

# Effect of Flaxseed Flour on Rheological Properties of Wheat Flour Dough and on Bread Characteristics

Yingying Xu<sup>1</sup>, Clifford A. Hall III<sup>2</sup> & Frank A. Manthey<sup>2</sup>

<sup>1</sup> Department of Cereal and Food Science, North Dakota State University, Fargo, ND, USA

<sup>2</sup> Department of Plant Sciences, North Dakota State University, Fargo, ND, USA

Correspondence: Clifford A. Hall III, Department of Plant Sciences, 210 Harris Hall, Dept. 7670, North Dakota State University, Fargo ND 58108-6050, USA. Tel: 1-701-231-6359. E-mail: Clifford.Hall@ndsu.edu

Received: July 3, 2014 Accepted: August 4, 2014 Online Published: August 8, 2014

doi:10.5539/jfr.v3n6p83

URL: <http://dx.doi.org/10.5539/jfr.v3n6p83>

## Abstract

Flaxseed (*Linum usitatissimum*) is an oilseed that is high in omega-3 fatty acid, dietary fiber and lignan. These components are responsible for the health promoting effects of flaxseed. Incorporating flaxseed into foodstuffs such as bread is an approach to increase dietary flaxseed. However, the need for a rapid screen method is needed since a complete baking process may take several hours. Correlating Farinograph parameters with bread characteristics may result in a rapid test that would allow for researchers to identify the proper levels of flaxseed addition to bread without a lengthy baking procedure. Therefore, the effect of 0, 6, 10, and 15% (wt/wt) flaxseed flour (FF) on Farinograph rheological properties of bread flour dough and on bread characteristics were investigated. Results showed that FF significantly ( $p < 0.05$ ) increased dough water absorption, peak time, and mixing tolerance index, but decreased dough stability. Oven spring was significantly lower for all flaxseed treatments compared to the control. However, the loaf volume of bread made with 6 and 10% FF did not differ significantly ( $p < 0.05$ ) from the control. The FF concentrations tested did not affect the specific volume of the bread even though the water absorption values were higher for doughs with FF. The breads containing flaxseed had darker crust color and a more yellow crumb color compared to control bread, but the crumb structure was not negatively impacted. Results indicated that Farinograph parameters of bread flour dough could be used as a method for screening FF addition to bread.

**Keywords:** flaxseed, farinograph, mixing tolerance index, oven spring, specific volume, loaf volume

## 1. Introduction

Bread is one of the most widely consumed staple foods worldwide. Maintaining and enhancing bread quality is therefore essential to human health. Various efforts have been made to improve the nutritional quality of wheat products through supplementation with a wide range of non-traditional ingredients (Hooda & Jood, 2003; Ptitchkina, Novokreschonova, Piskunova, & Morris, 1998; Shogren, Mohamed, & Carriere, 2003). Flaxseed has been used in European breads for centuries; however, the renewed interest in flaxseed as an ingredient in bread is supported by flaxseed health benefits reported a decade ago (Thompson & Cunnane, 2003). Flaxseed is a rich source of dietary fiber (28%). Dietary fiber has been widely viewed as a component essential to lowering the risk of colon cancer (Kim, 2000). Flaxseed contains roughly 38-45% oil, in which  $\alpha$ -linolenic acid (ALA), a short chained omega-3 (n-3) fatty acid, accounts for approximately 52% of the total fatty acids. Omega-3 fatty acids are generally regarded as being important for maintaining cardiovascular health (Ascherio et al., 1996; Djousse et al., 2001; Hu et al., 1999; Pan et al., 2012). Lignans are also of great interest due to the research findings of their protective role against several types of cancer (Bowen, 2001; Demark-Wahnefried et al., 2001; Yang, Landau, Huang, & Newmark, 2001). Flaxseed is by far the richest dietary source of lignans (Thompson, Robb, Serraino, & Cheung, 1991).

Traditionally, flaxseed has been added to bakery products in the forms of whole seed or ground flaxseed meal. The impact of flaxseed on the physicochemical and sensory properties of cereal products has been reported (Alpaslan & Hayta, 2006; Conforti & Davis, 2006; Koca & Anil 2007; Lee, Inglett, & Carriere, 2004; Marpalle, Sonawane & Arya, 2014; Menten, Bakalbassi, & Ercan, 2013; Shearer & Davies, 2005). Pohjanheimo, Hakala, Tahvonen, Salminen, & Kallio (2006) investigated the quality of flaxseed fortified bread rolls by monitoring sensory attributes, instrumental texture measurement and chemical analysis. They reported that the bread

containing flaxseed retained moisture and softness more efficiently than the control, and that no off-odors were detected in flax bread during a 6-day storage period at room temperature. Mentes, Bakkalbassi and Ercan (2013) also reported reduced staling in bread containing flaxseed. Furthermore, they reported that 10% flaxseed bread had higher loaf and specific volumes compared to the control. In contrast, Marpalle, Sonawane and Arya (2014) reported lower loaf and specific volumes for 10% flaxseed fortified bread compared to control breads.

Several studies have shown that the important nutraceutical components were stable in the bread baking process. The principle lignan in flaxseed, secoisolariciresinol diglucoside (SDG), was determined to be stable as measured by recovered SDG in commercial and model baked goods that included bread, bagels, cookies, and muffins (Muir & Westcott, 2000; Hyvärinen et al., 2006). ALA was also reported to be stable in the baking process and in storage (Chen, Ratnayake & Cunnane, 1994; Mentes, Bakkalbassi, & Ercan, 2013). These reports support the use of baked products as a method to deliver flaxseed nutraceuticals to humans.

Farinograph is an instrument that can be used to understand physical properties of dough. The rheological properties of dough affect both the machinability of the dough and the quality of the end product. Farinograph is one of the most extensively used methods to measure the rheological characteristics of dough (Bloksma & Bushuk, 1988). In addition, water absorption calculation from the Farinograph provides the researcher with close approximation of the optimal water addition to the flour to make the optimal dough. The stability time and mixing tolerance index values generally give some indication of the tolerance of the dough to breakdown during mixing (Shuey, 1984; AACCI, 2000). Collectively, the measured Farinograph properties indicate if a specific flour is classified as weak or strong. Strong gluten flour is preferred for bread making over a weak gluten flour since the gluten has structural and gas retaining properties, which ultimately is important in bread (Wang & Khan, 2009). However, flour blends may be needed to create finished products with the proper sensory and quality characteristics. Farinograph test can be completed in less than 30 minutes while full baking tests can take several hours. Therefore, the use of Farinograph would allow researchers to screen more formulations that contain non-traditional ingredients in a shorter amount of time compared to a complete baking test if a correlation can be established between rheological properties and final bread quality.

Although many researchers have studied the impact of flaxseed on the physicochemical and sensory properties of bakery products, information is lacking concerning the effect of flaxseed on the rheological properties of wheat flour dough, and the correlation of these rheological parameters with bread quality characteristics. Thus, the objective of this investigation was to study the effects of flaxseed flour on the rheological properties of bread flour dough (water absorption capacity, dough development time, dough stability, and mixing tolerance index), and bread characteristic (oven spring, loaf volume, loaf weight, specific volume, moisture content, and water activity). In addition, correlations among rheological properties and bread quality characteristics will be determined.

Flaxseed addition levels between 6 and 15% were used in this study. The rationale for the various levels of flaxseed in this study was based on the ALA content delivered via bread. Gebauer, Psota, Harris & Kris-Etherton (2006) summarized dietary recommendations for ALA (1.4 to 3 g daily) made by health agencies worldwide. An adequate intake (AI) was set by the Institute of Medicine of the National Academies (2005) for ALA as 1.6 g/d for men and 1.1 g/d for women. Consumption of 100 g bread containing 6% FF provides approximately 1.26 g ALA, which is very close to both AI data for women and the lower range of recommended ALA intake level by international health agencies. In contrast to 100 g of bread, one slice of bread made with 6% flaxseed would provide approximately 0.32 g of ALA, requiring 4 slices per day to obtain the recommended level of ALA provided that no other dietary ALA is available. Furthermore, increasing the flaxseed level in bread to 10 and 15% would provide approximately 0.58 and 0.87 g of ALA per slice of bread, respectively. Thus, two slices of bread would meet the AI level for ALA.

## 2. Methods

### 2.1 Experimental Materials

Commercial bread flour (Dakota Maid) was obtained from a local foodservice company (Fargo, ND). The bread flour was unbleached white flour that contained malted barley flour and ascorbic acid. Flaxseed (Omega variety) was obtained from Specialty Commodities Inc. (Fargo, ND), milled using a centrifugal cutting mill (Commitrol Model MG, Urshel Laboratories, Valparaiso, IN) and sieved according to the method of Manthey, Lee & Hall (2002). The coarse ground flaxseed remained on top of the sieve and the fine ground flaxseed passed through the sieve. Fine flaxseed particle ( $< 531 \mu\text{m}$ ) was defined as flaxseed flour (FF) and was stored in sealed bags at 4°C in the dark until needed. Prior to experiments, FF was equilibrated in black sealed plastic bags at room temperature (22 °C) for 24 hr.

## 2.2 Farinograph Procedure

Farinograph characteristics for the control flours and flaxseed flour mixtures were determined in duplicate, per replication, by a Brabender Farinograph (Model 8124; Brabender OHG, Duisberg, Germany) according to AACCI method 54-21 (2000). Flour weight on 14% moisture basis (m.b.) was calculated using the following equation:

$$\text{Flour weight on 14\% m.b.} = (100 - 14)/(100 - M) \times \text{flour weight} \quad (1)$$

where M = flour moisture content (%). Flour (50 g on 14% m.b.) was placed in the mixing bowl, and the burette of the farinograph was filled with water. The pen was adjusted to the 9 min position and the instrument was allowed to run. When the pen reached the 0 min position, water was added from the burette. The sides of the mixing bowl were scraped as the dough formed, and the addition of water was continued until the curve leveled at the 500 Brabender Units (BU) line. Water absorption, peak time, mixing tolerance index (MTI), and stability profiles were calculated from the farinograms. Water absorption is the amount of water needed to center the Farinograph curve at the 500 BU line for flour/water dough (Shuey, 1984). The time between the first addition of the water and the development of the maximum dough consistency was defined as the dough development time, otherwise known as peak time. The mixing tolerance index (MTI) was the difference in BU between the top of the curve and the top of the curve measured 5 min after the peak time was reached. Stability was defined as the difference in time between the point at which the top of the curve peak first intercepts the 500-BU line (arrival time) and the point at which the top of the curve leaves the 500-BU line (departure time).

## 2.3 Bread Making Procedure

Optimized straight-dough bread making method 10-10.03 (AACCI, 2000) was followed for bread making. The FF flour levels of 6, 10 and 15% were used in the formulations as a replacement for the wheat flour. For example, the 10% FF breads were made with 90% wheat flour and 10% FF. All other ingredients follow the formula as described in AACCI method 10-10.03 (2000). Moisture values in the formulas were adjusted according to the Farinograph results. After mixing the ingredients, doughs were fermented 90 minutes and proofed for 33 minutes prior to baking at 210 °C. Bread quality (e.g. loaf volume, specific volume) tests were performed according to the methods described by Sharadanant and Khan (2003). Loaf volume was measured using a rapeseed displacement measuring apparatus 1 hr after baking. Loaf weight was determined and specific volume was calculated as loaf volume (cc) / loaf weight (g). Proof height and baked height were measured in cm. Oven spring (cm) was calculated as the difference between the baked height and the proof height (Khalil, Mansour & Dawoud, 2000). Water activity and moisture content of the bread crumb was measured using an AquaLab water activity meter (Pullman, WA) and AACCI Method 44-15A (2000), respectively.

## 2.4 Statistical Analysis

The experimental design was a randomized complete block. The experiment was replicated three times. Dough measurements and baking were completed on three separate days where duplicates of each formulation were prepared as described above. The treatment means (n=6) were subjected to analysis of variance by using SAS software (SAS System for Windows, release 8.2, SAS Institute, Cary, NC, USA), and means were separated by Fisher's protected LSD at the  $p \leq 0.05$  probability level. Pearson's correlation coefficients between the four treatment means of the evaluated dough and bread characteristics were determined using SAS software.

# 3. Results and Discussion

## 3.1 Effect of Flaxseed Flour on Rheological Properties

The Farinograph profiles of bread flour and bread flour/15% FF blend were clearly different (Figure 1). Although not shown, the farinograms of the 5 and 10% FF blends were different from the control. The profiles showed that FF at all levels changed the shape of the farinogram of the commercial bread flour; indicating an effect on dough properties.

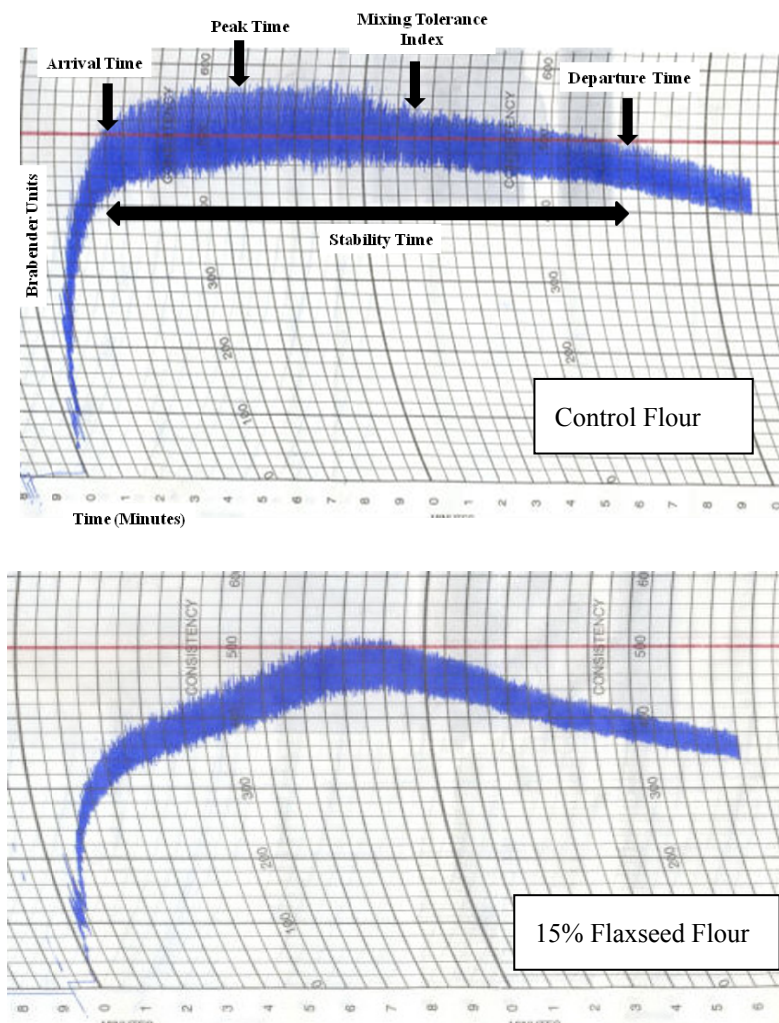


Figure 1. Farinograph profile of bread flour (Top) and 15% flaxseed flour/bread flour mixture (Bottom). The top farinogram includes key Farinograph characteristics

The Farinograph characteristics of the bread flour/FF blends varied significantly ( $p \leq 0.05$ ) (Table 1). Water absorption increased with increasing FF addition (Table 1). The maximum water absorption was 67.4%, as observed for the 15 % FF sample. Koca and Anil (2007) and Marpalle et al. (2014) also observed increasing water absorption values with increasing flaxseed addition to wheat flour. However, water absorption values reported by Koca and Anil (2007) were 2% lower than what we observed. Differences in the composition of the bread flour or in the FF may account for the differences in water absorption. However, the trend of increasing water absorption was observed with increasing addition of FF to bread flour. Usually, increased water absorption indicates stronger dough (Shuey, 1984). However, the increased water absorption in the FF containing doughs might be due to the presence of mucilage or gum in flaxseed. Flaxseed contains approximately 8 % mucilage (BeMiller, 1973), which might compete with the flour protein for water. The mucilage acts as a hydrocolloid and it can absorb many times its weight in water. Other researchers have observed increased water absorptions in flours with added hydrocolloids such as k-carrageenan and xanthan gums (Rosell, Rojas, & Benedito de Barber, 2001) and gum acacia (Sidhu & Bawa, 2004). Fedeniuk and Biliaderis (1994) reported that flaxseed gum has water holding capacities of 1600 to 3000 g water/100 g gum. This suggests that the increased Farinograph water absorption was likely due to the presence of the flaxseed gum.

Table 1. Farinograph characteristics of flaxseed–bread flour blends

Treatment	Water Absorption (%)	Peak Time (min)	MTI (BU)	Stability (min)
BF	63.9d	6.4c	33.0c	15.3a
6 % FF	65.4c	7.3bc	51.5b	7.8b
10 % FF	66.4b	8.4ab	78.5a	5.3c
15 % FF	67.4a	8.9a	82.5a	3.3d

Note: Means followed by the same letter in columns are not significantly different at  $p > 0.05$  ( $n=6$ ).

BF = bread flour; FF = flaxseed flour; MTI = mixing tolerance index.

With the increase in the FF from 0 to 15 % in the blends, peak time increased from 6.4 min to 8.9 minutes, indicating slower dough development at higher FF levels. The higher dough MTI value indicates weaker flour that tends to form doughs that break down rapidly during mixing (Shuey, 1984; AACCI, 2000). In our experiment, the MTI increased from 33 to 82.5 BU, which indicates weakening of the dough as the level of FF in the flour blend increased. The stability value is an indication of the flour strength (Bloksma & Bushuk, 1988; Gupta & MacRitchie, 1994). High values suggest strong dough. The sharp decrease in stability with the increasing proportion of FF in the blends was attributed to the dilution or weakening of the gluten matrix. The physical interruption of gluten matrix was likely the cause of the dough weakening as the gluten proteins are responsible for the viscoelastic network and dough strength (Gupta & MacRitchie, 1994). The changes in MTI and stability of the FF fortified dough follow similar trends reported by Garden (1993) and Koca and Anil (2007).

### 3.2 The Effect of FF Addition on Bread Processing and Bread Quality

Mixing time and oven spring are two processing parameters that can impact bread characteristics. Mixing time increased with FF addition (Table 2), which was partly due to the higher water absorption of the FF/bread flour blends. Oven spring has been attributed to the evaporation of water and retention of carbon dioxide, as well as thermal expansion of gases (Campbell, 2003). Gluten is important because it provides structure and slows the diffusion of gases during baking, which in turn increases oven spring (Gan, Ellis, & Schofield, 1995; Hosney, 1984). Thus, the decreased oven spring in FF fortified breads was likely due to the effects of FF on gluten formation, resulting in greater carbon dioxide loss.

Table 2. The effect of flaxseed flour on bread processing and bread quality

Treatment	Mixing Time (min)	Oven spring (cm)	Loaf Weight (g)	Loaf volume (cc)	Specific volume (cc/g)	Moisture Content (%)	Water Activity
BF	4.00a	2.7a	35.1a	192ab	5.5ab	42.39a	0.951c
6 % FF	4.25a	2.2b	35.2a	203a	5.8a	42.70a	0.960b
10 % FF	4.50a	2.0b	35.5a	179bc	5.0ab	43.24a	0.962b
15 % FF	4.75a	1.9b	35.7a	170c	4.8b	43.47a	0.969a

Note: Means followed by the same letter in columns are not significantly different at  $p > 0.05$  ( $n=6$ ).

BF = bread flour; FF = flaxseed flour.

Crumb water activity (Table 2) was slightly higher in the FF fortified breads, which was expected due to the well-known water holding capacity of flaxseed gum (Fedeniuk & Biliaderis, 1994). The moisture content increased with increasing FF (Table 2), but was not significantly different. The increased moisture content and water activity might be the basis for the observed increase in moistness of flaxseed rolls reported by Pohjanheimo et al. (2006). The moisture was defined as “the feeling of moistness on the cut surface of the sample when pressed against lips” (Pohjanheimo et al., 2006). These authors reported moisture sensory scores of 7.0 and 7.4 for the control and flaxseed bread rolls, respectively. Koca and Anil (2007) also reported that the crumb texture sensory scores were better in breads with higher flaxseed levels. However, these values were not

significantly different. Flaxseed improved the bread quality in terms of moisture and softness during storage (Pohjanheimo et al., 2006), suggesting an important role of flax gum (Fedeniuk & Biliaderis, 1994).

Although more water was used during the dough formation step with increasing FF concentrations, loaf weight for all of the treatments was about 35 g and did not differ significantly ( $p > 0.05$ ). This might be due to water evaporation during baking. The gluten structure traps gases (Campbell, 2003), thus the interference with gluten structure by FF may cause less water entrapment resulting in bread with similar moisture contents and weights to that of the control bread (Table 2).

One of the most important physical qualities in bread is loaf volume, which has a strong influence on consumer preference. Loaf volume of bread containing FF up to 10% did not differ significantly ( $p > 0.05$ ) from the control, whereas further increasing FF in the formula reduced loaf volume significantly (Table 2, Figure 2). Marpalle et al. (2014) reported that only 5 % flaxseed addition produced loaf volumes that were not different from the control. In our study, bread made with 6% FF had slightly higher loaf and specific volumes compared to the control. Increasing the amount of FF resulted in a darker bread crust (Figure 2). This observation might be related to the Maillard browning reaction, which could possibly be caused by interactions between flaxseed proteins and carbonyl compounds formed from the breakdown of sugars during baking. Crumb color became more yellow due to the yellow color of FF. Although crumb texture showed evidence of thickened cells, crumb structures were not drastically impaired upon substitution of wheat flour by up to 15% FF. Similar observations were recently reported by Marpalle et al. (2014).



Figure 2. Exterior (A) and interior (B) of loaves of bread containing different levels of FF (0, 6, 10, and 15%, from left to right)

### 3.3 The Correlations Between Farinograph Parameters and Bread Making Properties

To understand the interrelationship between Farinograph parameters of FF/wheat flour dough and bread characteristics, correlations between water absorption, peak time, MTI, stability, oven spring, loaf weight, loaf volume, specific volume, moisture content, and water activity were determined (Table 3). Both water absorption and peak time were positively correlated with MTI and water activity ( $r = 0.82$  to  $0.93$ , respectively), but negatively correlated with stability, specific volume, oven spring, and loaf volume (ranging from  $r = -0.69$  to  $-0.95$ ). In addition, water absorption was highly correlated with peak time ( $r = 0.96$ ). A significant negative



correlations between MTI and stability, specific volume, oven spring, and loaf volume (ranging from  $r = -0.72$  to  $-0.84$ ) suggested that MTI was a good indicator for predicting the baking performance of bread flours partially replaced by FF. Large MTI values of a flour suggests poor baking characteristics. Stability was positively correlated with oven spring and loaf volume ( $r = 0.82$  and  $0.56$ , respectively), and negatively correlated with moisture content and water activity ( $r = -0.77$  and  $-0.92$ , respectively). Farinograph parameters, with the exception of stability, were inversely correlated with loaf volume, which is one of the most important bread qualities (Bruckner, Habernicht, Carlson, Wichman, & Talbert, 2001).

Table 3. Correlations between Farinograph parameters of FF/wheat flour dough and bread characteristics

Parameters	Peak Time	MTI	Stability	Specific Volume	Oven Spring	Loaf Weight	Loaf Volume	Moisture Content	Water Activity
Water Absorption	0.96**	0.82*	-0.95**	-0.69	-0.71*	0.31	-0.71*	0.66	0.90**
Peak Time		0.89**	-0.93**	-0.82*	-0.82*	0.46	-0.82*	0.7	0.93**
MTI			-0.84**	-0.74*	-0.72*	0.34	-0.76*	0.66	0.7
Stability				0.56	0.82*	-0.31	0.56	-0.77*	-0.92**
Specific Volume					0.57	-0.57	0.98**	-0.52	-0.65*
Oven Spring						-0.59*	0.49	-0.66*	-0.91**
Loaf Weight							-0.4	0.42	0.52
Loaf Volume								-0.48	-0.60*
Moisture Content									0.70*

Note: \*, significant at  $p < 0.05$ ; \*\*, significant at  $p < 0.01$ .

#### 4. Conclusion

Flaxseed flour significantly ( $p < 0.05$ ) impacted the rheological properties of wheat flour dough as indicated by Farinograph parameters. Water absorption did increase with increasing FF, which is beneficial; however, lower peak time, MTI, and dough stability were negative outcomes resulting from FF addition. In contrast to dough properties, replacement of wheat flour with up to 10% (wt/wt) FF was possible without significantly affecting bread quality characteristics such as loaf volume. However, 15% FF addition resulted in an unacceptable bread loaf volume reduction. The baking performance of FF enriched bread flour may be predicted by their corresponding farinograph profiles. In particular, the combination of MTI and stability time could be used to predict formulations that might result in breads with good quality. Thus, Farinograph profiles could be a useful tool to develop FF bread formulas without caring out the long baking process. In the current study, no attempt was made to optimize the bread production through the use of additives. Thus, future research could focus on assessing the ability of food additives, such as vital wheat gluten, in maintaining bread quality as FF addition is increased beyond 10%.

#### References

- AACCI. (2000). Approved Methods of the American Association of Cereal Chemists International. American Association of Cereal Chemists, St Paul, MN.
- Alpaslan, M., & Hayta, M. (2006). The effects of flaxseed, soy and corn flours on the textural and sensory properties of a bakery product. *Journal of Food Quality*, 29, 617-27. <http://dx.doi.org/10.1111/j.1745-4557.2006.00099.x>
- Ascherio, A., Rimm, E. B., Giovannucci, E. L., Spiegelman, D., Stampfer, M., & Willett W. C. (1996). Dietary fat and risk of coronary heart disease in men: Cohort follow up study in the United States. *British Medical Journal*, 313, 84-90. <http://dx.doi.org/10.1136/bmj.313.7049.84>
- BeMiller, J.N. (1973). Quince seed, psyllium seed, flaxseed, and okra gums. In R. L. Whistler & J. N. BeMiller (Eds.), *Industrial gums* (pp. 339-67). (2nd ed.). New York: Academic Press.

- Bloksma, A. H., & Bushuk, W. (1988). Rheology and chemistry of dough. In Y. Pomeranz (Ed.), *Wheat chemistry and technology* (pp. 131-217). (3rd ed.) St. Paul, MN, American Association of Cereal Chemists.
- Bowen, P.E. (2001). Evaluating the health claim of flaxseed and cancer prevention. *Nutrition Today*, 36, 144-158. <http://dx.doi.org/10.1097/00017285-200105000-00011>
- Bruckner, P., Habernicht, D., Carlson, G., Wichman, D., & Talbert, L. (2001). Comparative bread quality of white flour and whole grain flour for hard red spring and winter wheat. *Crop Science*, 41, 1917-1920. <http://dx.doi.org/10.2135/cropsci2001.1917>
- Campbell, G. M. (2003). Bread aeration. In S.P. Cauvain (Ed.), *Bread making: improving quality* (pp. 352-74). Cambridge, England: Woodhead publishing. <http://dx.doi.org/10.1533/9781855737129.2.352>
- Chen, Z., Ratnayake, W., & Cunnane, S.C. (1994). Oxidative Stability of flaxseed lipids during baking. *Journal of the American Oil Chemist Society*, 71, 629-32. <http://dx.doi.org/10.1007/BF02540591>
- Conforti, F., & Davis, S.F. (2006). The effect of soya flour and flaxseed as a partial replacement for bread flour in yeast bread. *International Journal of Food Science and Technology*, 41(S2), 95-101. <http://dx.doi.org/10.1111/j.1365-2621.2006.01410.x>
- Demark-Wahnefried, W., Price, D., Polascik, T., Robertson, C., Anderson, E., Paulson, D., Walther, P., Gannon, M., & Vollmer, R. T. (2001). Pilot study of dietary fat restriction and flaxseed supplementation in men with prostate cancer before surgery: Exploring the effects on hormonal levels, prostate specific antigen, and histopathologic features. *Urology*, 58, 47-52. [http://dx.doi.org/10.1016/S0090-4295\(01\)01014-7](http://dx.doi.org/10.1016/S0090-4295(01)01014-7)
- Djousse, L., Pankow, J., Eckfeldt, J., Folsom, A., Hopkins, P., Province, M., Hong, Y., & Ellison, R. (2001). Relation between dietary linolenic acid and coronary artery disease in the National Heart, Lung, and Blood Institute family heart study. *American Journal of Clinical Nutrition*, 74, 612-619.
- Fedeniuk, R., & Biliaderis, C. (1994). Composition and physicochemical properties of linseed (*Linum usitatissimum* L.) mucilage. *Journal of Agriculture and Food Chemistry*, 42, 240-247. <http://dx.doi.org/10.1021/jf00038a003>
- Gan, Z., Ellis, P., & Schofield, J. D. (1995). Gas Cell Stabilisation and Gas Retention in WheatBread Dough. *Journal of Cereal Science*, 21, 215-230. <http://dx.doi.org/10.1006/jcrs.1995.0025>
- Garden, J. (1993). *Flaxseed gum: extraction, characterization, and functionality*. (unpublished doctoral dissertation). North Dakota State University, Fargo, ND.
- Gebauer, S., Psota, T., Harris, W., & Kris-Etherton, P. M. (2006). n-3 Fatty acid dietary recommendations and food sources to achieve essentiality and cardiovascular benefits. *American Journal of Clinical Nutrition*, 83, 1526S-1535S.
- Gupta, R., & Macritchie, F. (1994). Allelic Variation at Glutenin Subunit and Gliadin Loci, Glu-1, Glu-3 and Gli-1 of Common Wheats. II. Biochemical Basis of the Allelic Effects on Dough Properties. *Journal of Cereal Science*, 19, 19-29. <http://dx.doi.org/10.1006/jcrs.1994.1004>
- Hooda, S., & Jood, S. (2003). Physicochemical, rheological, and organoleptic characteristics of wheat-fenugreek supplemented blends. *Nahrung*, 47, 265-268. <http://dx.doi.org/10.1002/food.200390062>
- Hoseney, R. C. (1984). Gas retention in bread doughs. *Cereal Foods World*, 29, 305-308
- Hu, F., Stampfer, M., Manson, J., Rimm, E., Wolk, A., Colditz, G., Hennekens, C., & Willett W. (1999). Dietary intake of alpha-linolenic acid and risk of fatal ischemic heart disease among women. *American Journal of Clinical Nutrition*, 69, 890-897.
- Hyvärinen, H., Pihlaja J., Hiidenhovi, J., Hietaniemi, V., Korhonen, H., & Ryhänen, E. (2006). Effect of processing and storage on the stability of flaxseed lignan added to bakery products. *Journal of Agriculture and Food Chemistry*, 54, 48-53. <http://dx.doi.org/10.1021/jf0507590>
- IOM. (2005). *Dietary fats: total fat and fatty acids*. In: *dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids (Macronutrients)* (pp. 422-541). Washington, DC: National Academies Press.
- Khalil, A., Mansour, E., & Dawoud, F. (2000). Influence of malt on rheological and baking properties of wheat-cassava composite flours. *Lebensmittel-Wissenschaft & Technologie*, 33, 159-164. <http://dx.doi.org/10.1006/fstl.1999.0629>
- Kim, Y. (2000). AGA technical review: Impact of dietary fiber on colon cancer occurrence. *Gastroenterology*, 118, 1235-1257. [http://dx.doi.org/10.1016/S0016-5085\(00\)70377-5](http://dx.doi.org/10.1016/S0016-5085(00)70377-5)
- Koca, A., & Anil, M. (2007). Effect of flaxseed and wheat flour blends on dough rheology and bread quality. *Journal of the Science of Food and Agriculture*, 87, 1172-1175. <http://dx.doi.org/10.1002/jsfa.2739>



- Lee, S., Inglett, G., & Carriere, C. (2004). Effect of nutrim oat bran and flaxseed on rheological properties of cakes. *Cereal Chemistry*, 81, 637-642. <http://dx.doi.org/10.1094/CCHEM.2004.81.5.637>
- Manthey, F., Lee, R., & Hall, C. (2002). Processing and cooking effects on lipid content and stability of  $\alpha$ -linolenic acid in spaghetti containing ground flaxseed. *Journal of Agriculture and Food Chemistry*, 50, 1668-1671. <http://dx.doi.org/10.1021/jf011147s>
- Mentes, O., Bakkalbassi, E., & Ercan, R. (2013). Effect of the use of ground flaxseed on quality and chemical composition of bread. *Food Science and Technology International*, 19, 549-556. <http://dx.doi.org/10.1177/1082013212462231>
- Muir, A., & Westcott, N. (2000). Quantitation of the lignan secoisolariciresinol diglucoside in baked goods containing flax seed or flax meal. *Journal of Agriculture and Food Chemistry*, 48, 4048-4052. <http://dx.doi.org/10.1021/jf990922p>
- Pan, A., Chen, M., Chowdhury, R., Wu, J. H., Sun, Q., Campos, H., ... Hu, F. B. (2012).  $\alpha$ -Linolenic acid and risk of cardiovascular disease: a systematic review and meta-analysis. *American Journal of Clinical Nutrition*, 96, 1262-1273. <http://dx.doi.org/10.3945/ajcn.112.044040>
- Pohjanheimo, T., Hakala, M., Tahvonen, R., Salminen, S., & Kallio, H. (2006). Flaxseed in breadmaking, effects on sensory quality, aging, and composition of bakery products. *Journal of Food Science*, 71, S343-S348. <http://dx.doi.org/10.1111/j.1750-3841.2006.00005.x>
- Ptitchkina, N., Novokreschonova, L., Piskunova, G., & Morris, E. (1998). Large enhancements in loaf volume and organoleptic acceptability of wheat bread by small additions of pumpkin powder: possible role of acetylated pectin in stabilizing gas-cell structure. *Food Hydrocolloids*, 12, 333-337. [http://dx.doi.org/10.1016/S0268-005X\(98\)00024-1](http://dx.doi.org/10.1016/S0268-005X(98)00024-1)
- Rosell, C., Rojas, J., & Benedito de Barber, C. (2001). Influence of hydrocolloids on dough rheology and bread quality. *Food Hydrocolloids*, 15, 75-81. [http://dx.doi.org/10.1016/S0268-005X\(00\)00054-0](http://dx.doi.org/10.1016/S0268-005X(00)00054-0)
- Sharadanant, R., & Khan, K. (2003). Effect of Hydrophilic Gums on the Quality of Frozen Dough: II. Bread Characteristics. *Cereal Chemistry*, 80, 773-780. <http://dx.doi.org/10.1094/CCHEM.2003.80.6.773>
- Shearer, A., & Davies, C. (2005). Physicochemical properties of freshly baked and stored whole- wheat muffins with and without flaxseed meal. *Journal of Food Quality*, 28, 137-153. <http://dx.doi.org/10.1111/j.1745-4557.2005.00004.x>
- Shogren, R., Mohamed, A., & Carriere, C. (2003). Sensory analysis of whole wheat/soy flour bread. *Journal of Food Science*, 68, 2141-2145. <http://dx.doi.org/10.1111/j.1365-2621.2003.tb07033.x>
- Shuey, W. C. (1984). Interpretation of the farinogram. In D'Appolonia, B., & W. Kunerth (Eds.), *The farinograph handbook* (pp. 31-32). (3rd ed.). St. Paul, American Association of Cereal Chemists, Inc.
- Sidhu, J. P. S., & Bawa, A. S. (2004). Effect of gum acacia incorporation on the bread making performance of Punjab wheat. *International Journal of Food Properties*, 7, 175-183. <http://dx.doi.org/10.1081/JFP-120025394>
- Thompson, L. U., Robb, P., Serraino, M., & Cheung, F. (1991). Mammalian lignan production from various foods. *Nutrition and Cancer*, 16, 43-52. <http://dx.doi.org/10.1080/01635589109514139>
- Thompson, L. U., & Cunnane, S. (2003). *Flaxseed in human nutrition* (p. 457). (2nd ed.). Champaign, AOCS Press. <http://dx.doi.org/10.1201/9781439831915>
- Wang, W., & Khan, K. (2009). Effect of the molecular weight distribution of glutenin protein from an extra-strong wheat flour on rheological and breadmaking properties through reconstitution studies. *Cereal Chemistry*, 86, 623-632. <http://dx.doi.org/10.1094/CCHEM-86-6-0623>
- Yang, C. S., Landau, J. M., Huang, M. T., & Newmark, H. L. (2001). Inhibition of carcinogenesis by dietary polyphenolic compounds. *Annual Review of Nutrition*, 21, 381-406. <http://dx.doi.org/10.1146/annurev.nutr.21.1.381>

## Copyrights

Copyright for this article is retained by the author(s), with first publication rights granted to the journal.

This is an open-access article distributed under the terms and conditions of the Creative Commons Attribution license (<http://creativecommons.org/licenses/by/3.0/>).