Utilization of legume flours in wafer sheets

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Abstract
In this study, it was aimed to analyze the impacts of replacement of 20% of wheat flour by lentil, chickpea, or bean flours on batter rheology as well as hardness, weight loss, sorption characteristics, and color of the wafer sheets. All formulations showed shear thinning behavior obeying power law. Lentil flour-containing formula gave the highest flow behavior index and the lowest consistency coefficient value. Hardness of wafer sheets increased when legume flours were used. Increase in hardness value was less when chickpea flour was used as compared with the other legume flours. It was observed that upon baking, legume flour-added samples had lower weight loss values. Usage of chickpea flour resulted in the lowest weight loss. Sorption results implied localized sorption indicating multilayer water molecules showing similar properties to liquid water. Wafers containing legume flours were not significantly different than the control wafer in terms of monolayer moisture content, $K$ and $C$ values of Gugenheim, Anderson and de Boer (GAB) model. The color of chickpea flour-containing wafer was the closest to that of control sample. Overall, wafer sheets prepared by replacement of 20% wheat flour by chickpea flour was agreed to be the best in terms of the analyzed parameters.

KEYWORDS
bean flour, chickpea flour, lentil flour, physical properties, wafer sheet

1 INTRODUCTION

As a fast-moving consumer good, snacks become an important part of the diet of individuals constituting a profit-making sector. In 2013–2014, global sales reached to $374 billion (Nielsen, 2014). Increasing consumer awareness in nutrition and health, governmental restrictions, and new lifestyles seem to contribute to the growth of the healthy snack sector. In 2016, healthy snacks sales achieved $21.1 billion revenue (Grand View Research, 2017). Vegetables (kale, potato, and spinach), grain formulations (ancient, whole, and multi), and pulses (lentil, pea, bean, and chickpea) are widely used in these formulations (Research and Markets, 2017).

Wafers are one of the favorite snacks in the market. In 2016, the wafer market reached $44.06 billion, and by 2021, it is expected to rise to $55 billion (Technavio, 2017). On the other hand, there are limited studies on wafers in literature. Mert, Sahin, and Sumnu (2015) developed gluten-free wafers by replacing rice flour with corn, buckwheat, and chestnut flours at different ratios. According to this study, gluten-free wafer sheets prepared by buckwheat–rice flour blend had the most similar texture properties to the wafers formulated
with wheat flour. Hempel, Jacob, and Rohm (2007) investigated the impacts of inulin addition as a source of prebiotic and different flours on quality attributes of wafer crackers. It was concluded that partial replacement of wheat flour by rye flour or spelt wheat flour had no adverse effect on sensory properties of wafer crackers. Oliver and Sahi (1995) studied the influences of types of wheat cultivars on the rheology of wafer batter. Hard milling wheat varieties produced batters with stronger rheological properties than soft milling varieties.

Incorporation of legume flours in wafer formulations fulfills the consumer demands for functional foods because legumes possess nutraceutical properties for prevention of insulin resistance and glycemia (Ma et al., 2011; Rizkalla, Bellisle, & Slama, 2002), cardiovascular diseases (Anderson & Gustafson, 1988), obesity (Karlström et al., 1987), and colon cancer (Geil & Anderson, 1994; Mathers, 2002). Legumes constitute a rich source of nutritive compounds such as protein, fibers, minerals, and vitamins. Bojňanská, Frantičková, Lišková, and Tokár (2012) reported legume protein content to be about 17–40%, which was as high as protein content of meat (18–25%). They have dietary fiber up to 30% on dry basis. They are also a good source of polyphenols and antioxidants (Han, Janz, & Gerlat, 2010), prebiotics for the intestinal tract, vitamin B especially B2 and B3, and minerals (manganese, iron, zinc, phosphorus, and calcium; Rysová, Ouhrabková, Gabrovská, Paulí, & Winterová, 2010). Many researchers have studied legumes for their functional attributes such as water holding, foaming stability and capacity, water swelling and retention capacity, oil absorption, emulsifying stability and capacity (Arab, Helmy, & Bareh, 2010; Butt & Batool, 2010). Legumes and cereals are generally advised to be consumed mutually in order to assure amino acid complementation (Duranti, 2006). Therefore, incorporation of legumes into cereal products is widely studied. However, the effects of incorporation of legume flours on physical properties of wafer sheets have not been studied before.

The main purpose of this study is to analyze the effects of lentil, chickpea, and bean flour utilization in wafer formulation in terms of batter rheology as well as hardness, weight loss, and color of the wafer. In addition, it was also aimed to analyze sorption behavior of wafer sheets because sorption isotherms provide insights on the stability and shelf life of foods throughout the storage (Wani & Kumar, 2016). Although sorption behavior of wafer sheets is important, there is no study in literature about their sorption isotherms.

## 2 | MATERIALS AND METHODS

### 2.1 | Materials

Wheat flour, lentil flour, chickpea flour, bean flour, and sodium bicarbonate (Pakmaya, Kocaeli, Turkey) were purchased from a local market in Istanbul, Turkey. Hydrogenated vegetable fat (rapeseed, palm, and cottonseed oil) was procured from AAK (Tekirdağ, Turkey). Soy lecithin was obtained from Lipoid GmbH (Ludwigshafen, Germany). Total dietary fiber assay kit (TDF-100A, Sigma Aldrich Chemical Co., St. Louis, MO, USA) was deployed for the determination of soluble and insoluble fibers of the flours.

### 2.2 | Nutritional analyses of flours

Moisture, fat, protein, soluble and insoluble fiber, and ash contents of the flours were determined using AACC methods (44-15A, 30-25, 46-13, 32-07, and 08-01, respectively; AACC, 2000). Carbohydrate content was calculated stoichiometrically.

### 2.3 | Batter preparation

The wheat flour-containing sample was used as control. Control formulation was composed of 100% wheat flour, 182% water, 1% hydrogenated vegetable fat, 0.5% lecithin, and 0.5% sodium bicarbonate (on flour weight basis). In order to investigate the effects of partial replacement of wheat flour by different flours on rheological properties of batter and quality of wafer sheets, 20% of wheat flour was replaced by lentil, chickpea, or bean flour. Batter was prepared first by dissolving sodium bicarbonate in water at ambient temperature (Tufan, 2018). Control flour or flour mixes were incorporated into water, and the blend was mixed (Kitchen Aid5K45SS, USA) for 10 s by 50 rpm and then for 20 s by 105 rpm. Next, lecithin–oil premix which was prepared by dissolving lecithin in hydrogenated vegetable fat at 60°C and left to cool was added, and the blend was further mixed for 30 s by 105 rpm. The batter was sieved in order to eliminate the lumps and stored for 5 min for the bubbles to rise up before baking.

### 2.4 | Rheological analyses of the batter

Rheological behavior of wafer batter was analyzed by a cone and plate rheometer (Kinexus, Malvern Instruments, Worcestershire, UK). The cone is 40 mm in diameter with an angle of 4°. Before the measurement, the
batters were left for 10 min for the recovery of sample from residual stresses (Mert et al., 2015). A sample of 2 g was put between the rotating cone and plate, and the excess batter was taken from the edges. Shear rate ramp analysis was performed. Shear rate versus shear stress data were recorded between 0.05 and 200 s⁻¹ of shear rate range. The measurements were carried out at 20°C.

### 2.5 Baking

A wafer oven of laboratory type with 26 × 21 cm of plate dimensions was employed for baking; 125 ± 3 ml of batter was poured over the bottom plate and right after the top plate was latched (Tufan, 2018). To lower the difference of color between the lower and upper surfaces of the sheet caused by more contact time with the bottom plate, the temperatures of the top and bottom plates were adjusted as 168°C and 160°C, respectively. Batters were baked for 2.5 min, which was set to reach 2% moisture content for the control wafer.

### 2.6 Analyses of wafer sheets

#### 2.6.1 Hardness

Three-point bend test with Texture Analyzer (TA, XT Plus, Stable Micro Systems, UK) was used for measuring the hardness of wafer sheets. Wafers with dimensions of 6 cm × 6 cm were cut from the sheet center and placed under the probe. Operating parameters for the compression mode were set as 19.6 N of calibration force, 5.0 g of trigger force, and 2.00 mm/s of test speed (Tufan, 2018). The highest force data attained by the probe in the course of breaking of the sheet (N) were taken.

#### 2.6.2 Weight loss

Percentages of weight loss of the wafer batters during baking were calculated using Equation (1) (Tufan, 2018):

\[
\text{Weight Loss(\%)} = 100 \times \frac{W_i - W_f}{W_i},
\]

where \(W_i\) is the weight of the deposited batter (g) and \(W_f\) is the weight of the wafer upon baking (g).

#### 2.6.3 Sorption isotherms

Samples with 4-mm thickness and 8-cm diameter taken from the center of the sheets were used for the sorption behavior studies. For this purpose, wafer discs sectioned from the center of the sheets were kept in the enclosed desiccators that contained the saturated solutions of potassium sulfate (relative humidity [RH]: 96.79%), barium chloride (RH: 92.52%), potassium chloride (RH: 86.27%), sodium chloride (RH: 76.43%), potassium iodide (RH: 68.39%), magnesium nitrate (RH: 58.09%), magnesium chloride (RH: 34.34%), lithium chloride (RH: 11.84%), and sodium hydroxide (RH: 8.86%) until water activity of the sheets reached equilibrium with the desiccator’s RH. Moisture analyzer (Ohaus Corporation, Parsippany, USA) was used to measure the equilibrium moisture contents.

GAB model was employed to investigate the sorption characteristics of the wafers (Equation 2):

\[
W_e = \frac{W_0CKa_w}{(1 - Ka_w)(1 - Ka_w + CKa_w)},
\]

where \(W_0\) is the monolayer moisture content (% d.b.), \(W_e\) is the equilibrium moisture content (% d.b.), \(K\) and \(C\) are the sorption parameters of the GAB model, and \(a_w\) is the water activity of the wafer.

Sorption isotherms were analyzed by converting Equation (2) into a quadratic equation to find the \(W_0\), and \(K\) and \(C\) parameters (Kim, Kim, Kim, Shin, & Chang, 1998).

\[
\frac{a_w}{W_e} = \frac{1}{W_0CK} + \frac{C - 2}{W_0C}a_w + \frac{K(1-C)}{W_0C}a_w^2
\]

The nonlinear least square regression (MS Excel 2016) was applied to determine the \(W_0\), and \(K\) and \(C\) parameters.

#### 2.6.4 Total color change

Colors of the samples taken from the center of the wafer sheets were measured by a colorimeter (Konica Minolta, CM-5, Japan). CIE \(L^*a^*b^*\) (CIELAB) scale was used to evaluate the color values. Total color change (\(\Delta E^*\)) was determined using Equation (4) by taking the color values of control wafer, which were \(L^*_{\text{reference}} = 75.60\), \(a^*_{\text{reference}} = 2.88\), and \(b^*_{\text{reference}} = 23.89\), as the reference.

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

#### 2.7 Statistical analysis

One-way analysis of variance (ANOVA) was used to evaluate the experimental data recorded during the study and to detect any significant difference between samples.
(p ≤ .05). If there exists a significant difference, comparisons were made by Tukey’s test (with 95% confidence level). Minitab (Version 16.2.0.0, Minitab Inc., Coventry, UK) were used for all statistical tests.

3 | RESULTS

The effects of 20% wheat flour replacement by lentil, chickpea, or bean flour were studied with respect to batter rheology, as well as hardness, weight loss, sorption behavior, and color of wafer sheets.

3.1 | Rheology of wafer batters

All formulations showed non-Newtonian flow characteristics with variation in viscosity for different shear rates. Shear stress (τ, Pa) versus shear rate (γ, 1/s) data were fitted well to power law model (R² ≥ .99; Equation 5);

\[ \tau = K\dot{\gamma}^n, \]

where \( n \) is the flow behavior index and \( K \) is the consistency coefficient (Pa·s\(^n\); Sahin & Sumnu, 2006).

Power law model constants and coefficients of determination values of different batter formulations are given in Table 1. All flow behavior indexes were below 1, implying the shear thinning (pseudoplastic) behavior of the batter, that is, decreasing apparent viscosity when shear rate is increased. The highest and lowest \( n \) values were obtained in the presence of lentil and bean flours, respectively. ANOVA results showed that replacement of wheat flour by bean flour increased consistency coefficient values (\( K \)) significantly. The lowest \( K \) value was observed in the case of lentil flour-containing batter. As will be explained in Section 4, this might be related to total dietary fiber content of lentil flour.

3.2 | Hardness of wafer sheets

ANOVA results showed that partial replacement of wheat flour by legume flours increased the wafer hardness.

3.3 | Weight loss of wafer sheets

Weight loss results are depicted in Figure 2. According to ANOVA results, lower weight loss values were observed when wheat flour was partially replaced by legume flours. Bean flour and lentil flour substitution resulted

| Legume flour type   | n   | K (Pa·s\(^n\)) | R²   |
|---------------------|-----|---------------|------|
| Control             | 0.586\(^b\) | 3.028\(^b\) | .994 |
| Bean flour          | 0.509\(^c\) | 4.953\(^a\) | .989 |
| Chickpea flour      | 0.564\(^bc\) | 3.695\(^ab\) | .993 |
| Lentil flour        | 0.694\(^a\) | 1.484\(^c\) | .999 |

Note. Different letters in the same column indicate statistically significant difference (p ≤ .05).

![Figure 1](image1.png)

![Figure 2](image2.png)
in less weight loss than did the control, whereas chickpea attained the least weight loss value.

3.4 | Sorption analyses of wafers

According to Figure 3, all samples depicted type II S-shaped sorption isotherms at 20°C (Brunauer, Deming, Deming, & Teller, 1940).

From the nonlinear least square regression, \( W_0 \) and \( C \) and \( K \) parameters of GAB model are calculated and displayed in Table 3. The \( W_0 \) values varied between 5.18 and 6.10 (% d.b.). This result agrees with the previously reported values of 6.9% for the wafer sheets (Martínez-Navarrete, Moraga, Talens, & Chiralt, 2004), cookies as 3.97–4.58% (Palou, López-Malo, & Argaiz, 1997) and extruded snacks as 7.3% (Wani & Kumar, 2016) at ambient temperature. \( C \) and \( K \) values of the model are in agreement with the previously reported values of, respectively, 16.9 and 0.841 for the wafer sheets (Martínez-Navarrete et al., 2004), 5.9 and 0.98 for the cookies, 9.0 and 0.96 for the crackers (Kim et al., 1998), and 12.5 and 0.78 for the extruded snacks (Wani & Kumar, 2016).

According to ANOVA results, addition of legume flour to the formulation did not affect monolayer moisture content as well as \( C \) and \( K \) parameters of GAB sorption model (Table 3).

3.5 | Total color change

Total color change of the wafers is represented in Figure 4. According to ANOVA results, incorporation of legume flour augmented the color development level. Lentil and bean and flour samples showed the maximum color development, whereas wafers with chickpea flour had the minimum color development.

4 | DISCUSSION

4.1 | Rheology of wafer batters

Lentil flour-containing batter had the highest \( n \) value. This indicates that this batter had the most similar structure to Newtonian flow among the other batters and had the minimum decrease in apparent viscosity when shear rate is increased (Ronda, Oliete, Gómez, Caballero, & Pando, 2011). Conversely, bean flour batter had the sharpest decrease in viscosity (the lowest \( n \) value) when shear rate was increased.

Increasing consistency coefficients with bean flour incorporation was related to the rich fiber content of the bean flour-added batter (Table 2). It was inferred that higher fiber content retained more moisture in the system, resulting in higher consistencies. Demirkesen, Mert, Sumnu, and Sahin (2010) related the higher viscosities

| Legume flour type | Protein (%) | TDF (%) | Carbohydrate (%) |
|-------------------|-------------|---------|------------------|
| Control           | 4.31 ± 0.15\(^{b}\) | 1.00 ± 0.29\(^{b}\) | 24.95 ± 0.39\(^{a}\) |
| Bean flour        | 4.95 ± 0.14\(^{ab}\) | 2.84 ± 0.25\(^{a}\) | 21.36 ± 0.48\(^{b}\) |
| Chickpea flour    | 5.03 ± 0.15\(^{ab}\) | 2.07 ± 0.24\(^{ab}\) | 22.99 ± 0.38\(^{ab}\) |
| Lentil flour      | 5.31 ± 0.14\(^{a}\) | 1.32 ± 0.25\(^{b}\) | 23.51 ± 0.41\(^{ab}\) |

Note. Different letters in the same column indicate statistically significant difference (\( p \leq .05 \)).

Abbreviation: TDF, total dietary fiber.
caused by fibers (especially insoluble fibers) to strong water absorption capacity. Lentil flour-containing batter with its lower total dietary fiber content had the lowest consistency coefficient among other legume flours.

4.2 | Hardness of wafer sheets

Higher hardness values of legume flour-containing wafers can be explained by the increase in protein content (Table 2). This result is in agreement with the results of other studies in literature (Gallagher, Kenny, & Arendt, 2005; Petitot, Boyer, Minier, & Micard, 2010; Tiwari, Brennan, Jaganmohan, Surabi, & Alagusundaram, 2011). These studies argue that the increase in protein content causes higher hardness results.

Wang, Rosell, and Benedetto de Barber (2002) found out that fibers from different sources could give hardening or softening impacts. Lebesi and Tzia (2011) suggested that specific types of fibers might not affect the texture. In some of the studies, increasing fiber content has generally been linked to increase in hardness of the bakery products (Ajila, Leelavathi, & Rao, 2008; Gularte, de la Hera, Gómez, & Rosell, 2012; Sudha, Vetrimani, & Leelavathi, 2007; Yildiz, Demirkesen, & Mert, 2016). In these researches, the hardening effect of fibers was generally related to the effect of decreasing the volume. Peressini, Pin, and Sensidoni (2011) claimed that the harder texture could be explained not only by volume reduction but also by starch content. Low starch level causing low gelatinization might increase the hardness (Sabanis, Makri, & Doxastakis, 2006). Bean flour wafers had the highest hardness results, which might be caused by its low starch and high total dietary fiber contents (Table 2).

4.3 | Weight loss of wafer sheets

Higher fiber content of legume flours resulted in lower weight loss (Table 2 and Figure 2). This could be explained by hydroxyl groups in fiber molecules that enhance water interactions by hydrogen bonding (Sabanis, Lebesi, & Tzia, 2009).

In literature, generally elevated water holding capacity of flours is advised for handling purposes and quality of final products. Nevertheless, this is arguable for wafer production for the sake of batter spreadability on the oven plates. In addition, minimum moisture content of the final product is aimed, which is difficult with flour having high water holding capacity. In this respect, water holding capability is an important factor, and it is appropriate to adjust it together with the other process conditions and material properties.

4.4 | Sorption analyses of wafers

Among many sorption models, GAB model has been widely applied and called as the most inclusive sorption theory in literature (Al-Muhtaseb, McMinn, & Magee, 2002), up to 0.90 water activity levels.

Monolayer moisture content (W₀) shows that the moisture content strongly adsorbed to the surface of the material providing the maximum storage time and minimum deterioration at constant temperature (Goula et al., 2008). Up to glass transition temperature or this moisture content, food is at its most stable texture (Sablani, Kasapis, & Rahman, 2007). Parameter C indicates the strength of the water molecule binding to the sorbate’s primary binding sites. High C values imply stronger binding and the higher enthalpy difference of the monolayer and the multilayer water molecules. “K parameter shows the link between the water molecules in the multilayer and bulk water.” K is below unity, and as K approaches unity, monolayer water molecules act as liquid water (Muzaffar & Kumar, 2016).

Because the incorporation of legume flour to the formulation provided the same monolayer values as the control, it is inferred that incorporation of legume flours retained the stability of wafer sheets.

ANOVA results showed that the incorporation of legume flours did not have an effect on C values providing a quite strong monolayer with localized sorption (Table 3). As for K values, being not affected significantly by legume flour addition, they are relatively high and almost 1. The high K values were probably due to the fiber content. Fiber content and K values were positively correlated with Pearson correlation coefficient of 0.90 (p = .097). Approximating K values to unity makes the multilayer water molecule behaviors closer to those of bulk water. Combined analysis of higher K and higher C values for all formulations indicates localized sorption with strongly bounded monolayer water molecules, and successive molecules are loosely arranged in multilayers (Quirijns, Van Boxtel, Van Loon, & Van Straten, 2005).

| TABLE 3 | GAB sorption model parameters of wafer sheets prepared by the replacement of wheat flour by 20% bean flour, chickpea flour, or lentil flour |
|-----------------|-----------------|----------------|----------------|
| Legume flour type   | W₀ (% d.b.) | C         | K             |
| Control                  | 6.10 a         | 19.29 a     | 0.77 a         |
| Bean flour              | 5.18 a         | 20.32 a     | 0.83 a         |
| Chickpea flour          | 6.03 a         | 16.38 a     | 0.78 a         |
| Lentil flour            | 5.68 a         | 19.47 a     | 0.78 a         |

Note. Different letters in the same column indicate statistically significant difference (p ≤ .05).
4.5 | Total color change

Boosted Maillard reactions due to high amino acid content of legume flours might be the reason for an increase in color difference from the control when legume flours are used. Gómez, Oliete, Rosell, Pando, and Fernández (2008) showed that color of the cake crusts was darker with increased chickpea flour ratio in the formulation, which was linked to the elevated protein content by the chickpea flour engaged in Maillard reactions. Luminosity values of cookies and cakes decreased by the addition of red lentil, navy bean, green lentil, pinto bean, and yellow lentil flours (De la Hera, Ruiz-París, Oliete, & Gómez, 2012; Zucco, Borsuk, & Arntfield, 2011).

The higher color development in lentil flour- and bean flour-containing samples was possibly due to higher protein content of these formulae, which caused elevated Maillard browning (Table 2). The lowest color development by chickpea flour might be due to the decreased weight loss of chickpea flour samples due to more moisture retention (Figure 2). Browning reactions are accelerated at low- to medium-moisture content and at elevated temperatures (Purlis, 2010).

Ashoor and Zent (1984) suggested that glycine, lysine, tyrosine, and tryptophan are the most prominent amino acids on browning. For chickpea flour addition, lower color change compared with that of the lentil and bean could also be due to the lower content of glycine and lysine in chickpea flour (FAO, 1981).

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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