	28.167	24.646
Legume Flour (g)	0.000	3.521	7.042	10.563
Fat (g)	0.352	0.352	0.352	0.352
Sodium Bicarbonate (g)	0.183	0.183	0.183	0.183
Lecithin (g)	0.176	0.176	0.176	0.176
Total (g)	100.000	100.000	100.000	100.000

Table 2.2 Formulation of batters prepared by 10%, 20% and 30% replacement of reference wheat flour by bean flour

	Bean Flour Concentration			
Ingredient	0% (Control)	10%	20%	30%
Water (g)	64.080	64.579	65.302	65.536
Wheat Flour (g)	35.209	31.248	27.209	23.647
Bean Flour (g)	0.000	3.472	6.802	10.134
Fat (g)	0.352	0.347	0.340	0.338
Sodium Bicarbonate (g)	0.183	0.181	0.177	0.176
Lecithin (g)	0.176	0.174	0.170	0.169
Total (g)	100.000	100.000	100.000	100.000

Table 2.3 Formulation of batters prepared by 10%, 20% and 30% replacement of reference wheat flour by carob flour

	Carob Flour Concentration			
Ingredient	0% (Control)	10%	20%	30%
Water (g)	64.080	64.080	64.381	64.628
Wheat Flour (g)	35.209	31.688	27.931	24.270
Carob Flour (g)	0.000	3.521	6.983	10.401
Fat (g)	0.352	0.352	0.349	0.347
Sodium Bicarbonate (g)	0.183	0.183	0.182	0.180
Lecithin (g)	0.176	0.176	0.175	0.173
Total (g)	100.000	100.000	100.000	100.000

The consistencies were adjusted by a cylindrical cup of 125 mL with a hole at the bottom. The cup was filled with batter and the time of the flow was recorded as 13±1 seconds.

Lecithin-oil premix was prepared by dissolving lecithin in oil at 60°C and after cooling, it was stored at 4°C. Prior to use, the premix was melted.

To prepare the wafer batter, sodium bicarbonate was dissolved in water at room temperature. Wheat flour and/or flour blends were added to the water and the mixture was mixed by the mixer (Kitchen Aid5K45SS, USA) for 10 seconds at 50 rpm, for 20 s at 105 rpm. Then lecithin- oil premix was added and the batter were mixed again for 30 s at 150 rpm. The batter was passed through a sieve to separate the lumps and left for 5 min for the bubbles to be released prior to baking.

2.2.2 Baking

A laboratory type of wafer baking machine with the dimensions of 26×21 cm was used. Wafer batter of 125±3 ml was poured onto the lower plate and immediately the upper plate was closed and latched. This amount was adjusted according to the spreadability of the batter on the plate. After 1 min of baking, excess batter forming bobbles at the edges of the wafer machine were trimmed.

Since the batter contacts to the lower plate a little earlier then the upper plate, baking already starts on this plate and nonuniformity occurs on this side of the wafer sheet. To minimize this delay between the plates, the temperatures of the lower and upper plates were set as 160°C and 168°C, respectively. The baking time was adjusted as 2.5 min according to the final moisture of the control batter to reach 2% moisture on wet basis (w.b.).

After baking is complete, the wafers taken from the oven were weighed in order to record the initial weigh upon baking. They were left at the room temperature to cool down and reweighed after 30 min.

2.2.3 Nutritional Analyses of Flours

Moisture, protein, fat, ash, soluble and insoluble fiber contents of the flours were determined and carbohydrate content was found by difference. Approved Methods of American Association of Cereal Chemists were employed for these analyses (AACC, 2000).

2.2.3.1 Moisture Content Determination

Moisture contents of the flours were determined by drying the samples at 103°C (Memmert, Schwabach, Germany) till the weight of the samples were constant with the precision of 0.01g (Adventurer, Ohaus Corporation, Parsippany, USA).

Moisture content was interpreted on % wet basis (g moisture/ g sample) (AACC approved method 44-15A, 2000). All measurements were done twice.

2.2.3.2 Protein Content Determination

Protein content was determined by Kjeldahl method (AACC approved method 46-13, 2000). Behr Labor-Technik (Düsseldorf/Germany) digestion system and steam distillation units were used for this purpose.

Flour sample of 1±0.01 g are digested with 5 g Kjeldahl tablets (composed of sodium sulphate, potassium sulphate, titanium (IV) oxide, copper (II) sulphate, Merck, Darmstadt, Germany), boiling chips and 25 ml 98% sulfuric acid in digestion unit for 2 h and 40 min. After digestion, the digests were cooled and transferred into the distillation unit. Three drops of methyl red were added to 50 ml of 4% boric acid solution giving a slightly pink color and the solution was also placed into the unit. After steam distillation is completed with 0.1 N sodium hydroxide solution, the distillate with pale yellow-green color is collected into a flask. The distillate was titrated with 0.1 N hydrochloric acid solution. The spent volumes of the titrant were recorded. Blank determination was also carried out. Protein content was calculated on % wet basis. All measurements were done twice.

2.2.3.3 Fat Content Determination

Fat content of the flours were analyzed by Soxhlet extraction method (AACC approved method 30-25, 2000). n-Hexane (Sigma Aldrich Chemical Co., St. Louis, MO, USA) was used as the solvent.

Flour sample of 7±0.01 g that had been previously dried, were placed into the extractor (Behr Labor-Technik, Düsseldorf/Germany) after tightly wrapping with filter papers. After 4 h of extraction at 100°C, the flasks containing extracts were heated at 100°C, then dried at 103°C to remove the remaining solvent, until the establishment of constant weight. Fat content was calculated on % wet basis. All measurements were done twice.

2.2.3.4 Ash Content Determination

The ash (inorganic residue) content of the flours were determined by incinerating the samples at muffle furnace (AACC approved method 08-01, 2000).

Silica crucibles were ignited in the 103°C drying oven for 3 h to evaporate the moisture and placed in desiccators to be cooled down. Flour sample of 3±0.1 g was weighed and placed into the crucibles. The crucibles were put in 650°C and incinerated for 4 h till the formation of white ash. The crucibles were placed in the desiccators. By the establishment of constant weight, these values were recorded. The ash content was interpreted on % wet basis. All measurements were done twice.

2.2.3.5 Soluble and Insoluble Dietary Fiber Content Determination

The soluble and insoluble dietary fiber content of the flours were determined using AACC (2000) method 32-07. The method comprises the consecutive enzymatic digestion of 1 g sample by heat stable α-amylase, protease and amyloglucasidase. The analysis was carried out by Total Dietary Fiber Assay Kit. By this method, firstly insoluble dietary fiber (IDF) was precipitated, filtered, washed and dried. Soluble dietary fiber (SDF), which passed to the filtrate, was separately precipitated by ethyl alcohol, filtered and dried. SDF and IDF values were corrected for protein, ash, and blank values. The analysis was performed twice.

2.2.4 Analyses of Batter

Specific gravity and rheology of the batter were analyzed.

2.2.4.1 Specific Gravity Measurement

Specific gravities of the batter were measured by dividing the weight of a batter with the weight of water at the same volume (Turabi, Sumnu, & Sahin, 2008). A pycnometer was used for this purpose. Wafer batter after 5 min relaxation was used to eliminate the errors caused by the bubbles. All measurements were done twice.

2.2.4.2 Rheological Measurements

Rheology measurements were carried out by rheometer with cone and plate geometry (Kinexus, Malvern Instruments, Ltd, Worcestershire, UK). The rotating cone has an angle of 4º, diameter of 40 mm, and gap of 0.001 mm.

The wafer batters were rested for 10 min prior to rheometer for sample recovery from the residual stresses. About 2 g of sample was placed in between the cone and plate and the excess batter was trimmed from the edges. The shear rate ramp mode was operated. Shear rate versus shear stress values were recorded between a shear rate range of 0.05 to 200 s^{-1}.

All the measurements were done at 20ºC and twice.

2.2.5 Analyses of Wafer Sheet

Weight loss, color parameters, hardness and the sorption behavior of the wafer sheets were studied.

2.2.5.1 Weight Loss

Weight loss of the wafers were determined by the weight values of the batter deposited and the weight of sheet upon baking. It was depicted as the percentage weight loss of the batter Equation 2.1:

$$Weight\ Loss(\%) = 100 \times \frac{W_i - W_f}{W_i} \qquad (2.1)$$

Where

W_i : weight of the batter and

W_f : weight of the sheet after baking

For each sample, the measurements were replicated five times.

2.2.5.2 Hardness

Hardness values of the wafer samples were evaluated as the highest force attained during breaking by 3-point bending. For this purpose, Texture Analyzer (TA, XT Plus, Stable Micro Systems, United Kingdom) was used. Sample with 6 cm × 6 cm size was taken from the center of the wafer sheet and positioned under the three-point bend probe. The device parameters for compression mode were adjusted as 2 kg calibration force, 2.00 mm/sec test speed and 5.0 g trigger force. The maximum force exerted by the probe during the breaking of the wafers (Newton) were recorded. For each sample, the measurements were replicated five times.

2.2.5.3 Color

Color measurement of the wafers was done by means of the spectrophotometer (Konica Minolta, CM-5, Japan). For this purpose, wafers were sectioned from the center of the wafer sheets. Color values were evaluated by CIE $L^*a^*b^*$ (CIELAB) color scale. In CIELAB system, ΔE^* means the magnitude of the total color difference from the reference material. It is defined by Equation (2.2) (Sahin & Sumnu, 2006):

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

where

$$\Delta L^* = L^*_{\text{sample}} - L^*_{\text{reference}}$$

$$\Delta a^* = a^*_{\text{sample}} - a^*_{\text{reference}}$$

$$\Delta b^* = b^*_{\text{sample}} - b^*_{\text{reference}}$$

'L^*' indicates the lightness, 'a^*' the redness/greenness, 'b^*' yellowness/blueness. Control wafer with 100% wheat flour was selected as the reference and it has the following color values;

$L^*_{\text{reference}}$=75.60 $a^*_{\text{reference}}$=2.88 and $b^*_{\text{reference}}$=23.89

All measurements were done by triplicate from the center of the bottom surface of the wafer sheets.

2.2.5.4 Sorption Isotherm

Wafer discs with 8 cm diameter and 4 mm thickness were used for the sorption behavior studies. For this purpose, wafer discs were sectioned from the center of the wafer sheets.

Wafer discs were stored in the air-tight desiccators containing the saturated solutions of sodium hydroxide (RH: 8.86%), lithium chloride (RH: 11.84%), magnesium chloride (RH: 34.34%), magnesium nitrate (RH: 58.09%), potassium iodide (RH: 68.39%), sodium chloride (RH: 76.43%), potassium chloride (RH: 86.27%), barium chloride (RH: 92.52%) and potassium sulphate (RH: 96.79%) till equilibrium was reached. Equilibrium moisture contents were measured by the moisture analyzer and interpreted on % wet basis (Ohaus Corporation, Parsippany, USA). Air-tight desiccators were stored at 25°C and analyses were done by duplicate.

To analyze the sorption behavior of the wafers, GAB model Equation (2.3) was employed

$$W_e = \frac{W_0 C K a_w}{(1-Ka_w)(1-Ka_w+CKa_w)} \tag{2.3}$$

where

We : Equilibrium moisture content (d.b.)

W_0 : Monolayer moisture content (d.b.)

a_w : Water activity of the sample

C, K: Free sorption parameters of the GAB model.

Sorption isotherms were discussed by transforming into a quadratic equation in order to determine the C, K and W0 parameters (Kim, Kim, Kim, Shin, & Chang, 1998)

$$\frac{a_w}{W_e} = \frac{1}{W_0CK} + \frac{C-2}{W_0C}a_w + \frac{K(1-C)}{W_0C}a_w^2 \quad (2.4)$$

From the non-linear least square regression analysis by MS Excel 2016, the C, K and W_0 parameters were found.

GAB model is recommended for the experimental data representing lower water activity values than 0.90 (Timmermann, Chirife, & Iglesias, 2001).

2.2.6 Statistical Analysis

The experimental data obtained throughout the study were evaluated by analysis of variance (ANOVA) to detect the significant differences in flour types and concentrations ($p \leq 0.05$). If significant difference was found, Tukey's Test with 95% confidence level was performed for comparison. Box-Cox transformation was applied if grouping could not be done despite the significant difference. All the statistical analyses were made by Minitab (Version 16.2.0.0, Minitab Inc., Coventry, United Kingdom). SPSS (Version 20, IBM, U.S.A.) was used in order to determine the Pearson correlation coefficients with 5% confidence level.

CHAPTER 3

RESULTS AND DISCUSSION

The effects of replacement of wheat flour by 10%, 20% and 30% bean, carob, chickpea and lentil flour are analyzed in terms of specific gravity and rheology of batter as well as wafer sheet weight loss, hardness, color and sorption behavior throughout this chapter. Analyses of nutritional components of the flours were carried out which are primary indicators for the discussion of the results. The calculated nutritional components of the flours and the stoichiometric conversion of these values to those of batters are represented in Table 3.1 and Table 3.2 respectively. Statistical analyses for protein, fiber and carbohydrate contents of the batters are depicted in Table A.1-A.3.

Table 3.1 Nutritional components of flours (g/100 g)

Flour Type	Carbo-hydrate	Total Dietary Fiber	Soluble Fiber	Insoluble Fiber	Protein	Fat	Moisture	Ash
Wheat	70.86	2.85	1.65	1.20	12.25	1.50	10.93	1.61
Bean	30.56	30.40	4.87	25.53	23.71	2.71	8.31	4.29
Carob	40.17	40.85	3.78	37.06	5.03	1.57	8.31	4.06
Chickpea	43.08	17.97	1.96	16.01	22.40	5.14	7.80	3.60
Lentil	50.37	7.31	0.71	6.60	26.42	3.64	2.76	9.50

Table 3.2 Nutritional components of legume flour added wafer batters (g/100 g)

Legume Type	Legume Flour Concentration (%)	Carbohydrate	Total Dietary Fiber	Soluble Fiber	Insoluble Fiber	Protein	Fat	Moisture	Ash
Control	0	24.95	1.00	0.58	0.42	4.31	0.88	67.93	0.75
	10	23.20	1.95	0.68	1.26	4.65	0.91	68.28	0.83
Bean Flour	20	21.36	2.84	0.78	2.06	4.95	0.93	68.84	0.91
	30	19.85	3.76	0.88	2.87	5.30	0.97	68.96	0.99
	10	23.87	2.34	0.65	1.69	4.06	0.88	67.84	0.84
Carob Flour	20	22.60	3.65	0.72	2.92	3.77	0.88	68.01	0.88
	30	21.38	4.94	0.79	4.15	3.50	0.79	68.15	0.99
Chickpea Flour	10	23.97	1.54	0.59	0.95	4.67	1.01	67.82	0.82
	20	22.99	2.07	0.60	1.47	5.03	1.14	67.71	0.89
	30	22.02	2.60	0.61	1.99	5.39	1.27	67.60	0.96
	10	24.23	1.16	0.55	0.61	4.81	0.96	67.88	0.79
Lentil Flour	20	23.51	1.32	0.51	0.80	5.31	1.03	67.83	0.83
	30	22.78	1.47	0.48	0.99	5.81	1.11	67.78	0.87

3.1 Specific Gravity of Wafer Batters

Statistical analyses showed that addition of legume flours did not affect batter specific gravity significantly (Table A.4).

Specific gravity of batters is mostly related to the air incorporation of batters during mixing in literature. In this study, the reason for constant specific gravity of batters with legume flour addition might be due to the water adjustment for the required viscosity level. Since all batters had liquid like consistencies, air incorporation was low and batters were rested prior to analysis for a certain period for air gas removal, the specific gravity might have remained constant. Dogan (2006) reported that the wafer batter densities were independent of water and gluten content. Tiefenbacher (2017) reported the specific gravity of wafer batter is about 1 g/ml which is similar to the 1.11-1.12 g/ml value found in this study.

3.2 Rheology of Wafer Batters

As mentioned before, in some of the formulations more water addition was required in order to make the batter spreadable on the baking plates. Consistencies were adjusted by the flow time through a hole in a cylindrical cup. The amount of water added in different formulations is shown in Table 2.1-2.3.

According to the flow curves (Figure 3.1-3.4), all batter formulations followed non-Newtonian behavior due to variation in viscosity values with changing shear rates. In this regard, shear stress (τ, Pa) versus shear rate ($\dot{\gamma}$,1/s) were fitted to power law model (Equation 3.1);

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

where K is the consistency coefficient ($Pa \cdot s^n$) and n is the flow behavior index (Sahin & Sumnu, 2006). All experimental data shows a good fit with power law model ($R^2 \geq 0.99$).

K and n values are shown in Table 3.3. According to the table, all n values were below 1, indicating that the batters showed shear thinning (pseudoplastic) behavior and apparent viscosity decreased by increasing shear rate.

According to two-way ANOVA results (Table A.5) the highest n values were observed for 30% lentil flour containing batter. This result implied that this batter had the most similar structure to Newtonian type of fluids and showed the least decrease in apparent viscosity as shear rates increased among the other batters (Ronda et al., 2011). On the other hand, 30% chickpea flour containing batter had the most dramatic decrease by increasing shear rate having the lowest n value. Flow behavior index decreased with increasing legume flour which showed more effective shear thinning. ANOVA results also indicated the close flow behavior of lentil flour added batters to Newtonian flow. Chickpea and bean flour added samples had the most shear thinning with the lowest n values.

According to two-way ANOVA results after Box-Cox Transformation (Table A.7), replacement of wheat flour by 30% legume flour increased consistency coefficient (K) values. This might be due to the water addition which were not sufficient in 30% carob and bean flour replacement. Two-way ANOVA results also showed that highest consistency coefficients were observed for bean and chickpea flour added batters, despite the additional water addition into bean flour batters. This result is in agreement with higher fiber content of these samples than control batter (Table A.2). In many studies, higher viscosity or consistency values are associated with high water absorption capacity caused by higher protein content. However, having the highest protein content, lentil flour added batters had the lowest K values. Therefore, it can be concluded that fiber content of the flours is more dominant than protein content on affecting consistency. Demirkesen, Mert, Sumnu and Sahin (2010) as well as Gularte, de la Hera, Gómez and Rosell (2012) related the increasing viscosity values with fiber content due to strong water absorption of fibers especially with insoluble fibers. Carob and bean flour containing batters were the highest in fiber content especially in insoluble fibers. However, having the highest fiber content; carob flour containing samples did not attain the highest consistency values. It is possible that water addition to carob flour batter maintained the same consistency as control wafer formulation. Gómez, Moraleja, Oliete, Ruiz and Caballero (2010), also showed that increasing fiber content resulted in higher K and lower n values.

Table 3.3 Power law constants of legume flour added wafer batters at 20°C

Legume Flour Type	Legume Flour Concentration (%)	n	K ($Pa \cdot s^n$)	R^2
Control	0	0.586^{bcd}	3.028^{bc}	0.994
Bean Flour	10	0.515^{cde}	4.903^{abc}	0.992
	20	0.532^{cde}	4.239^{abc}	0.989
	30	0.506^{de}	5.159^{ab}	0.990
Carob Flour	10	0.623^{abc}	2.745^{bc}	0.997
	20	0.606^{abcd}	2.779^{bc}	0.990
	30	0.607^{abcd}	2.928^{bc}	0.992
Chickpea Flour	10	0.619^{abcd}	2.542^{bc}	0.998
	20	0.575^{cd}	3.288^{abc}	0.993
	30	0.453^{e}	6.865^{a}	0.989
Lentil Flour	10	0.692^{ab}	1.679^{bc}	0.999
	20	0.694^{ab}	1.484^{c}	0.999
	30	0.704^{a}	1.394^{c}	0.999

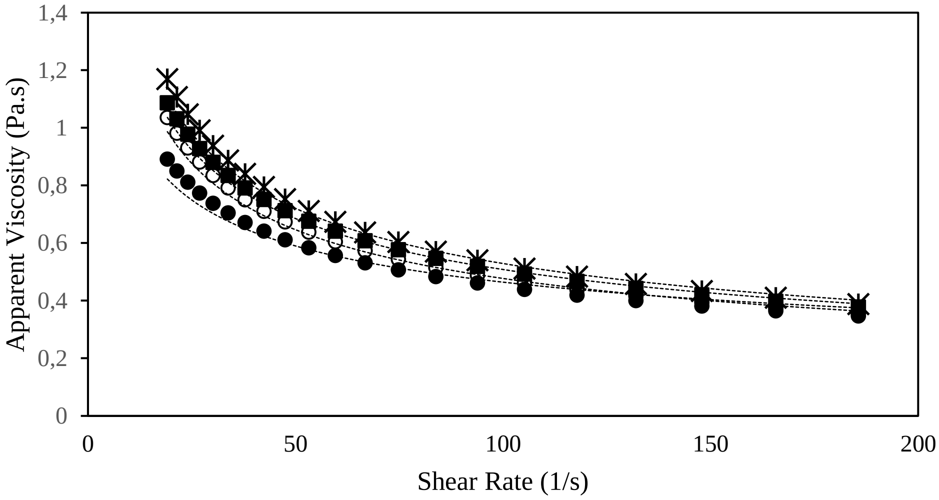

Figure 3.1 Apparent viscosity of wafer batters prepared by the replacement of wheat flour by bean flour at 10% (⁎), 20% (○), 30% (■) ratio, control batter (●) and model (---).

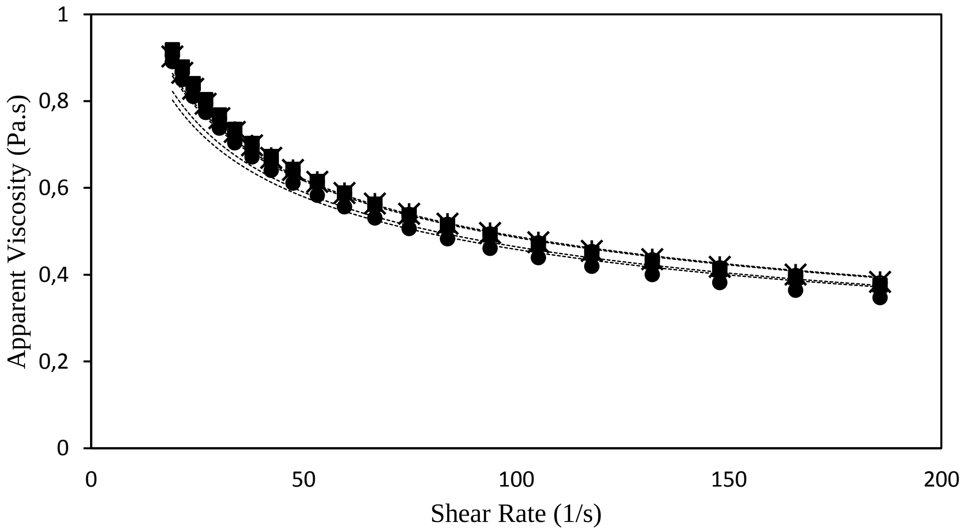

Figure 3.2 Apparent viscosity of wafer batters prepared by the replacement of wheat flour by carob flour at 10% (⁎), 20% (○), 30% (■) ratio, control batter (●) and model (---).

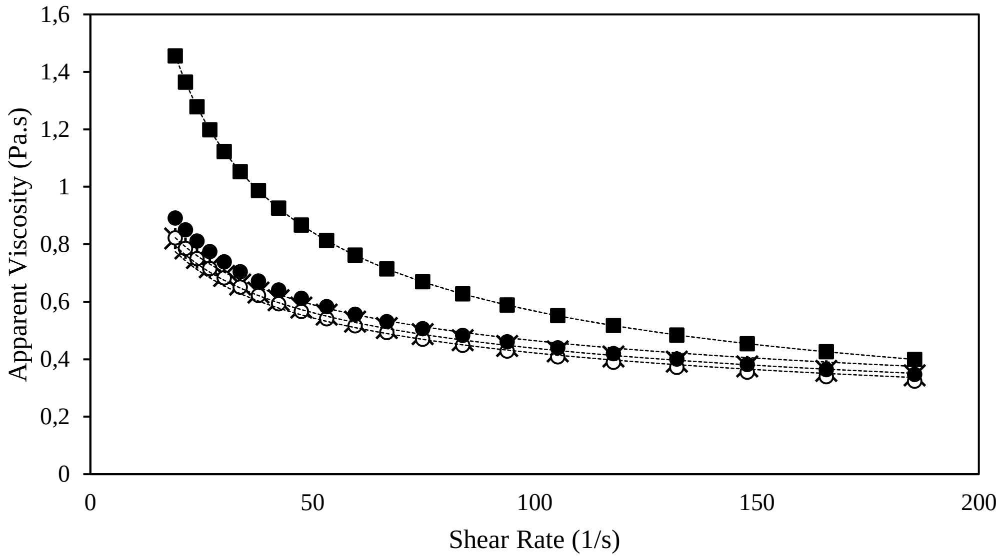

Figure 3.3 Apparent viscosity of wafer batters prepared by the replacement of wheat flour by chickpea flour at 10% (⁎), 20% (○), 30% (■) ratio, control batter (●) and model (---).

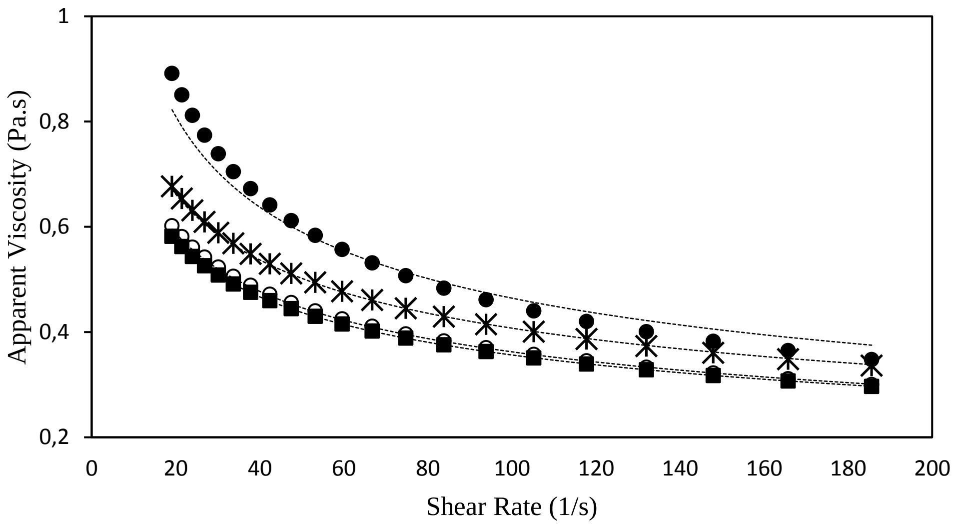

Figure 3.4 Apparent viscosity of wafer batters prepared by the replacement of wheat flour by lentil flour at 10% (⁎), 20% (○), 30% (■) ratio, control batter (●) and model (---).

3.3 Weight Loss of Wafer Sheets

Weight loss values upon baking are shown in Figure 3.5. These values are statistically different to some degree according to ANOVA results (Table A.9). From the results it can be inferred that the weight losses decreased by increasing legume flour content except lentil flour. These results are in agreement with many studies in the literature. Berk (2016) and Demirkesen, Sumnu and Sahin (2013) showed that increasing tigernut, buckwheat and carob flour in cakes resulted in decreased weight loss due to higher fiber content of these flours. Due to hydroxyl groups that fiber molecules have, water interactions through hydrogen bonding is enhanced (Sabanis, Lebesi, & Tzia, 2009). This effect caused less water loss during baking.

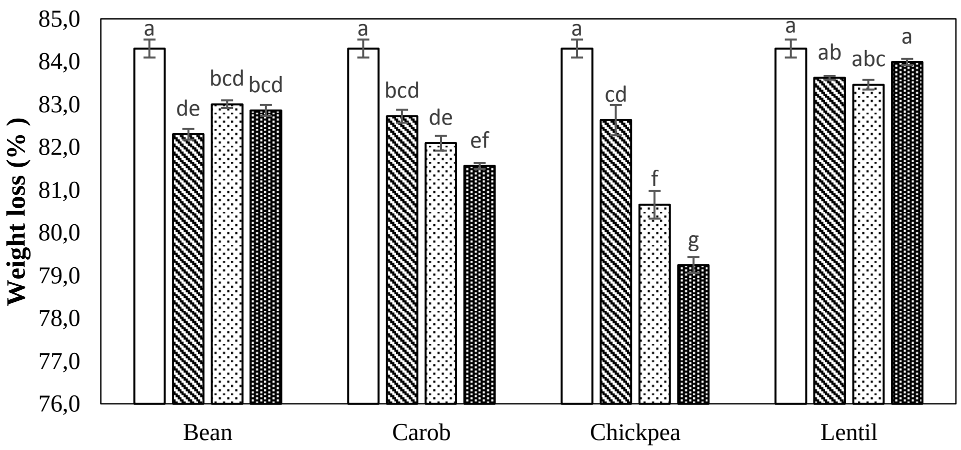

Figure 3.5 Weight loss of the wafer sheets prepared by replacement of wheat flour (□) by bean flour, carob flour, chickpea flour and lentil flour at 10% (▧), 20% (⸬) and 30%(▩) concentrations. Bars having different letters are significantly different ($p \leq 0.05$)

According to ANOVA results, lentil flour added batters and the control batter had the minimum fiber content (Table A.2). This result is in consonance with the highest weight loss values attained by control batter followed by lentil flour added batters. Although carob and bean flour added samples had the richest fiber contents, chickpea addition resulted in the highest water holding values and the least weight loss. This might be also due to the added water to carob and bean flour containing batters.

Weight loss values were found to be inversely correlated with the consistency index values with the correlation coefficient of -0.7 (p= 0.009). This indicates that higher consistency retained more moisture in the system, resulting in less weight loss.

Water holding capacity is defined as the water amount that is absorbed per gram of the material (Ma et al., 2011). In their study, water absorption capacity of chickpea flour was proposed to be higher than that of lentil. Kohajdová, Karovičová and Magala (2013) showed that bean flour was more efficient in water binding than lentil flour. These results are in agreement with the results of this study. Sreerama, Sashikala and Pratape (2012) stated that water holding phenomena could be related to the amino acid content and composition of carbohydrates. Kaur and Singh (2005) proposed the relation between water holding capacity and protein content. However, having the highest protein and carbohydrate content, lentil batters showed low water holding capacity, contradictory to the above-mentioned arguments.

In the literature, generally high water holding capacity of flours are favored in terms of handling and final quality of bakery products. However, this is questionable in terms of wafer production. Since, wafer batter is a liquid-like batter, the spreadability of the batters on the baking plates is important. Moreover, low moisture of final products is desired, which is hard in case of high water holding of the flour. Therefore, water holding capacity is an important parameter and it should be adjusted properly along with the other material and process parameters.

3.4 Hardness

Hardness is an important parameter for texture analysis which is an indicator for the quality of wafer sheets. Hardness results of the wafers produced by only wheat flour or partial replacement of wheat flour by different types and amounts of legume flours are depicted in Figure 3.6.

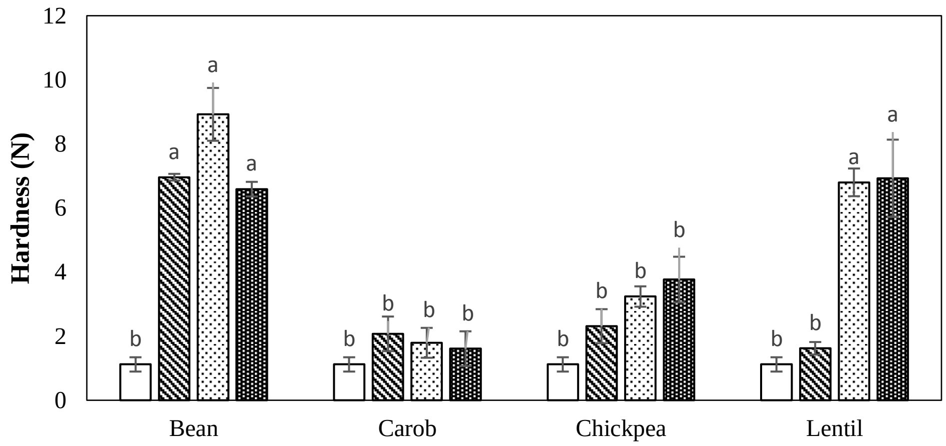

Figure 3.6 Hardness of wafer sheets prepared by replacement of wheat flour ( ) by bean flour, carob flour, chickpea flour and lentil flour at 10% ( ), 20% ( ) and 30%( ).Bars having different letters are significantly different (p≤0.05).

As can be seen from the figure, wafers with bean flour (10%, 20% and 30%) and lentil flour (20% and 30%) were found to be the hardest samples with significant difference from the others. According to two-way ANOVA results (Table A.10), only carob flour samples had the same values with the control wafer.

As already mentioned, legume flours are rich sources of plant protein and dietary fiber. According to two-way ANOVA results (Table A.10), addition of legume flour elevated the wafer hardness generally, except the case when carob flour batters which had the same protein content with the wheat flour batter (Table

A.1). This result coincides with the results of previous studies (Gallagher, Kenny, & Arendt, 2005; Petitot, Boyer, Minier, & Micard, 2010; Tiwari et al., 2011). These studies suggest that, increase in protein composition brings about higher hardness values. Indeed; lentil, chickpea and bean flour added batters had the highest protein content (Table A.1).

Fiber content is a critical parameter for the improvement of quality attributes. Up to a level, it enhances the physical properties, shelf life and sensorial acceptance (Demirkesen et al., 2010). Increasing fiber content has been generally discussed to elevate hardness of the baked products in the literature (Ajila, Leelavathi, & Rao, 2008; Gularte et al., 2012; Sudha, Vetrimani, & Leelavathi, 2007; Yildiz, Demirkesen, & Mert, 2016). In these studies, the effect of fiber on hardness is generally linked to the volume-decreasing impact through thickening of walls of gas cells produced during baking as well as high water binding capacity of fibers resulting in less available water for gluten development and starch-gluten interactions. The study conducted by Peressini, Pin and Sensidoni (2011) indicated that the volume reduction could not be the only explanation for harder texture. Starch composition is also determinant of texture. Decreased level of starch resulting in less gelatinization lifts up the hardness (Sabanis et al., 2006). All bean flour containing wafers attained the highest hardness values. The reason seemed to be the highest protein and the lowest starch composition (Table A.1 and A.3).

There exist studies in which decreasing firmness up to a certain fiber level and then increasing again (Demirkesen et al., 2010; Mudgil, Barak, & Khatkar, 2017). In the study of Wang, Rosell and Benedito de Barber (2002) fibers from different sources showed hardening or softening effects. Gómez, Moraleja, Oliete, Ruiz, and Caballero (2010) also concluded that the influence of fiber on texture is dependent on the fiber type and the product formulation. Lebesi and Tzia (2011) argued that some kind of fiber might not have an effect on the texture. Carob flour used in our study had the highest dietary fiber (about 40% w.b.) among the other flours (Table A.2). However, the addition of carob flour did not alter the hardness from the control formulation. This result leads to the inference that the fiber amount is not effective on wafer hardness.

In addition, flour particle size have been shown to influence the texture profile of the food products. Mancebo, Picón and Gómez (2015) as well as Zucco, Borsuk and Arntfield (2011) suggested that the finer particles gave more compact structure increasing hardness. Therefore, particle size of the flours used, could have affected the firmness.

3.5 Color of Wafer Sheets

Color of foods is a very important parameter for food choice, consumer acceptance and sweetness perception. It stimulates the pleasantness which is a vital element in selection of food (Stroebele & De Castro, 2004). Food color is altered by colors of the ingredients or process conditions.

Browning is widely referred as the formation of color upon baking and it is the result of non-enzymatic Maillard and caramelization reactions. Maillard reaction arises in the presence of reducing sugars and proteins/nitrogen containing compounds in temperatures above 50°C at 4-7 pH. Caramelization takes place upon heating of sugars at lower water activity above 120°C at 3-9 pH. Since temperatures of the plates were adjusted as 160°C and 168°C, both reactions take place during baking of wafer sheets (Kroh, 1994; Purlis, 2010). Total color differences of wafer sheets due to browning reactions are represented at Figure 3.7.

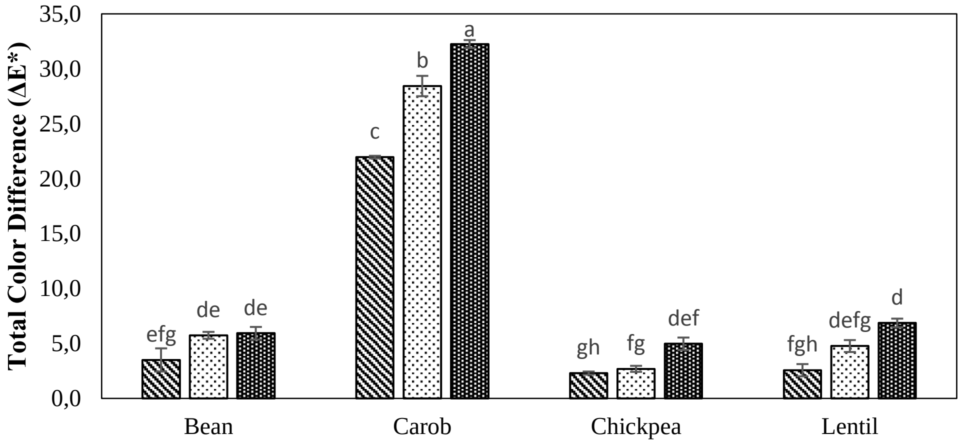

Figure 3.7 Total color differences of wafer sheets from control wafer prepared by replacement of wheat flour by bean flour, carob flour, chickpea flour and lentil flour at 10% (▧), 20% (⬚) and 30%(▩). Bars having different letters are significantly different (p≤0.05).

According to two-way ANOVA results of color differences (Table A.12), increasing legume flour ratio, boosted the level of color development. The reason seems to be the augmented Maillard reactions by elevated amino acid content from legume flours. There were also significant differences among the legume types. Carob flour containing samples showed the highest color difference. It is obvious that the natural color of the carob flour resulted in these values. Moreover, caramelization induced by the highest sugar composition of carob flour could have caused this effect. After carob flour samples, bean and lentil flour samples attained the highest color change possibly due to the enhanced Maillard reactions in the presence of high protein content of these batters. However, chickpea flour added samples had the least color change. This might be attributed to the lower water loss of chickpea flour containing samples, having more water retention. Browning reactions are impelled at low-medium water content and at higher temperatures (Purlis, 2010). Besides, Ashoor and Zent (1984) showed that lysine, glycine, tryptophan and tyrosine are the most effective amino acids on color development. In case of chickpea flour replacement, less color change compared to the bean and lentil might have resulted from the lower content of lysine and glycine amino acids in chickpea (FAO, 1981).

Similar results were reported by the previous studies. Gómez, Oliete, Rosell, Pando and Fernández (2008) observed that crust color of the cakes became darker as chickpea flour ratio in blend increased which was ascribed to the higher protein content of chickpea flour participated in Maillard browning. Also, luminosity scores of cakes and cookies decreased by increasing red lentil, yellow lentil, green lentil, navy bean and pinto bean flour (De la Hera et al., 2012; Zucco et al., 2011).

3.6 Sorption Behavior of Wafer Sheets

Cereal-based snacks and breakfast cereals have crispy texture related to water activity of these foods. They are generally consumed at their glassy state. When their water activity increases above the critical value when exposed to higher relative humidity environment, crispiness is lost due to plasticization (Roos, Roininen, Jouppila, & Tuorila, 1998). Apart from textural attributes, plasticization is also indicative for the stability of the food. In this regard, sorption behavior of foods is of great importance especially for low moisture foods in order to design the processing equipment and parameters especially for aeration, drying and storage. Sorption isotherms give idea on the shelf life and stability of foods during storage. It depicts the water activity corresponding to the surrounding relative humidity versus equilibrium moisture content of the foods at a constant temperature (Wani & Kumar, 2016).

There exists an extensive literature on study of sorption characteristics of different foods. The mentioned studies cover the study of mathematical models representing the sorption, effect of temperature on isotherm and heat of sorption measurements (Durakova & Menkov, 2005; Goula, Karapantsios, Achilias, & Adamopoulos, 2008; Katz & Labuza, 1981; Kaymak-Ertekin & Gedik, 2004;

Mrad, Bonazzi, Boudhrioua, Kechaou, & Courtois, 2012; Mrad, Bonazzi, Courtois, Kechaou, & Mihoubi, 2013; Muzaffar & Kumar, 2016; Palou, López-Malo, & Argaiz, 1997; Singh & Singh, 1996; Siripatrawan & Jantawat, 2006; Tsami, Marinos-Kouris, & Maroulis, 1990).

Sorption isotherm indicates the water binding behavior of the material. It is composed of three regions (a) where the water is strongly bound to the sorbate surface (monolayer) that it is not available for chemical reactions or plasticizing; (b) water is less strongly bound to the surface and exist in small capillaries (multilayer); (c) water is loosely bound and properties of water are similar to those of liquid water (Andrade, Lemus, & Perez, 2011).

Various models have been suggested in the literature for different food materials (Andrade et al., 2011; Basu, Shivhare, & Mujumdar, 2006) most of them being based on ingredients, outnumbering those for the complex food products. Among various models, GAB sorption model is widely employed due to its theoretical base, since it is a further clarification of previously most commonly applied BET and Langmuir models on physical adsorption (Andrade et al., 2011). It is suggested as the most inclusive model on sorption in literature (Al-Muhtaseb, McMinn, & Magee, 2002). According to Lomauro, Bakshi and Labuza (1985), sorption of more than 50% meat, fruit and vegetables could be analyzed by GAB model with high accuracy. However, GAB model is recommended for water activity up to 0.90 for two main reasons: This model is not suitable for higher moisture levels and the gravimetric method employed might not give accurate results for a complete isotherm (Basu et al., 2006).

In this study, all formulations displayed sigmoid S-shaped curves of type II at 20^{0}C, relating equilibrium moisture content to water activity data (Figure 3.8-3.11) (Brunauer, Deming, Deming, & Teller, 1940). Among all, the samples containing 20% and 30% carob flour showed the sharpest increase in equilibrium moisture content at higher water activities (Figure 3.9). This could be due to the dissolution of sugars (Goula et al., 2008).

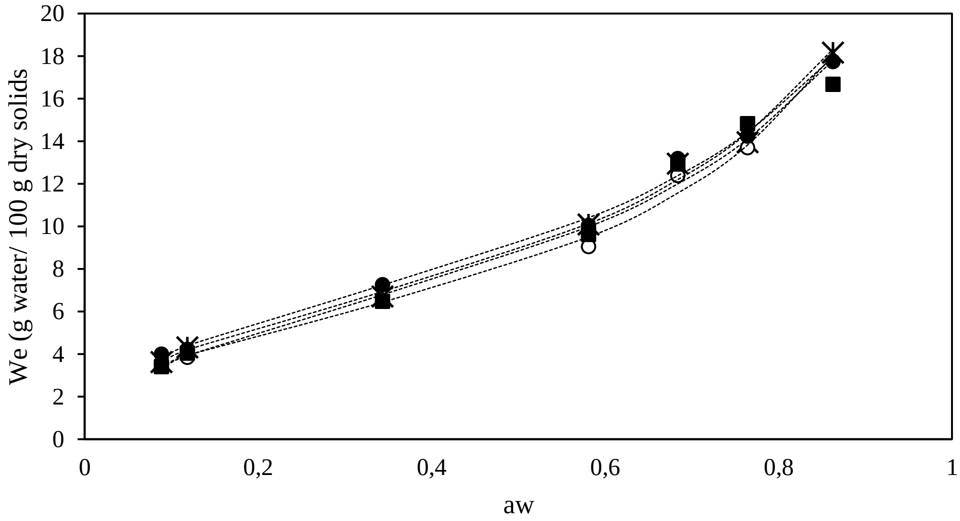

Figure 3.8 Water sorption isotherm of wafers prepared by the replacement of wheat flour by bean flour at 10% (⁎), 20% (○), 30% (■) ratio, control batter (●) and model (---).

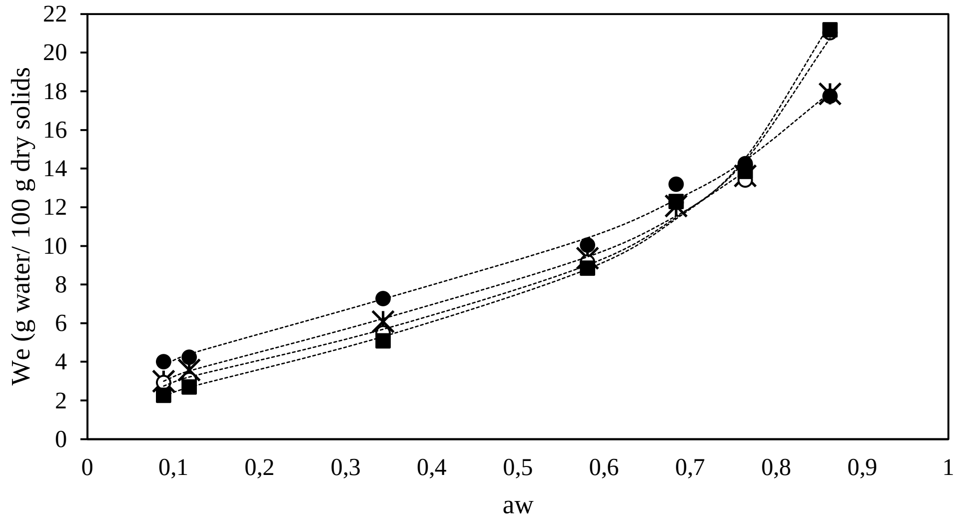

Figure 3.9 Water sorption isotherm of wafers prepared by the replacement of wheat flour by carob flour at 10% (⁎), 20% (○), 30% (■) ratio, control batter (●) and model (---).

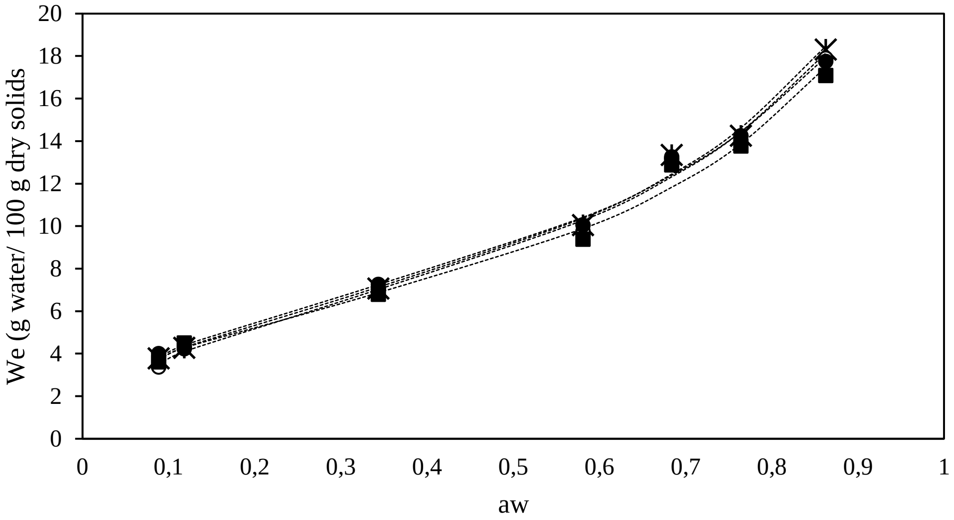

Figure 3.10 Water sorption isotherm of wafers prepared by the replacement of wheat flour by chickpea flour at 10% (⁎), 20% (○), 30% (■) ratio, control batter (●) and model (---).

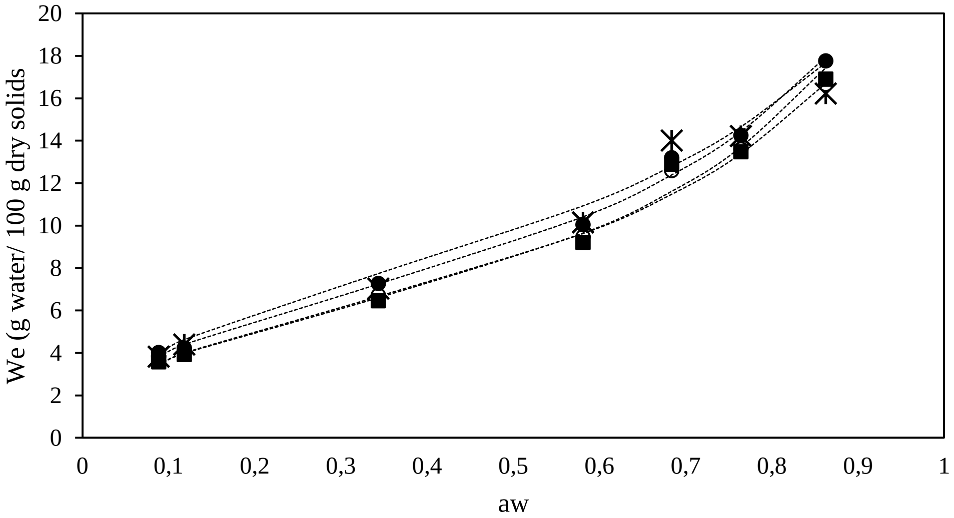

Figure 3.11 Water sorption isotherm of wafers prepared by the replacement of wheat flour by lentil flour at 10% (⁎), 20% (○), 30% (■) ratio, control batter (●) and model (---).

Equilibrium moisture content values increased with increasing relative humidity, due to hydrophilic nature of the proteins, fibers and carbohydrate in the material, an expected characteristics of amorphous state of materials (Muzaffar & Kumar, 2016).

As the employed model in the study, GAB equation is given as (Equation 3.2);

$$W_e = \frac{W_0 C K a_w}{(1-Ka_w)(1-Ka_w+CKa_w)} \tag{3.2}$$

where W_e equilibrium moisture content (% d.b.), C and K are the model constants.

Monolayer moisture content (W_0) implies the water content that is strongly adsorbed to the material surface and enabling the longest storage period with minimum deteriorative reactions in food at a constant temperature (Goula et al., 2008). Up to corresponding water content or glass transition temperature, food is at the most stable form (Sablani, Kasapis, & Rahman, 2007). C parameter characterizes the strength of the binding of the water molecules to the primary binding sites of the sorbate. The higher C values imply more strength and the larger enthalpy difference between the water molecules in the monolayer and the multilayer. K correction factor, on the other hand, indicates the relation of the multilayer molecules compared to the liquid water. K is less than unity and as K approaches 1, water molecules in the monolayer behave as bulk water (Muzaffar & Kumar, 2016).

From the non-linear least square regression analysis, the found W_0, C and K parameters are represented in Figure 3.12- 3.14.

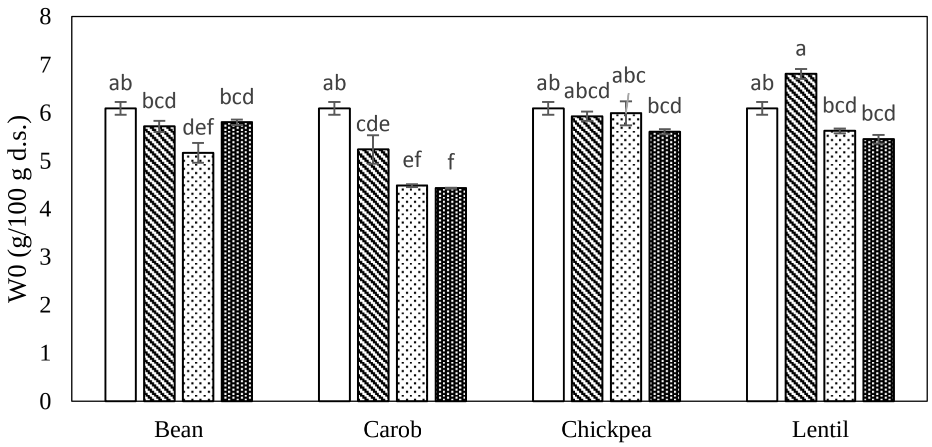

Figure 3.12 W_0 parameter of GAB sorption model of wafer sheets prepared by replacement of wheat flour (□) by bean flour, carob flour, chickpea flour and lentil flour at 10% (▧), 20% (⬚) and 30%(▩). Bars having different letters are significantly different (p≤0.05).

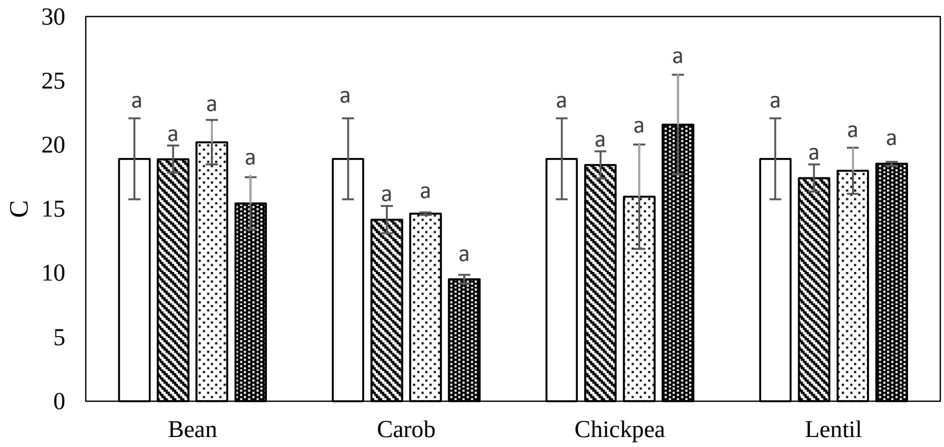

Figure 3.13 C parameter of GAB sorption model of wafer sheets prepared by replacement of wheat flour (□) by bean flour, carob flour, chickpea flour and lentil flour at 10% (▧), 20% (⬚) and 30% (▩). Bars having different letters are significantly different (p≤0.05).

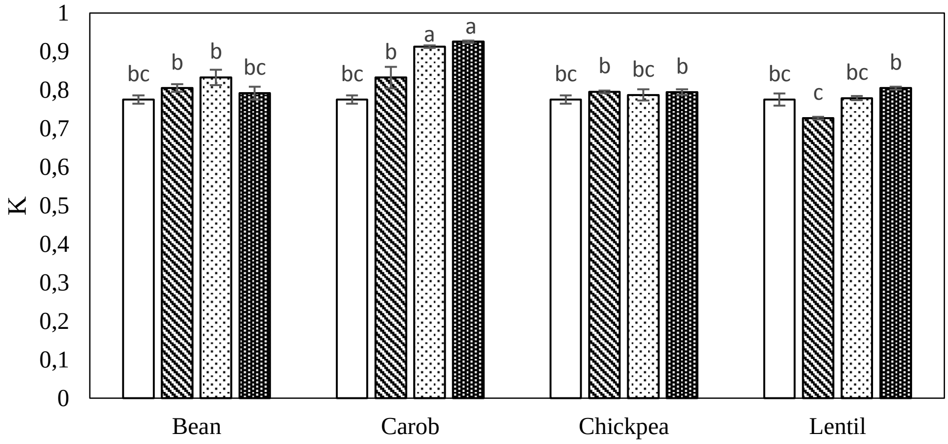

Figure 3.14 K parameter of GAB sorption model of wafer sheets prepared by replacement of wheat flour ( ) bean flour, carob flour, chickpea flour and lentil flour at 10% ( ), 20% ( ) and 30%( ). Bars having different letters are significantly different ($p \leq 0.05$).

According to Figure 3.12, the monolayer moisture contents vary between 4.44-6.69 (% d.b.). This results agree with those for the wafer sheets as 6.9% (Martínez-Navarrete, Moraga, Talens, & Chiralt, 2004), extruded snacks as 7.3% (Wani & Kumar, 2016), cookies as 3.97-4.58 (Palou et al., 1997) at ambient temperature. Two-way ANOVA results (Table A.14) showed that addition of legume flour to the formulation decreased monolayer values in the case of bean and carob flour. W_0 values seem to be inversely correlated with high fiber content coming from bean and carob flour with Pearson coefficient of -0.761 (p=0.003). In addition, decreasing W_0 values with bean and carob flour addition showed that incorporation of these flours decreased the stability of wafer sheets. On the other hand, 10% lentil flour, 10% and 20% chickpea containing formulation gave the best result.

C values of the model are in 9.5-22.1 range (Figure 3.13). These results are in agreement for those reported in literature for the wafer sheets as 16.9 (Martínez-

Navarrete et al., 2004), extruded snacks as 12.5 (Wani & Kumar, 2016), crackers as 9.0 and cookies as 5.9 (Kim, Kim, Kim, Shin, & Chang, 1998) at ambient temperature. The addition of legume flours did not affect C values (Table A.16) maintaining a relatively strong monolayer and localized sorption except in the case of carob flour. Addition of carob flour decreased the C value, possibly resulted by the lowest protein content of carob flour.

According to Figure 3.14, K parameter of GAB sorption model is in 0.72-0.93 range (Figure 3.14). These are quite high values, approaching to 1. The previous studies reported similar outcomes for wafer sheets as 0.841 (Martínez-Navarrete et al., 2004), extruded snacks as 0.78 (Wani & Kumar, 2016), crackers as 0.96 and cookies as 0.98 (Kim et al., 1998). Fiber content was correlated with K values with Pearson coefficient of 0.8 (p= 0.001) and it could be the reason for the approach of K value to 1. As the highest fiber containing batters, carob flour batters followed by bean flour batters gave the highest K values. On the other hand, lentil flour containing and control batters showed the least K value related to the lowest fiber content of them. Approaching K values to 1 approximates the multilayer water molecule behaviors to those of bulk liquid (Table A.18).

The results imply that the water in the multilayers have comparable characteristics to the liquid water for all the wafer formulations. Combined comprehension of higher C and higher K values for all formulas, depicts the localized sorption i.e. the organized layers and the different align of water molecules (Quirijns, Van Boxtel, Van Loon, & Van Straten, 2005).

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

In this study, the effects of legume flour utilization in wafer sheet production were studied. The replacement of wheat flour by legume flours up to 30% concentration did not have an influence on specific gravity of batters. In terms of rheology, all samples obeyed Power law with shear thinning behavior. Flow behavior index was affected by both legume flour type and concentration whereas consistency coefficient was affected by only flour type. When wheat flour was replaced by lentil flour, the lowest consistency coefficient and the highest flow behavior index values indicating the lowest apparent viscosity and shear thinning behavior were observed. Legume flour incorporation retained the moisture in the sheet and resulted in less weight loss after baking except lentil flour. Lentil flour replaced samples had the same weight loss compared to the control wafer. Hardness of the wafer sheets increased by legume flour addition and also as legume flour concentration increased, hardness values increased. Carob flour, chickpea flour and 10% lentil flour containing samples were the most similar to the control sample in terms of hardness. Total color difference reflected the natural color of the flours and the browning reactions. It would be obvious that carob flour showed the highest color difference due to its natural color. 10% chickpea and 10% lentil flour containing samples had the similar color values to the control. Sorption analyses of the wafers showed that sigmoid S-shaped curves of type II were obtained for all formulations. The samples containing 20% and 30% carob flour showed the sharpest increase in equilibrium moisture content at higher water activities due to dissolution of sugars. Localized sorption was evident from the isotherms and the behavior of water molecules in the multilayer were similar to those of liquid water. Monolayer moisture content of the control wafer was also obtained by 10% lentil, 10% chickpea and 20% chickpea flour replacement.

Overall, it could be concluded that legume flours could be used in wafer production to increase nutritional components without decreasing quality. Samples with 10% lentil flour replacement were the best in terms of the studied quality parameters.

For future studies, quality attributes of legume flour added wafers in composite products such as wafers enrobed with chocolate or sandwiched with cream could be investigated. Effects of wafer processing on nutritional content could be studied. Sorption and texture analyses could be done over a temperature range or in definite time intervals. Storage of wafers and effects of type of packaging materials could be studied. Glass transition temperatures of wafer sheets could be analyzed. Wafer formulas could be extended by other ingredients.

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APPENDIX A

STATISTICAL ANALYSES

Table A.1 Two way ANOVA and Tukey's Comparison Test for protein content of batters prepared by 10%, 20% and 30% replacement of reference wheat flour by bean flour, carob flour, chickpea flour and lentil flour.

General Linear Model: Protein versus Flour Type; Ratio (%)

```
Factor      Type   Levels  Values
Flour Type  fixed       5  B; CA; CH; L; R
Ratio (%)   fixed       3  10; 20; 30


Analysis of Variance for Protein, using Adjusted SS for Tests

Source                DF    Seq SS   Adj SS   Adj MS      F      P
Flour Type             4   9,30751  9,30751  2,32688  52,10  0,000
Ratio (%)              2   0,64785  0,64785  0,32393   7,25  0,006
Flour Type*Ratio (%)   8   1,59797  1,59797  0,19975   4,47  0,006
Error                 15   0,66994  0,66994  0,04466
Total                 29  12,22327


S = 0,211335   R-Sq = 94,52%   R-Sq(adj) = 89,40%


Grouping Information Using Tukey Method and 95,0% Confidence

Flour
Type   N  Mean  Grouping
L      6   5,3  A
CH     6   5,0  A
B      6   5,0  A
R      6   4,3    B
CA     6   3,8      C

Means that do not share a letter are significantly different.
```

```
Grouping Information Using Tukey Method and 95,0% Confidence

Ratio
(%)     N  Mean  Grouping
30     10   4,9  A
20     10   4,7  A B
10     10   4,5    B

Means that do not share a letter are significantly different.


Grouping Information Using Tukey Method and 95,0% Confidence

Flour  Ratio
Type   (%)    N  Mean  Grouping
L      30     2   5,8  A
CH     30     2   5,4  A B
L      20     2   5,3  A B
B      30     2   5,3  A B
CH     20     2   5,0  A B C
B      20     2   4,9    B C
L      10     2   4,8    B C D
CH     10     2   4,7    B C D
B      10     2   4,7    B C D
R      10     2   4,3      C D E
R      20     2   4,3      C D E
R      30     2   4,3      C D E
CA     10     2   4,1        D E
CA     20     2   3,8          E
CA     30     2   3,5          E

Means that do not share a letter are significantly different.
```

Table A.2 Two way ANOVA and Tukey‘s Comparison Test for fiber content of batters prepared by 10%, 20% and 30% replacement of reference wheat flour by bean flour, carob flour, chickpea flour and lentil flour.

General Linear Model: Fiber versus Flour Type; Ratio (%)

```
Factor      Type   Levels  Values
Flour Type  fixed       5  B; CA; CH; L; R
Ratio (%)   fixed       3  10; 20; 30


Analysis of Variance for Fiber, using Adjusted SS for Tests

Source               DF   Seq SS   Adj SS  Adj MS      F      P
Flour Type            4  28,3740  28,3740  7,0935  56,07  0,000
Ratio (%)             2   6,6968   6,6968  3,3484  26,47  0,000
Flour Type*Ratio (%)  8   4,5631   4,5631  0,5704   4,51  0,006
Error                15   1,8975   1,8975  0,1265
Total                29  41,5314
```

```
S = 0,355669   R-Sq = 95,43%   R-Sq(adj) = 91,17%


Grouping Information Using Tukey Method and 95,0% Confidence

Flour
Type   N  Mean  Grouping
CA     6   3,6  A
B      6   2,8    B
CH     6   2,1      C
L      6   1,3        D
R      6   1,0        D

Means that do not share a letter are significantly different.


Grouping Information Using Tukey Method and 95,0% Confidence

Ratio
(%)     N  Mean  Grouping
30     10   2,8  A
20     10   2,2    B
10     10   1,6      C

Means that do not share a letter are significantly different.
Grouping Information Using Tukey Method and 95,0% Confidence

Flour  Ratio
Type   (%)    N  Mean  Grouping
CA     30     2   4,9  A
B      30     2   3,8  A B
CA     20     2   3,6  A B
B      20     2   2,8    B C
CH     30     2   2,6    B C D
CA     10     2   2,3    B C D E
CH     20     2   2,1      C D E
B      10     2   1,9      C D E
CH     10     2   1,5      C D E
L      30     2   1,5      C D E
L      20     2   1,3        D E
L      10     2   1,2          E
R      30     2   1,0          E
R      20     2   1,0          E
R      10     2   1,0          E

Means that do not share a letter are significantly different.
```

Table A.3 Two way ANOVA and Tukey's Comparison Test for carbohydrate content of batters prepared by 10%, 20% and 30% replacement of reference wheat flour by bean flour, carob flour, chickpea flour and lentil flour.

General Linear Model: Carbohydrate versus Flour Type; Ratio (%)

```
Factor      Type   Levels  Values
Flour Type  fixed       5  B; CA; CH; L; R
Ratio (%)   fixed       3  10; 20; 30
```

Analysis of Variance for Carbohydrate, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Flour Type	4	38,8873	38,8873	9,7218	27,89	0,000
Ratio (%)	2	17,0915	17,0915	8,5457	24,51	0,000
Flour Type*Ratio (%)	8	6,2900	6,2900	0,7863	2,26	0,083
Error	15	5,2289	5,2289	0,3486		
Total	29	67,4977				

S = 0,590417   R-Sq = 92,25%   R-Sq(adj) = 85,02%

Grouping Information Using Tukey Method and 95,0% Confidence

Flour Type	N	Mean	Grouping
R	6	24,9	A
L	6	23,5	B
CH	6	23,0	B
CA	6	22,6	B
B	6	21,5	C

Means that do not share a letter are significantly different.
Grouping Information Using Tukey Method and 95,0% Confidence

Ratio (%)	N	Mean	Grouping
10	10	24,0	A
20	10	23,1	B
30	10	22,2	C

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95,0% Confidence

Flour Type	Ratio (%)	N	Mean	Grouping
R	30	2	24,9	A
R	20	2	24,9	A
R	10	2	24,9	A
L	10	2	24,2	A B
CH	10	2	24,0	A B
CA	10	2	23,9	A B
L	20	2	23,5	A B C
B	10	2	23,2	A B C
CH	20	2	23,0	A B C
L	30	2	22,8	A B C
CA	20	2	22,6	A B C
CH	30	2	22,0	B C D
CA	30	2	21,4	C D
B	20	2	21,4	C D
B	30	2	19,9	D

Means that do not share a letter are significantly different.

Table A.4 Two way ANOVA and Tukey's Comparison Test for specific gravity of wafer batters prepared by 10%, 20% and 30% replacement of wheat flour by bean flour, carob flour, chickpea flour and lentil flour.

General Linear Model: Specific Gravity versus Flour Type; Ratio

```
Factor      Type   Levels  Values
Flour Type  fixed       4  B; CA; CH; L
Ratio       fixed       4  0; 10; 20; 30


Analysis of Variance for Specific Gravity, using Adjusted SS for Tests

Source            DF     Seq SS     Adj SS     Adj MS     F      P
Flour Type         3  0.0000955  0.0000955  0.0000318  2.21  0.127
Ratio              3  0.0001296  0.0001296  0.0000432  3.00  0.062
Flour Type*Ratio   9  0.0001413  0.0001413  0.0000157  1.09  0.421
Error             16  0.0002304  0.0002304  0.0000144
Total             31  0.0005967


S = 0.00379452   R-Sq = 61.39%   R-Sq(adj) = 25.20%


Grouping Information Using Tukey Method and 95.0% Confidence

Flour
Type   N  Mean  Grouping
CH     8   1.1  A
L      8   1.1  A
CA     8   1.1  A
B      8   1.1  A

Means that do not share a letter are significantly different.


Grouping Information Using Tukey Method and 95.0% Confidence

Ratio  N  Mean  Grouping
10     8   1.1  A
20     8   1.1  A B
 0     8   1.1  A B
30     8   1.1    B

Means that do not share a letter are significantly different.


Grouping Information Using Tukey Method and 95.0% Confidence

Flour
Type   Ratio  N  Mean  Grouping
L      10     2   1.1  A
CH     20     2   1.1  A
CH     10     2   1.1  A
B      10     2   1.1  A
L      20     2   1.1  A
L       0     2   1.1  A
```

```
CH      30      2   1.1  A
CH       0      2   1.1  A
CA      30      2   1.1  A
CA      20      2   1.1  A
CA      10      2   1.1  A
CA       0      2   1.1  A
B        0      2   1.1  A
L       30      2   1.1  A
B       20      2   1.1  A
B       30      2   1.1  A

Means that do not share a letter are significantly different.
```

Table A.5 Two way ANOVA and Tukey's Comparison Test for flow behavior index (n) of wafer batters prepared by 10%, 20% and 30% replacement of reference wheat flour by bean flour, carob flour, chickpea flour and lentil flour.

General Linear Model: Flow Behavior In versus Flour Type; Ratio (%)

```
Factor       Type   Levels  Values
Flour Type   fixed       5  B; CA; CH; L; R
Ratio (%)    fixed       3  0,1; 0,2; 0,3


Analysis of Variance for Flow Behavior Index (n)_1, using Adjusted SS for
Tests

Source                DF    Seq SS    Adj SS    Adj MS      F      P
Flour Type             4  0,113166  0,113166  0,028291  38,14  0,000
Ratio (%)              2  0,007241  0,007241  0,003620   4,88  0,023
Flour Type*Ratio (%)   8  0,023609  0,023609  0,002951   3,98  0,010
Error                 15  0,011127  0,011127  0,000742
Total                 29  0,155143


S = 0,0272364   R-Sq = 92,83%   R-Sq(adj) = 86,13%


Unusual Observations for Flow Behavior Index (n)_1

     Flow Behavior
Obs    Index (n)_1       Fit    SE Fit   Residual  St Resid
  9       0,487500  0,532500  0,019259  -0,045000     -2,34 R
 10       0,577500  0,532500  0,019259   0,045000      2,34 R
 23       0,493900  0,453250  0,019259   0,040650      2,11 R
 24       0,412600  0,453250  0,019259  -0,040650     -2,11 R

R denotes an observation with a large standardized residual.
```

```
Grouping Information Using Tukey Method and 95,0% Confidence

Flour
Type   N  Mean  Grouping
L      6   0,7  A
CA     6   0,6    B
R      6   0,6    B C
CH     6   0,5      C D
B      6   0,5        D

Means that do not share a letter are significantly different.
```

```
Grouping Information Using Tukey Method and 95,0% Confidence

Ratio
(%)      N  Mean  Grouping
0,1    10   0,6  A
0,2    10   0,6  A B
0,3    10   0,6    B

Means that do not share a letter are significantly different.
```

```
Grouping Information Using Tukey Method and 95,0% Confidence

Flour  Ratio
Type   (%)    N  Mean  Grouping
L      0,3    2   0,7  A
L      0,2    2   0,7  A B
L      0,1    2   0,7  A B
CA     0,1    2   0,6  A B C
CH     0,1    2   0,6  A B C
CA     0,3    2   0,6  A B C D
CA     0,2    2   0,6  A B C D
R      0,3    2   0,6    B C D
R      0,2    2   0,6    B C D
R      0,1    2   0,6    B C D
CH     0,2    2   0,6      C D
B      0,2    2   0,5      C D E
B      0,1    2   0,5      C D E
B      0,3    2   0,5        D E
CH     0,3    2   0,5          E

Means that do not share a letter are significantly different.
```

Table A.6 One way ANOVA and Tukey‘s Comparison Test for flow behavior index (n) of wafer batters prepared by replacement of wheat flour by legume flours

One-way ANOVA: Flow Behavior Index (n) versus Batter Type

```
Source       DF        SS        MS      F      P
Batter Type  12  0,143822  0,011985  14,05  0,000
Error        13  0,011090  0,000853
Total        25  0,154912
```

```
S = 0,02921   R-Sq = 92,84%   R-Sq(adj) = 86,23%


                                Individual 95% CIs For Mean Based on
                                Pooled StDev
Level      N     Mean    StDev  ---------+---------+---------+---------+
10%B       2  0,51495  0,01846        (---*----)
10%CA      2  0,62335  0,00092                   (---*----)
10%CH      2  0,61890  0,02645                  (----*---)
10%L       2  0,69210  0,00028                          (---*----)
20%B       2  0,53250  0,06364          (---*----)
20%CA      2  0,60615  0,01478                 (----*---)
20%CH      2  0,57520  0,01994              (----*---)
20%L       2  0,69415  0,00304                          (---*----)
30%B       2  0,50355  0,04490       (---*----)
30%CA      2  0,60740  0,00198                 (----*---)
30%CH      2  0,45325  0,05749  (---*----)
30%L       2  0,70360  0,00552                           (---*----)
Reference  2  0,58565  0,00431               (----*---)
                                ---------+---------+---------+---------+
                                       0,50      0,60      0,70      0,80

Pooled StDev = 0,02921


Grouping Information Using Tukey Method

Batter Type  N     Mean  Grouping
30%L         2  0,70360  A
20%L         2  0,69415  A B
10%L         2  0,69210  A B
10%CA        2  0,62335  A B C
10%CH        2  0,61890  A B C D
30%CA        2  0,60740  A B C D
20%CA        2  0,60615  A B C D
Reference    2  0,58565    B C D
20%CH        2  0,57520      C D
20%B         2  0,53250      C D E
10%B         2  0,51495      C D E
30%B         2  0,50355        D E
30%CH        2  0,45325          E

Means that do not share a letter are significantly different.
```

Table A.7 Two way ANOVA and Tukey‘s Comparison Test for consistency index (k) of wafer batters prepared by 10%, 20% and 30% replacement of reference wheat flour by bean flour, carob flour, chickpea flour and lentil flour.

General Linear Model: Consistency Index versus Flour Type; Ratio (%)

```
Factor       Type   Levels  Values
Flour Type   fixed       5  B; CA; CH; L; R
Ratio (%)    fixed       3  0,1; 0,2; 0,3
```

```
Analysis of Variance for Consistency Index (k)_1, using Adjusted SS for
Tests

Source               DF   Seq SS   Adj SS  Adj MS      F      P
Flour Type            4  38,9696  38,9696  9,7424  13,88  0,000
Ratio (%)             2   5,4434   5,4434  2,7217   3,88  0,044
Flour Type*Ratio (%)  8  16,9435  16,9435  2,1179   3,02  0,031
Error                15  10,5271  10,5271  0,7018
Total                29  71,8835


S = 0,837740   R-Sq = 85,36%   R-Sq(adj) = 71,69%


Unusual Observations for Consistency Index (k)_1

     Consistency
Obs  Index (k)_1      Fit   SE Fit  Residual  St Resid
  9      5,43600  4,23900  0,59237   1,19700      2,02 R
 10      3,04200  4,23900  0,59237  -1,19700     -2,02 R
 23      5,28100  6,86500  0,59237  -1,58400     -2,67 R
 24      8,44900  6,86500  0,59237   1,58400      2,67 R

R denotes an observation with a large standardized residual.


Grouping Information Using Tukey Method and 95,0% Confidence

Flour
Type   N  Mean  Grouping
B      6   4,8  A
CH     6   4,2  A B
R      6   3,0    B
CA     6   2,8    B C
L      6   1,5      C

Means that do not share a letter are significantly different.


Grouping Information Using Tukey Method and 95,0% Confidence

Ratio
(%)     N  Mean  Grouping
0,3    10   3,9  A
0,1    10   3,0  A
0,2    10   3,0  A
```

Since p value indicates significant difference but grouping could not be done, Box-Cox transformation was applied and the transformation gave rounded value as -2. The corrected two way ANOVA and Tukey‘s Comparison Test for consistency index (k) of wafer batters prepared by 10%, 20% and 30% replacement of reference wheat flour by bean flour, carob flour, chickpea flour and lentil flour are depicted below:

General Linear Model: Corrected Consistency Index versus Flour Type; Ratio (%)

```
Factor      Type   Levels  Values
Flour Type  fixed       5  B; CA; CH; L; R
Ratio (%)   fixed       3  0.1; 0.2; 0.3


Analysis of Variance for Corrected Consistency Index K2, using Adjusted
SS for
     Tests

Source                DF   Seq SS   Adj SS  Adj MS      F      P
Flour Type             4  11.5169  11.5169  2.8792  14.39  0.000
Ratio (%)              2   1.6476   1.6476  0.8238   4.12  0.038
Flour Type*Ratio (%)   8   4.9475   4.9475  0.6184   3.09  0.028
Error                 15   3.0007   3.0007  0.2000
Total                 29  21.1128


S = 0.447267   R-Sq = 85.79%   R-Sq(adj) = 72.52%


Unusual Observations for Corrected Consistency Index K2

       Corrected
     Consistency
Obs     Index K2      Fit   SE Fit  Residual  St Resid
 23      4.09942  4.98676  0.31627  -0.88734     -2.81 R
 24      5.87410  4.98676  0.31627   0.88734      2.81 R

R denotes an observation with a large standardized residual.


Grouping Information Using Tukey Method and 95.0% Confidence

Flour
Type   N  Mean  Grouping
B      6   3.8  A
CH     6   3.5  A B
R      6   2.9    B C
CA     6   2.7      C D
L      6   2.1        D

Means that do not share a letter are significantly different.


Grouping Information Using Tukey Method and 95.0% Confidence

Ratio
(%)     N  Mean  Grouping
0.3    10   3.3  A
0.2    10   2.9  A B
0.1    10   2.8    B

Means that do not share a letter are significantly different.


Grouping Information Using Tukey Method and 95.0% Confidence
```

Flour Type	Ratio (%)	N	Mean	Grouping
CH	0.3	2	5.0	A
B	0.3	2	4.0	A B
B	0.1	2	3.8	A B C
B	0.2	2	3.6	A B C
CH	0.2	2	3.0	B C
R	0.3	2	2.9	B C
R	0.1	2	2.9	B C
R	0.2	2	2.9	B C
CA	0.2	2	2.7	B C
CA	0.3	2	2.7	B C
CH	0.1	2	2.6	B C
CA	0.1	2	2.6	B C
L	0.1	2	2.1	C
L	0.2	2	2.1	C
L	0.3	2	2.0	C

Means that do not share a letter are significantly different.

Table A.8 One way ANOVA and Tukey‘s Comparison Test for consistency index (k) of wafer batters prepared by replacement of wheat flour by legume flours.

One-way ANOVA: Consistency Index (k) versus Batter Type

Source	DF	SS	MS	F	P
Batter Type	12	61,081	5,090	6,29	0,001
Error	13	10,520	0,809		
Total	25	71,601			

S = 0,8996   R-Sq = 85,31%   R-Sq(adj) = 71,75%

```
                               Individual 95% CIs For Mean Based on Pooled
StDev
Level      N    Mean   StDev     +---------+---------+---------+---------
10%B       2  4,9030  0,4610                   (-----*----)
10%CA      2  2,7450  0,0665          (-----*----)
10%CH      2  2,5420  0,5035          (----*-----)
10%L       2  1,6790  0,0198      (-----*----)
20%B       2  4,2390  1,6928                (-----*----)
20%CA      2  2,7785  0,2652           (----*-----)
20%CH      2  3,2875  0,7389             (----*-----)
20%L       2  1,4840  0,0057     (-----*----)
30%B       2  5,1595  1,2381                    (-----*----)
30%CA      2  2,9275  0,1110           (-----*----)
30%CH      2  6,8650  2,2401                           (----*-----)
30%L       2  1,3945  0,0021     (-----*----)
Reference  2  3,0284  0,0602            (----*-----)
                                 +---------+---------+---------+---------
                               0,0       2,5       5,0       7,5
```

Pooled StDev = 0,8996
Grouping Information Using Tukey Method

```
Batter Type  N   Mean  Grouping
30%CH        2  6,865  A
30%B         2  5,159  A B
10%B         2  4,903  A B C
20%B         2  4,239  A B C
20%CH        2  3,288  A B C
Reference    2  3,028    B C
30%CA        2  2,928    B C
20%CA        2  2,779    B C
10%CA        2  2,745    B C
10%CH        2  2,542    B C
10%L         2  1,679    B C
20%L         2  1,484      C
30%L         2  1,394      C

Means that do not share a letter are significantly different.
```

Table A.9 Two way ANOVA and Tukey's Comparison Test for % weight loss of wafer sheets prepared by 10%, 20% and 30% replacement of reference wheat flour by bean flour, carob flour, chickpea flour and lentil flour.

General Linear Model: % Weight Loss versus Flour Type; Ratio

```
Factor      Type   Levels  Values
Flour Type  fixed       5  B; CA; CH; L; Ref
Ratio       fixed       3  10; 20; 30


Analysis of Variance for % Weight Loss, using Adjusted SS for Tests

Source            DF   Seq SS   Adj SS  Adj MS       F      P
Flour Type         4  110.034  110.034  27.508  160.56  0.000
Ratio              2    6.623    6.623   3.312   19.33  0.000
Flour Type*Ratio   8   27.841   27.841   3.480   20.31  0.000
Error             60   10.280   10.280   0.171
Total             74  154.778


S = 0.413918   R-Sq = 93.36%   R-Sq(adj) = 91.81%


Unusual Observations for % Weight Loss

     % Weight
Obs      Loss      Fit  SE Fit  Residual  St Resid
 20   81.2264  82.6309  0.1851   -1.4044     -3.79 R
 25   79.7217  80.6532  0.1851   -0.9315     -2.52 R

R denotes an observation with a large standardized residual.


Grouping Information Using Tukey Method and 95.0% Confidence
```

Flour Type	N	Mean	Grouping
Ref	15	84.3	A
L	15	83.7	B
B	15	82.7	C
CA	15	82.1	D
CH	15	80.8	E

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95.0% Confidence

Ratio	N	Mean	Grouping
10	25	83.1	A
20	25	82.7	B
30	25	82.4	C

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95.0% Confidence

Flour Type	Ratio	N	Mean	Grouping
Ref	10	5	84.3	A
Ref	30	5	84.3	A
Ref	20	5	84.3	A
L	30	5	84.0	A
L	10	5	83.6	A B
L	20	5	83.5	A B C
B	20	5	83.0	B C D
B	30	5	82.9	B C D
CA	10	5	82.7	B C D
CH	10	5	82.6	C D
B	10	5	82.3	D E
CA	20	5	82.1	D E
CA	30	5	81.6	E F
CH	20	5	80.7	F
CH	30	5	79.2	G

Means that do not share a letter are significantly different.

Table A.10 Two way ANOVA and Tukey's Comparison Test for hardness of samples prepared by 10%, 20% and 30% replacement of reference wheat flour by bean flour, carob flour, chickpea flour and lentil flour.

General Linear Model: HARDNESS versus RATIO; FLOUR TYPE

Factor	Type	Levels	Values
RATIO	fixed	3	10; 20; 30
FLOUR TYPE	fixed	5	b; ca; ch; l; ref

Analysis of Variance for HARDNESS, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
RATIO	2	33,059	33,059	16,530	11,62	0,000
FLOUR TYPE	4	403,466	403,466	100,866	70,92	0,000
RATIO*FLOUR TYPE	8	80,292	80,292	10,037	7,06	0,000
Error	60	85,333	85,333	1,422		
Total	74	602,150				

S = 1,19257   R-Sq = 85,83%   R-Sq(adj) = 82,52%

Unusual Observations for HARDNESS

Obs	HARDNESS	Fit	SE Fit	Residual	St Resid	
34	11,7338	8,9216	0,5333	2,8122	2,64	R
35	6,6804	8,9216	0,5333	-2,2412	-2,10	R
54	6,3097	3,7666	0,5333	2,5431	2,38	R
62	10,9719	6,9265	0,5333	4,0453	3,79	R
63	3,9600	6,9265	0,5333	-2,9666	-2,78	R

R denotes an observation with a large standardized residual.

Grouping Information Using Tukey Method and 95,0% Confidence

RATIO	N	Mean	Grouping
20	25	4,4	A
30	25	4,0	A
10	25	2,8	B

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95,0% Confidence

FLOUR TYPE	N	Mean	Grouping
b	15	7,5	A
l	15	5,1	B
ch	15	3,1	C
ca	15	1,8	D
ref	15	1,1	D

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95,0% Confidence

RATIO	FLOUR TYPE	N	Mean	Grouping
20	b	5	8,9	A
10	b	5	7,0	A
30	l	5	6,9	A
20	l	5	6,8	A
30	b	5	6,6	A
30	ch	5	3,8	B
20	ch	5	3,2	B
10	ch	5	2,3	B
10	ca	5	2,1	B

```
20      ca      5   1,8    B
10      l       5   1,6    B
30      ca      5   1,6    B
20      ref     5   1,1    B
30      ref     5   1,1    B
10      ref     5   1,1    B
```

Means that do not share a letter are significantly different.

Table A.11 One way ANOVA and Tukey's Comparison Test for hardness of wafer samples prepared by replacement of wheat flour by legume flours.

One-way ANOVA: HARDNESS versus SAMPLE

```
One-way ANOVA: HARDNESS versus SAMPLE


Source  DF      SS     MS      F      P
SAMPLE  12  438,09  36,51  22,78  0,000
Error   52   83,35   1,60
Total   64  521,44


S = 1,266   R-Sq = 84,02%   R-Sq(adj) = 80,33%
                        Individual 95% CIs For Mean Based on Pooled StDev
Level   N   Mean  StDev   +---------+---------+---------+---------
10%b    5  6,960  0,234                      (---*---)
10%ca   5  2,073  1,206      (---*---)
10%ch   5  2,310  1,188       (---*--)
10%l    5  1,621  0,438     (--*---)
20%b    5  8,922  1,843                             (---*---)
20%ca   5  1,792  1,043     (---*---)
20%ch   5  3,236  0,712          (---*---)
20%l    5  6,800  0,967                      (---*--)
30%b    5  6,587  0,511                     (---*---)
30%ca   5  1,608  1,216     (--*---)
30%ch   5  3,767  1,592            (---*--)
30%l    5  6,927  2,697                      (---*---)
ref     5  1,118  0,498   (---*---)
                          +---------+---------+---------+---------
                        0,0       3,0       6,0       9,0


Pooled StDev = 1,266
```

Grouping Information Using Tukey Method

SAMPLE	N	Mean	Grouping
20%b	5	8,922	A
10%b	5	6,960	A
30%l	5	6,927	A
20%l	5	6,800	A
30%b	5	6,587	A
30%ch	5	3,767	B
20%ch	5	3,236	B
10%ch	5	2,310	B
10%ca	5	2,073	B
20%ca	5	1,792	B
10%l	5	1,621	B
30%ca	5	1,608	B
ref	5	1,118	B

Means that do not share a letter are significantly different.

Table A.12 Two way ANOVA and Tukey‘s Comparison Test for total color difference of wafer samples prepared by 10%, 20% and 30% replacement of reference wheat flour by bean flour, carob flour, chickpea flour and lentil flour.

General Linear Model: Total Color Difference versus Flour Type; Ratio

Factor	Type	Levels	Values
Flour Type	fixed	5	B; CA; CH; L; Ref
Ratio	fixed	3	10; 20; 30

Analysis of Variance for Total Color Difference, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Flour Type	4	7309,39	7309,39	1827,35	1475,36	0,000
Ratio	2	195,14	195,14	97,57	78,77	0,000
Flour Type*Ratio	8	160,45	160,45	20,06	16,19	0,000
Error	60	74,31	74,31	1,24		
Total	74	7739,29				

S = 1,11291   R-Sq = 99,04%   R-Sq(adj) = 98,82%

Unusual Observations for Total Color Difference

Obs	Total Color Difference	Fit	SE Fit	Residual	St Resid	
5	4,6921	2,5670	0,4977	2,1250	2,13	R
6	6,8169	4,7659	0,4977	2,0511	2,06	R
30	7,0516	4,9755	0,4977	2,0761	2,09	R
31	7,1653	3,5014	0,4977	3,6639	3,68	R
33	1,3641	3,5014	0,4977	-2,1372	-2,15	R
41	7,9582	5,9311	0,4977	2,0272	2,04	R
51	24,7605	28,4330	0,4977	-3,6726	-3,69	R

R denotes an observation with a large standardized residual.

Grouping Information Using Tukey Method and 95,0% Confidence

Flour Type	N	Mean	Grouping
CA	15	27,5	A
B	15	5,1	B
L	15	4,7	B
CH	15	3,3	C
Ref	15	-0,0	D

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95,0% Confidence

Ratio	N	Mean	Grouping
30	25	10,0	A
20	25	8,3	B
10	25	6,1	C

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95,0% Confidence

Flour Type	Ratio	N	Mean	Grouping
CA	30	5	32,2	A
CA	20	5	28,4	B
CA	10	5	22,0	C
L	30	5	6,9	D
B	30	5	5,9	D E
B	20	5	5,7	D E
CH	30	5	5,0	D E F
L	20	5	4,8	D E F G

```
B       10      5   3,5          E F G
CH      20      5   2,7            F G
L       10      5   2,6            F G
CH      10      5   2,3              G H
Ref     30      5  -0,0                H
Ref     20      5  -0,0                H
Ref     10      5  -0,0                H

Means that do not share a letter are significantly different.
```

Table A.13 One way ANOVA and Tukey's Comparison Test for total color difference of wafer samples prepared by replacement of wheat flour by legume flours.

One-way ANOVA: Total Color Difference_1 versus Batter Samples

```
Source           DF       SS      MS       F      P
Batter Samples  12  6901,72  575,14  402,44  0,000
Error           52    74,31    1,43
Total           64  6976,03

S = 1,195   R-Sq = 98,93%   R-Sq(adj) = 98,69%


                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level  N    Mean  StDev  -+---------+---------+---------+--------
10%B   5   3,501  2,357     (-*)
10%CA  5  21,967  0,254                        (*)
10%CH  5   2,306  0,318    (*)
10%L   5   2,567  1,246    (-*)
20%B   5   5,742  0,702        (*)
20%CA  5  28,433  2,070                              (*-)
20%CH  5   2,691  0,616     (*)
20%L   5   4,766  1,213       (*)
30%B   5   5,931  1,286        (*)
30%CA  5  32,250  0,813                                  (*)
30%CH  5   4,976  1,262       (*)
30%L   5   6,869  0,878         (*)
ref    5   0,000  0,000  (*)
                         -+---------+---------+---------+--------
                          0        10        20        30
```

```
Pooled StDev = 1,195

Grouping Information Using Tukey Method

Batter
Samples  N    Mean  Grouping
30%CA    5  32,250  A
20%CA    5  28,433    B
10%CA    5  21,967      C
30%L     5   6,869        D
30%B     5   5,931        D E
20%B     5   5,742        D E
30%CH    5   4,976        D E F
20%L     5   4,766        D E F G
10%B     5   3,501          E F G
20%CH    5   2,691            F G
10%L     5   2,567            F G H
10%CH    5   2,306              G H
ref      5   0,000                H

Means that do not share a letter are significantly different.
```

Table A.14 Two way ANOVA and Tukey's Comparison Test for W_0 parameter of GAB sorption model of wafer samples prepared by 10%, 20% and 30% replacement of reference wheat flour by bean flour, carob flour, chickpea flour and lentil flour.

General Linear Model: W0_1 versus Flour Type; Ratio (%)

```
Factor      Type   Levels  Values
Flour Type  fixed       5  B; CA; CH; L; R
Ratio (%)   fixed       3  0,1; 0,2; 0,3


Analysis of Variance for W0_1, using Adjusted SS for Tests

Source                DF    Seq SS   Adj SS   Adj MS      F      P
Flour Type             4   7,11982  7,11982  1,77995  44,55  0,000
Ratio (%)              2   1,38463  1,38463  0,69231  17,33  0,000
Flour Type*Ratio (%)   8   1,90146  1,90146  0,23768   5,95  0,002
Error                 15   0,59936  0,59936  0,03996
Total                 29  11,00526


S = 0,199893   R-Sq = 94,55%   R-Sq(adj) = 89,47%
```

Unusual Observations for W0_1

Obs	W0_1	Fit	SE Fit	Residual	St Resid	
13	5,56663	5,27000	0,14135	0,29663	2,10	R
14	4,97336	5,27000	0,14135	-0,29663	-2,10	R

R denotes an observation with a large standardized residual.

Grouping Information Using Tukey Method and 95,0% Confidence

Flour Type	N	Mean	Grouping
R	6	6,1	A
L	6	5,9	A
CH	6	5,9	A B
B	6	5,6	B
CA	6	4,7	C

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95,0% Confidence

Ratio (%)	N	Mean	Grouping
0,1	10	5,9	A
0,2	10	5,5	B
0,3	10	5,5	B

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95,0% Confidence

Flour Type	Ratio (%)	N	Mean	Grouping
L	0,1	2	6,7	A
R	0,2	2	6,1	A B
R	0,1	2	6,1	A B
R	0,3	2	6,1	A B
CH	0,2	2	6,0	A B C
CH	0,1	2	5,9	A B C D
B	0,3	2	5,8	B C D
B	0,1	2	5,7	B C D
L	0,2	2	5,7	B C D
CH	0,3	2	5,6	B C D
L	0,3	2	5,4	B C D
CA	0,1	2	5,3	C D E
B	0,2	2	5,2	D E F
CA	0,2	2	4,5	E F
CA	0,3	2	4,4	F

Means that do not share a letter are significantly different.

Table A.15 One way ANOVA and Tukey‘s Comparison Test for W_0 parameter of GAB sorption model of wafer samples prepared by replacement of wheat flour by legume flours.

One-way ANOVA: W0 versus Batter Type

```
Source        DF      SS      MS      F      P
Batter Type   12  9,4114  0,7843  19,37  0,000
Error         13  0,5264  0,0405
Total         25  9,9378

S = 0,2012   R-Sq = 94,70%   R-Sq(adj) = 89,81%


                              Individual 95% CIs For Mean Based on
                              Pooled StDev
Level      N    Mean   StDev  --------+---------+---------+---------+-
10%B       2  5,7189  0,1660                  (--*---)
10%CA      2  5,2700  0,4195            (---*---)
10%CH      2  5,9356  0,1362                    (---*---)
10%L       2  6,6908  0,1429                              (---*--)
20%B       2  5,1786  0,2928           (---*---)
20%CA      2  4,4828  0,0393  (---*---)
20%CH      2  6,0270  0,3555                     (---*---)
20%L       2  5,6798  0,0699                 (---*---)
30%B       2  5,8121  0,0819                   (---*--)
30%CA      2  4,4358  0,0144  (--*---)
30%CH      2  5,6112  0,0772                (---*---)
30%L       2  5,4472  0,1267              (---*---)
Reference  2  6,1044  0,1909                      (---*---)
                              --------+---------+---------+---------+-
                                    4,80      5,60      6,40      7,20

Pooled StDev = 0,2012


Grouping Information Using Tukey Method

Batter Type  N    Mean  Grouping
10%L         2  6,6908  A
Reference    2  6,1044  A B
20%CH        2  6,0270  A B C
10%CH        2  5,9356  A B C D
30%B         2  5,8121    B C D
10%B         2  5,7189    B C D
20%L         2  5,6798    B C D
30%CH        2  5,6112    B C D
30%L         2  5,4472    B C D
10%CA        2  5,2700      C D E
20%B         2  5,1786        D E F
20%CA        2  4,4828          E F
30%CA        2  4,4358            F

Means that do not share a letter are significantly different.
```

Table A.16 Two way ANOVA and Tukey‘s Comparison Test for C parameter of GAB sorption model of wafer samples prepared by 10%, 20% and 30% replacement of reference wheat flour by bean flour, carob flour, chickpea flour and lentil flour.

General Linear Model: C_1 versus Flour Type; Ratio (%)

```
Factor      Type   Levels  Values
Flour Type  fixed       5  B; CA; CH; L; R
Ratio (%)   fixed       3  0,1; 0,2; 0,3


Analysis of Variance for C_1, using Adjusted SS for Tests

Source                DF  Seq SS  Adj SS  Adj MS     F      P
Flour Type             4  165,62  165,62   41,40  3,41  0,036
Ratio (%)              2    5,44    5,44    2,72  0,22  0,802
Flour Type*Ratio (%)   8  102,03  102,03   12,75  1,05  0,444
Error                 15  182,07  182,07   12,14
Total                 29  455,15


S = 3,48394   R-Sq = 60,00%   R-Sq(adj) = 22,66%


Grouping Information Using Tukey Method and 95,0% Confidence

Flour
Type   N  Mean  Grouping
R      6  19,3  A
CH     6  19,0  A B
B      6  18,3  A B
L      6  17,9  A B
CA     6  12,9    B

Means that do not share a letter are significantly different.


Grouping Information Using Tukey Method and 95,0% Confidence


Ratio
(%)     N  Mean  Grouping
0,2    10  18,0  A
0,1    10  17,4  A
0,3    10  17,0  A

Means that do not share a letter are significantly different.


Grouping Information Using Tukey Method and 95,0% Confidence

Flour  Ratio
Type   (%)    N  Mean  Grouping
CH     0,3    2  22,1  A
B      0,2    2  20,3  A
```

```
L       0,2    2  19,5  A
R       0,3    2  19,3  A
R       0,2    2  19,3  A
R       0,1    2  19,3  A
B       0,1    2  19,0  A
L       0,3    2  18,5  A
CH      0,1    2  18,4  A
CH      0,2    2  16,4  A
L       0,1    2  15,7  A
B       0,3    2  15,6  A
CA      0,2    2  14,6  A
CA      0,1    2  14,6  A
CA      0,3    2   9,4  A

Means that do not share a letter are significantly different.
```

Table A.17 One way ANOVA and Tukey‘s Comparison Test for C parameter of GAB sorption model of wafer samples prepared by replacement of wheat flour by legume flours.

One-way ANOVA: C versus Batter Type

```
Source       DF     SS    MS     F      P
Batter Type  12  257,6  21,5  1,96  0,121
Error        13  142,1  10,9
Total        25  399,7

S = 3,306   R-Sq = 64,45%   R-Sq(adj) = 31,63%


                             Individual 95% CIs For Mean Based on
                             Pooled StDev
Level      N    Mean  StDev  ---+---------+---------+---------+------
10%B       2  18,974  2,653                 (---------*--------)
10%CA      2  14,559  4,168          (-------*---------)
10%CH      2  18,434  2,005                (---------*--------)
10%L       2  15,727  3,082             (-------*---------)
20%B       2  20,318  2,450                    (---------*--------)
20%CA      2  14,588  0,139          (-------*---------)
20%CH      2  16,375  5,748              (-------*---------)
20%L       2  19,470  2,530                  (-------*---------)
30%B       2  15,567  2,879             (-------*--------)
30%CA      2   9,446  0,487  (---------*--------)
30%CH      2  22,080  5,490                       (---------*--------)
30%L       2  18,473  0,205                (---------*--------)
Reference  2  19,292  4,471                  (-------*---------)
                             ---+---------+---------+---------+------
                              6,0      12,0      18,0      24,0

Pooled StDev = 3,306
```

```
Grouping Information Using Tukey Method

Batter Type  N    Mean  Grouping
30%CH        2  22,080  A
20%B         2  20,318  A
20%L         2  19,470  A
Reference    2  19,292  A
10%B         2  18,974  A
30%L         2  18,473  A
10%CH        2  18,434  A
20%CH        2  16,375  A
10%L         2  15,727  A
30%B         2  15,567  A
20%CA        2  14,588  A
10%CA        2  14,559  A
30%CA        2   9,446  A

Means that do not share a letter are significantly different.
```

Table A.18 Two way ANOVA and Tukey's Comparison Test for K parameter of GAB sorption model of wafer samples prepared by 10%, 20% and 30% replacement of reference wheat flour by bean flour, carob flour, chickpea flour and lentil flour.

General Linear Model: K_1 versus Flour Type; Ratio (%)

```
Factor      Type   Levels  Values
Flour Type  fixed       5  B; CA; CH; L; R
Ratio (%)   fixed       3  0,1; 0,2; 0,3


Analysis of Variance for K_1, using Adjusted SS for Tests

Source               DF     Seq SS     Adj SS     Adj MS      F      P
Flour Type            4  0,0568773  0,0568773  0,0142193  47,77  0,000
Ratio (%)             2  0,0070955  0,0070955  0,0035477  11,92  0,001
Flour Type*Ratio (%)  8  0,0133079  0,0133079  0,0016635   5,59  0,002
Error                15  0,0044652  0,0044652  0,0002977
Total                29  0,0817458


S = 0,0172535   R-Sq = 94,54%   R-Sq(adj) = 89,44%
Unusual Observations for K_1

Obs       K_1       Fit    SE Fit   Residual  St Resid
 13  0,801603  0,829368  0,012200  -0,027765     -2,28 R
 14  0,857133  0,829368  0,012200   0,027765      2,28 R

R denotes an observation with a large standardized residual.
```

Grouping Information Using Tukey Method and 95,0% Confidence

Flour Type	N	Mean	Grouping
CA	6	0,9	A
B	6	0,8	B
CH	6	0,8	B C
R	6	0,8	C
L	6	0,8	C

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95,0% Confidence

Ratio (%)	N	Mean	Grouping
0,3	10	0,8	A
0,2	10	0,8	A
0,1	10	0,8	B

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method and 95,0% Confidence

Flour Type	Ratio (%)	N	Mean	Grouping
CA	0,3	2	0,9	A
CA	0,2	2	0,9	A
B	0,2	2	0,8	B
CA	0,1	2	0,8	B
B	0,1	2	0,8	B
L	0,3	2	0,8	B
CH	0,1	2	0,8	B
CH	0,3	2	0,8	B
B	0,3	2	0,8	B
CH	0,2	2	0,8	B C
L	0,2	2	0,8	B C
R	0,2	2	0,8	B C
R	0,1	2	0,8	B C
R	0,3	2	0,8	B C
L	0,1	2	0,7	C

Means that do not share a letter are significantly different.

Table A.19 One way ANOVA and Tukey‘s Comparison Test for K parameter of GAB sorption model of wafer samples prepared by replacement of wheat flour by legume flours.

One-way ANOVA: K versus Batter Type

Source	DF	SS	MS	F	P
Batter Type	12	0,072493	0,006041	19,52	0,000
Error	13	0,004023	0,000309		
Total	25	0,076516			

```
S = 0,01759   R-Sq = 94,74%   R-Sq(adj) = 89,89%
                                Individual 95% CIs For Mean Based on
                                Pooled StDev
Level       N     Mean    StDev   -+---------+---------+---------+--------
10%B        2  0,80539  0,01426             (---*---)
10%CA       2  0,82937  0,03927                 (--*---)
10%CH       2  0,79543  0,00472            (---*--)
10%L        2  0,72136  0,00446   (---*---)
20%B        2  0,83237  0,02848                 (---*---)
20%CA       2  0,91295  0,00456                             (--*---)
20%CH       2  0,78465  0,02053          (---*---)
20%L        2  0,78273  0,00768          (---*---)
30%B        2  0,79098  0,02370           (---*---)
30%CA       2  0,92611  0,00411                              (---*---)
30%CH       2  0,79464  0,00979            (---*--)
30%L        2  0,80482  0,00519             (---*---)
Reference   2  0,77481  0,01488         (---*---)
                                  -+---------+---------+---------+--------
                                 0,700     0,770     0,840     0,910

Pooled StDev = 0,01759


Grouping Information Using Tukey Method

Batter Type  N     Mean  Grouping
30%CA        2  0,92611  A
20%CA        2  0,91295  A
20%B         2  0,83237    B
10%CA        2  0,82937    B
10%B         2  0,80539    B
30%L         2  0,80482    B
10%CH        2  0,79543    B
30%CH        2  0,79464    B
30%B         2  0,79098    B C
20%CH        2  0,78465    B C
20%L         2  0,78273    B C
Reference    2  0,77481    B C
10%L         2  0,72136      C

Means that do not share a letter are significantly different.
```