Effects of Flaxseed Enrichment on Wheat Dough and Bread Crumb

Tanundorn Veng [1], Eakasit Sritham [2]
[1,2] Department of Food Engineering, School of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand.
Email : [1] 63601158@kmitl.ac.th, [2] eakasit.sr@kmitl.ac.th

Abstract

The effects of ground flaxseed enrichment (10%, 15% and 20%) on large deformation rheological behavior of dough and instrumental textural properties, specific volume, and hardening kinetics of bread were investigated. Dough samples were characterized using the Kieffer-type extensibility rig. The texture profile analysis (TPA) technique and compression test were conducted on bread crumbs. The peak load, deformation at peak load (D-Peak), and distance to rupture point (D-Rupture) of dough showed a tendency to decrease with increasing level of flaxseed enrichment. However, the reduction of these values was significant only when the enrichment was at 20% whereby the values of peak load, D-Peak, and D-Rupture decreased for 29.5%, 25.6%, and 47.7%, respectively. Similarly, for bread product, the enrichment could be made up to 15% without significant change in the hardness, cohesiveness, springiness, chewiness, and specific volume. Bread with 20% flaxseed enrichment showed a significant increase of hardness and chewiness by 41.0% and 21.34%, respectively, and a decrease of cohesiveness, springiness and specific volume by 10.4%, 2.1% and 11.0%, respectively. Bread crumb hardening occurred with a higher rate at 4°C than at 18°C. Flaxseed enrichment could help retarding bread crumb hardening.

Index Terms— bread, dough, flaxseed, texture.

1. Introduction

Bread is among staple foods that have been consumed since the very first stage of civilization development in a certain region of the world and have now become part of main dietary worldwide. Most kinds of bread are produced from white flour, known as white bread. Bread could also be produced from whole wheat flour known as whole wheat bread. The whole wheat bread is more nutritional than white bread since much of the fibers, vitamins and minerals in the bran layer are retained in the whole wheat bread recipe [1]. However, white bread is preferable for many consumers primarily due to the less desirable textural characteristics of whole wheat bread as compared to that of white bread. Bread is perishable product and its shelf-life is mainly limited by a physicochemical deterioration known as staling, which leads to hardening and drying of texture, and losing moisture content. During storage, bread hardness progressively increases due to staling. Staling is an aging phenomenon primarily caused by the reorganization of starch molecules into a more crystalline structure [2].

A great deal of modern living diets appears to incorporate only small amount of dietary fibers. Long-term consumption of low fiber foods could lead to several health concerns. The nutritional and functional fortification of white bread became a trend of interest among bakery producers [3] and researchers [4].

The inclusion of dietary fibers could improve functional properties of white bread. Dietary fiber refers to the parts of fruits, vegetables, crops, nuts and legumes that humans cannot digest. The recommended dietary fiber intake for an adult is 25–38 g per day. It has been found that dietary fiber consumption could provide health benefits in terms of reducing the risk of some diseases, e.g. diabetes, obesity, coronary heart disease, bowel cancer and gallstones [5], [6].

The major sources of dietary fiber commonly used in bread making are cereal bran such as wheat bran, oat and barley bran, and other natural fibrous materials such as wheat fiber, apple or orange fiber, dietary fibers derived from potatoes, beet and carrot. Fiber possesses a number of functional properties, e.g., water holding, oil holding and swelling capacity, and viscosity or gel formation, that could affect the process and product qualities [7].

It has been reported that fiber enrichment could post some adverse effects on processing characteristics of dough and qualities of the final product. The development of dough stickiness and the reduction of loaf volume were observed in fiber-fortified bread products. Other undesirable characteristics such as the loss of mouth-feel and dark color have also been reported [8], [9]. Nevertheless, the effects of fiber fortification on the dough and baked products could be varied due to a broad range of bread recipes and processing conditions.

Flaxseed is another potential source of functional and nutritional food due to its unique nutritional profile. In addition to dietary fiber, flaxseed is high in polyunsaturated fatty acids (73% of total fatty acids), moderate in monounsaturated fatty acids (18%) and low in saturated fatty acids (9%), linoleic acid constitutes is about 16% of total fatty acids, α-linolenic acid (ALA) about 57% [10]. An extensive review of the effects of flaxseed enrichment on cereal-based products was also found elsewhere [11].

It is interesting to develop flaxseed enriched bread while limiting the adverse effects on processing characteristics of dough and textural quality of the baked product. The aim of this study was to investigate the effects of flaxseed enrichment on dough rheological characteristics and on instrumental textural quality and staling rate of bread at two different levels of storage temperatures.

2. Materials and Methods

Materials

Commercial breadmaking wheat flour (unbleached, 13.5% protein, Shuttle brand by Thai Flour Mill Industry Co., Ltd, Thailand) was used in this study. Other ingredients included iodized refined salt (Prung Thip brand), refined sugar (Mitr Phol brand), unsalted butter (Orchid brand), instant yeast (Perfect brand) and flaxseeds (Heritage brand) were obtained from local stores in Bangkok, Thailand.

Samples preparation

The treatment without flaxseed (the control treatment) was prepared with a standard formulation including sugar (3.12% flour weight basis, [fwb]), salt (1.25% fwb), yeast (1.87% fwb), butter (9.37% fwb) and distilled water (62.5% fwb).

To obtain dough, dried ingredients were mixed using a commercially available bakery mixing equipment (MIXER model B10C) for 3 minutes. Distilled water was then added and continually mixed for 7 more minutes. Dough samples were kneaded manually for 10 minutes, wrapped with parafilm and then proofed for 50 minutes at room temperature (26±2°C).

Prior to the use, flaxseeds were dried in a hot-air oven (Drying oven model 101-0A, Huanghua Faithful Instrument Co., LTD.) at 90°C for 10 minutes, and ground with a food grinder (Model HR2061, Philips) at the speed level 5 for 1 minute. Flaxseed enriched treatments were prepared by adding ground flaxseed for 10%, 15% and 20% (fwb) to the standard formulation. Bread samples were then obtained by baking the dough in an electric toaster (Model EOT4805K, Electrolux) at 165°C for 50 minutes.

Dough extensibility test

Large strain rheological properties of dough samples were measured using the TA.XT*plus* texture analyzer (Stable Micro System, Surrey, UK) equipped with a Kieffer-type extensibility rig. Test specimens were prepared with approximately 5 g of dough which was pressed in an acrylic mold to form a shape of 10 mm × 10 mm × 90 mm then stored at room temperature for 1 hour. The test was carried out using a speed of 5 mm/s [12]. From the obtained data, a distance to rupture point (D-Rupture), a distance to maximum force or deformation at peak load (D-Peak) and the maximum force (Peak load) were determined using the Texture Expert™ software.

Textural characterization of bread

Textural properties of bread crumb were obtained with Texture Profile Analysis (TPA) technique at 23±2°C. The test was performed using the TA.XT*plus* texture analyzer equipped with a cylindrical aluminum probe of 50-mm diameter under a compression mode. Bread specimens were prepared by cutting bread loaves into 2-cm thickness slices. Samples were double compressed at 2 mm/s up to 50% of their original height. The textural parameters including hardness, cohesiveness, springiness and chewiness were then inferred from the TPA plots using the bundled software "Texture Expert™".

Determination of bread loaf specific volume

The specific volume of the loaf was determined using the rapeseed displacement method according to AACC Standard 10-05 [13]. Rapeseed was fully poured into a container; the excess amount was swept off. The volume of rapeseeds was measured using a graduated cylinder and noted as V_{seed1}. Rapeseed were removed and a bread loaf was placed in the container. The container was again refilled with rapeseeds to cover the loaf and fully fill the container; the excess amount was swept off. The volume of rapeseeds was measured using a graduated cylinder noted as V_{seed2}. The volume of loaf (V_{loaf}) was then calculated using (1). The loaf was weighed, and the specific volume of loaf (v_{loaf}) was then calculated using (2):

$$V_{loaf}(cm^3) = V_{seed1} - V_{seed2} \quad (1)$$

$$v_{loaf}\ (cm^3/g) = V_{loaf}/m_{loaf} \quad (2)$$

Dietary fiber and moisture determination

Water content of bread crumb was determined in triplicate following the standard method AACC Method 44-15A [14] by which samples were dried with a hot-air oven (Memmert model UM500) at 105°C for 16 h.

Total dietary fiber of bread was determined in duplicate using the Enzymatic-Gravimetric method by Central Laboratory (Thailand) Co., Ltd.

Measurement of bread staling

The progress of bread staling at 4°C and 18°C storage temperatures was determined indirectly by observing the evolution of crumb hardness during the storage period of 7 days. Bread loaves were stored at 4°C and 18°C, for 1, 4 and 7 days. Test specimens were prepared similar to those for the TPA test. Hardness was measured using the TA.XT*plus* texture analyzer equipped with a cylindrical aluminum probe of 50-mm diameter under a compression mode at a test speed of 2 mm/s to 50% of their original height. Measurements were made for fresh bread and after 1, 4 and 7 days of storage. The evolution of hardness during storage was explained using the Avrami equation [15] which could be written as in (3):

$$(H_\infty - H_t)/(H_\infty - H_0) = \exp(-kt^n) \qquad (3)$$

Where H_∞ is the hardness at infinity time, H_t is the hardness at time t, H_0 is the hardness at the initial time, k is a rate constant, and n is the Avrami exponent [16], [17]. The parameters for Avrami model were estimated by fitting experimental data into (3) using a least squared minimization. Fitting routine was carried out in the software Excel (Microsoft Corporation, Washington, USA) with the “solver” tool assisted.

The coefficient of determination (R^2) was calculated as (4):

$$R^2 = 1 - \sum(H_i - H_{pred})^2 / \sum(H_i - H_{avg})^2 \qquad (4)$$

Where H_i is the hardness at time i, H_{pred} is the predicted or fitted hardness, and H_{avg} is the average value of harness.

The hardening of the bread crumb was compared using a half-life value ($t_{1/2}$). Half-life was defined as the time required to achieve 50% of the leveling-off extent of crumb firmness. Shorter half-life indicates a faster hardening process of bread crumb. Half-life was calculated using the values of k and n as shown in (5):

$$t_{1/2} = (-ln0.5/k)^{1/n} \qquad (5)$$

Statistical analysis

Experiments were conducted using a completely randomized design (CRD) in duplicates and triplicates, respectively, for dough and bread experiments. Statistical analyses were performed using IBM SPSS Statistics for Windows, Version 26.0. (IBM Corp., NY, USA). Analysis of variance (ANOVA) was performed to determine if a significant difference exists among treatment means. The Turkey’s test was chosen for the comparisons of treatment means. All statistical analyses were performed at 0.05 level of significance.

3. Results and Discussion

Large deformation rheological behavior of dough

Dough extensibility is an important characteristic in pre-determining the rise qualities and structure of bread product. In this experiment, three attributes including peak load, D-Peak and

D-Rupture were determined. The peak load or the force at the elastic limit of a sample is a measure of the tensile strength of the dough. It was found that the highest value of peak load of 0.44 N was observed from the control treatment and this value tended to decrease with the increasing flaxseed amount (Table I) suggesting that the tensile strength of dough was deteriorated upon the addition of flaxseed.

However, from statistical analysis, ground flaxseed could be added up to 15% without a significant effect on this value. The formation of dough involves several processes including biochemical, microbiological and physio-chemical processes which could all affect the rheological properties. Specifically, those are enzymatic activity, the hydration of insoluble proteins and polysaccharides, and the dissolution of globulins, albumins and soluble carbohydrates. In many previous studies, it has been reported the increase of water absorption upon the inclusion of flaxseed flour in dough formulation [18], [19]. The evidence from Farinograph suggested that the increased water absorption was likely due to the presence of mucilage or gum in flaxseed. This gum acts as hydrocolloid which is known for its excellent water absorption capacity. It would compete with gluten for water during dough processing resulting in the slower dough development time. The trend of changes in mixing tolerance index (MTI) and stability value up on the increase of flaxseed flour from 0%–15% indicated the weakening of wheat dough due to physical interruption or dilution of gluten matrix [19]. The distance to rupture point (D-Rupture) is a measure of dough extensibility. The greater the D-Rupture, the more extensible the dough [20]. Again, the control treatment exhibited the greatest D-Rupture value of approximately 107 mm. In general, D-Rupture tended to decrease with the increasing amount of flaxseed added. However, the value of D-Rupture was significantly lower than that of the control treatment only when the amount of flaxseed added was 20% of which the D-Rupture was approximately 59 mm.

Based on the results in this study together with prior reports [11], [21], the decrease of peak load and D-Rupture would primarily be the consequent of gluten dilution. The inclusion of insoluble and soluble cell wall materials from ground flaxseed could disrupt gluten matrix. Literature has reported that fiber addition impaired dough extensibility [7].

Table I. Large deformation rheological parameters of dough

Treatments	**Peak load** (N)	**D-Peak** (mm)	**D-Rupture** (mm)
Control	0.44 ± 0.03^{a}	75.08 ± 2.53^{a}	107.14 ± 15.76^{a}
10%FS	0.34 ± 0.02^{ab}	74.07 ± 2.42^{a}	96.76 ± 2.15^{ab}
15%FS	0.37 ± 0.03^{ab}	63.55 ± 5.23^{a}	89.63 ± 4.57^{ab}
20%FS	0.31 ± 0.04^{b}	40.32 ± 6.92^{b}	59.47 ± 11.15^{b}

Figures shown in the table are mean±SD (n=2). Means in the same column with different letters differ significantly ($p < 0.05$).

Dough extensibility is among the properties that plays important role in bakery making process and contributes to the quality of final product. The relationship between D-Rupture, which is a measure of dough extensibility, and a specific volume of bread loaf obtained in this study is given in Fig. 1. It was found that the D-Rupture significantly correlated with the specific volume of bread ($p<0.05$) with the correlation coefficient (R) value of 0.799.

Instrumental textural characteristics of bread crumb

The textural characteristics of bread samples obtained with TPA are given in Table II. Ground flaxseed could be added up to 15% without significant change on the hardness and chewiness values of bread crumb. The addition of 20% flaxseed caused significant increase of hardness by 41% (11.48 N) as compared to that of the control treatment (8.14 N). Similar impact of ground flaxseed enrichment on hardness of white bread was also reported by [22]. They found that the hardness of white bread crumb increased by 40% when flaxseed was added for 15%. This would be partly due to the denser texture of flaxseed enriched bread. Soluble dietary fiber is known for its high water-binding capacity. The presence of soluble fibers from flaxseed would lower the availability of water for gluten network formation during kneading which then led to the increase in of hardness [23].

Cohesiveness and springiness tended to decrease with the increasing of flaxseed amount. Like the case of hardness, the addition of flaxseed up to 15% did not affect these values. Significant changes of cohesiveness and springiness were detected only when flaxseed amount was 20% which lowered the values of cohesiveness and springiness by around 10% and 2%, respectively, as compared to that of the control treatment.

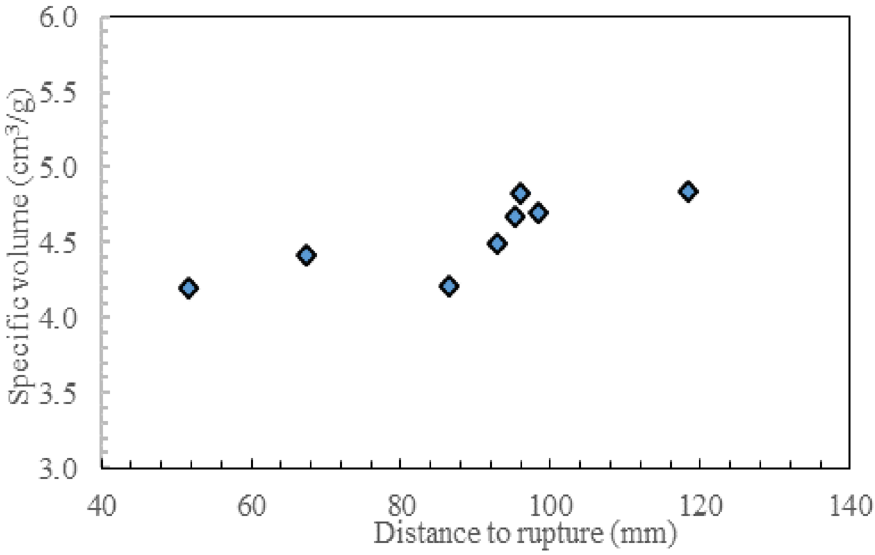

Fig. 1. Relationship between dough extensibility (in terms of distance-to-rupture) and specific volume of bread loaf

Table II. Textural and physical properties of bread samples

Treatments	Hardness (N)	Cohesiveness (%)	Springiness (%)	Chewiness (N)	Specific volume (cm^3/g)	Moisture content (%wb)	Dietary fiber (g/100g)
Control	8.14 ±0.91^a	77.58 ± 1.70^a	93.97 ± 0.94^a	5.95 ± 0.45^a	4.83 ± 0.01^a	41.61±0.01	2.68±017^a
10%FS	8.10 ± 0.62^a	72.85 ± 2.21^{ab}	93.67 ± 0.19^a	5.47 ± 0.23^a	4.68 ± 0.02^{ab}	42.21±0.59	4.85±0.09^b
15%FS	7.57 ± 0.37^a	73.33 ± 1.58^{ab}	92.75 ± 0.62^{ab}	5.20 ± 0.14^a	4.35 ± 0.21^{ab}	41.15±0.22	7.54±0.01^c
20%FS	11.48 ± 0.38^b	69.17 ± 3.49^b	91.86 ± 0.17^b	7.22 ± 0.26^b	4.30 ± 0.15^b	41.91±0.30	9.53±0.04^d

Figures in the table are mean±SD (n=3). The figures in the same column following by different letters differ significantly ($p<0.05$).

Bread springiness decreased with the increasing level of flaxseed enrichment indicating the reduction in elasticity of bread texture upon the inclusion of ground flaxseed into the bread formula. Dietary fibers could affect the firmness and springiness of bread depending on the sources of dietary fibers. For the most part, the decrease of elasticity would be a consequence of reducing in gluten content [6]. The evidence from electron microscopy revealed the lesser fine structure, and the coarser filaments and sheets of bread crumb with fibrous added compared to the control bread [7].

Physical characteristics of bread

The specific volume of flaxseed enriched bread tended to decrease with the amount flaxseed added, from 4.68 cm^3/g for 10% flaxseed to 4.30 cm^3/g for the treatment with 20% flaxseed (Table II). However, only the specific volume of 20% flaxseed enrichment bread that significantly lowered than that of the bread without flaxseed (control treatment).

Though the effect of enrichment with flaxseed on loaf volume (or specific volume) is not clear [11], [24]; it has been generally reported that the enrichment led to the reduction of specific volume or loaf volume due to gluten dilution [7]. In addition, the growth rate of yeast might be hindered by fungistatic activity which lowered carbon dioxide production and consequently dough expansion [25], [26]. It is however possible that flaxseed enrichment could give rise to the increase of specific volume of bread due to several reasons [11]. High water-binding capacity of soluble fiber in flaxseed would retain more water during mixing and so the higher internal pressure of the loaf would be created during baking due to evaporation, which in turn results in the increase of specific volume [27].

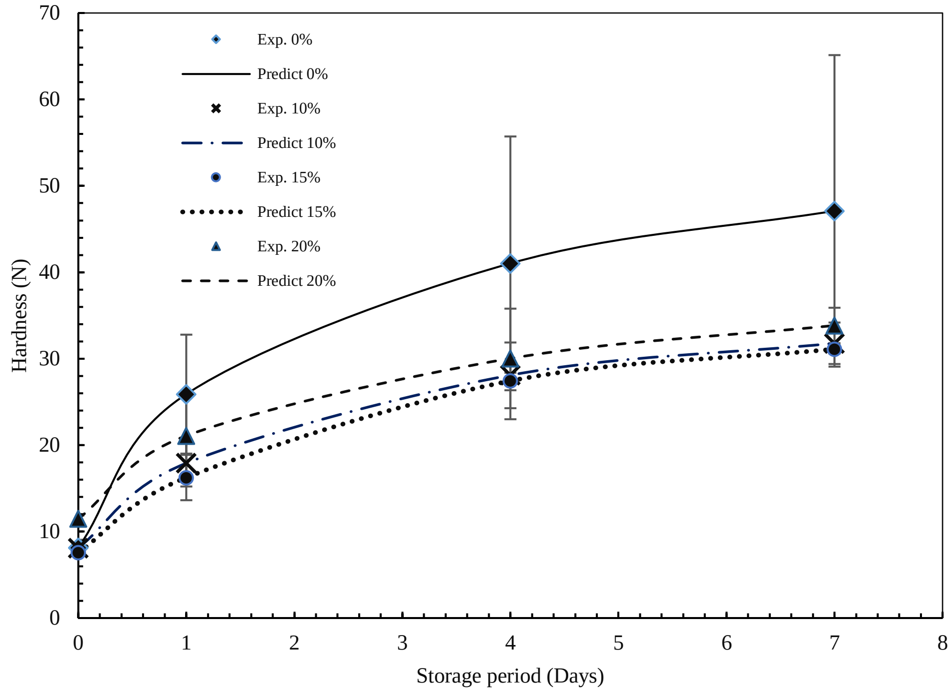

Fig. 2. Evolution of bread crumb hardness under storage temperature of 4°C. The error bars represent standard deviation (n=2). The lines were constructed with the Avrami parameters in Table III.

The dual effect of ground flaxseed enrichment on specific volume of bread loaf has been reported in several literatures [11], even in the same study [24]. In our study, however, ground flaxseed enrichment only resulted in the decrease of specific volume. Although, there was just a slight decrease in bread specific volume from 4.78 cm^3/g to 4.39 cm^3/g for the control and bread fortified with 20%, respectively. The reduction of specific volume was also found in the study on flax marc and flax flour enrichment in bread formula [28]. It was pointed out that the presence of lignan and dietary fiber in flaxseed resulted in the dilution of the gluten network [29]. The soluble dietary fiber in flaxseed could also let to the decrease of specific volume of baked products. Soluble fiber has been known for its pronounced ability in binding with water which could limit the amount of steam generated during the baking process [30].

The moisture content was in a range of approximately 41%–42%. There was no significant difference among the moisture content of all the treatments (Table II). Similar finding was also reported in [19] where flaxseed flour was incorporated to dough formulation in the amount of 0%–15%. The moisture content fell in a range of approximately 42%–43%; no significant difference was found.

It was found that the total dietary fiber (TDF) of the bread without flaxseed (control treatment) was 2.68% which is in good agreement with literature value for wheat flour [7]. The TDF content of flaxseed enriched bread was significantly higher than that of the control treatment; every increment in flaxseed enrichment level in this study resulted in a significant increase of TDF.

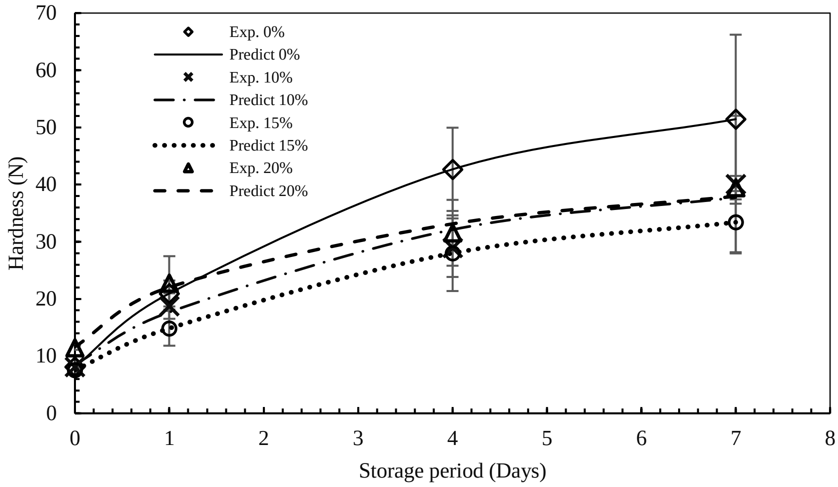

Fig. 3. Evolution of bread crumb hardness under storage temperature of 18°C. The error bars represent standard deviation (n=2). The lines were constructed with the Avrami parameters in Table III.

Table III. Hardening kinetic parameters of bread samples

Storage temperature	**Treatments**	H_0 (N)	H_∞ (N)	K (day^{-n})	n	R^2	**Half-life** (days)
4°C	Control	8.14	55.92	0.47	0.66	0.999	1.83
	10%FS	8.10	35.10	0.45	0.79	0.999	1.72
	15%FS	7.57	33.22	0.41	0.93	0.999	1.75
	20%FS	11.48	39.89	0.41	0.68	0.999	2.14
18°C	Control	8.14	57.36	0.30	1.00	0.999	2.29
	10%FS	8.52	41.53	0.33	0.97	0.970	2.17
	15%FS	7.57	36.98	0.29	1.03	0.999	2.37
	20%FS	11.48	44.80	0.38	0.74	0.988	2.29

Evolution of firmness during storage

The hardness value inferred from a TPA plot is a measure of crumb firmness. The value of hardness generally increases as a result of staling which could be a function of time, temperature, processing, and the formulation of bread [2]. Fig. 2 and Fig. 3 present the evolution of bread crumb firmness during storage at 4°C and 18°C, respectively. The Avrami model parameters, the coefficient of determination (R^2), and the half-life ($t_{1/2}$) are given in Table III. The R^2 values were higher than 0.999 for most of the treatments, except the treatments with 10% and 20% flaxseed enrichment stored at 18°C, which the R^2 values were 0.970 and 0.988, respectively.

For bread samples without flaxseed (control treatment), it could be seen that the hardening rate was faster at 4°C than at 18°C. After one day of storage, the hardness increased from 8.14 N to 25.90 N at 4°C, while at 18°C, it increased to 20.96 N. This could be also interpreted in terms of the constant rate (k) or the half-life ($t_{1/2}$). The values of k were 0.47 and 0.30 and the values of $t_{1/2}$ were 1.83 and 2.29, respectively at 4°C and 18°C. A similar trend of hardening rate at different temperature was also found in gluten-free bread stored at 4°C and 20°C [17].

The difference in hardening rates between the control treatment and the treatments with ground flaxseed enrichment was not obvious when considered in terms of Avrami parameters and $t_{1/2}$. It is presumably due to the limited number of data points obtained in this study. Even though, for fresh bread, flaxseed enriched samples exhibited higher hardness values than that of the control, the opposite was found during storage period particularly at days 4 and 7, in both levels of storage temperature. This would be attributed to the improved moisture retention of flaxseed enriched bread that helped retard the increase of firmness. Flaxseed mucilage accounts for about 8% of the seed weight [31]. Soluble fiber presents in the mucilage is mainly polysaccharides which give rise to the excellent water binding capacity (WBC). The WBC of flaxseed mucilage is in the range of 1600–3000 g_{water}/100 g_{solid} [32].

By average, the hardening rate of bread samples stored at 4°C was higher than that at 18°C. At 4°C, average values of rate constant and half-life were 0.44 and 1.86 days, respectively; while at 18°C those values were, respectively, 0.33 and 2.28 days. It has also been reported in previous study that starch retrogradation at 4°C was significantly faster than at 20°C [17]. The results were in good agreement with the statement in prior literatures where it was stated that in the temperature range of -1°C to 43°C the rate of starch retrogradation is higher at lower temperature [33], [34].

4. Conclusion

Large deformation rheological parameters of dough including peak load, deformation at peak load (D-Peak), and distance to rupture point (D-Rupture), tended to decrease with the increasing level of ground flaxseed enrichment. However, flaxseed could be enriched up to 15% without any effect on rheological properties of dough. At 20% flaxseed enrichment, the values of peak load, D-Peak, and D-Rupture decreased by 29.5%, 25.6%, and 47.7%, respectively. Flaxseed enrichment could be made up to 15% without significant effect on hardness, cohesiveness, springiness, chewiness and specific volume of bread. As compared to the control treatment (0% flaxseed), the bread with 20% flaxseed enrichment showed significant increase of hardness and chewiness by 41.0%, and 21.34%, respectively, and the decrease of cohesiveness, springiness and specific volume by 10.4%, 2.1% and 11.0%, respectively. The firming rate of bread crumb at 4°C was faster than at 18°C. Flaxseed enrichment revealed the ability to retard bread crumb hardening during storage at both levels of temperature.

References

[1] K. Dewettinck, F. Van Bockstaele, B. Kühne, D. Van de Walle, T. M. Courtens, and X. Gellynck, "Nutritional value of bread: Influence of processing, food interaction and consumer perception," J. Cereal Sci., vol. 48, no. 2, pp. 243–257, Sep. 2008.

[2] P. Rayas-Duarte and E. S. Murtini, "Bread staling," in Breadmaking, 3rd ed., S. Cauvain, Ed. Elsevier, 2020, pp. 561–585.

[3] Y. A. Begum, S. Chakraborty, and S. C. Deka, "Bread fortified with dietary fibre extracted from culinary banana bract: its quality attributes and in vitro starch digestibility," Int. J. Food Sci. Technol., vol. 55, no. 6, pp. 2359–2369, Jun. 2020.

[4] J. K. Chavan, S. S. Kadam, and N. R. Reddy, "Nutritional enrichment of bakery products by supplementation with nonwheat flours," Crit. Rev. Food Sci. Nutr., vol. 33, no. 3, pp. 189–226, Jan. 1993.

[5] G. Zielinski and B. Rozema, "Review of fiber methods and applicability to fortified foods and supplements: choosing the correct method and interpreting results," Anal. Bioanal. Chem., vol. 405, no. 13, pp. 4359–4372, May 2013.

[6] M. K. Jarosław Wyrwisz, "The Application of Dietary Fiber in Bread Products," J. Food Process. Technol., vol. 06, no. 05, pp. 1–4, 2015.

[7] A. S. Sivam, D. Sun-Waterhouse, S. Quek, and C. O. Perera, "Properties of Bread Dough with Added Fiber Polysaccharides and Phenolic Antioxidants: A Review," J. Food Sci., vol. 75, no. 8, pp. R163–R174, Oct. 2010.

[8] G. G. Codină, A. M. Istrate, I. Gontariu, and S. Mironeasa, "Rheological properties of wheat-flaxseed composite flours assessed by mixolab and their relation to quality features," Foods, vol. 8, no. 8, p. 333, 2019.

[9] P. Marpalle, S. K. Sonawane, and S. S. Arya, "Effect of flaxseed flour addition on physicochemical and sensory properties of functional bread," LWT - Food Sci. Technol., vol. 58, no. 2, pp. 614–619, Oct. 2014.

[10] P. M. Ganorkar and R. K. Jain, "Flaxseed - A nutritional punch," Int. Food Res. J., vol. 20, no. 2, pp. 519–525, 2013.

[11] S. Mercier, S. Villeneuve, C. Moresoli, M. Mondor, B. Marcos, and K. A. Power, "Flaxseed-Enriched Cereal-Based Products: A Review of the Impact of Processing Conditions," Compr. Rev. Food Sci. Food Saf., vol. 13, no. 4, pp. 400–412, Jul. 2014.

[12] D. N. A. Zaidel, N. L. Chin, R. A. Rahman, and R. Karim, "Rheological characterisation of gluten from extensibility measurement," vol. 86, pp. 549–556, 2008.

[13] C. S. James, Analytical Chemistry of Foods, 1st ed. Boston, MA: Springer US, 1995.

[14] AACC Method 44-15A. Approved Methods of the AACC, 10th Edition, MN American Association of Cereal Chemists, St Paul. 2000.

[15] M. Avrami, "Kinetics of Phase Change. II Transformation-Time Relations for Random Distribution of Nuclei," J. Chem. Phys., vol. 8, no. 2, pp. 212–224, Feb. 1940.

[16] E. Armero and C. Collar, "Crumb Firming Kinetics of Wheat Breads with Anti-staling Additives," J. Cereal Sci., vol. 28, no. 2, pp. 165–174, Sep. 1998.

[17] F. Ronda and Y. H. Roos, "Staling of fresh and frozen gluten-free bread," J. Cereal Sci., vol. 53, no. 3, pp. 340–346, 2011.

[18] S. I. Koneva, E. Y. Egorova, L. A. Kozubaeva, S. S. Kuzmina, and A. S. Zakharova, "Influence of Flaxseed Flour on Dough Rheology from Wheat-Flaxseed Meal," in Advances in Engineering Research, 2018, vol. 151, pp. 370–377.

[19] Y. Xu, C. A. Hall III, and F. A. Manthey, "Effect of Flaxseed Flour on Rheological Properties of Wheat Flour Dough and on Bread Characteristics," J. Food Res., vol. 3, no. 6, pp. 83–91, Aug. 2014.

[20] E. Chiang, "How to Test Dough Extensibility and Why You Need To." https://bakerpedia.com/test-dough-extensibility-why-you-need-to/ (accessed Feb. 18, 2022).

[21] D. Rosada, "Dough strength: Evaluation and techniques. What's Rising?," Baking Institute Newsletter, San Francisco, 2004.

[22] F. D. Conforti and S. F. Davis, “The effect of soya flour and flaxseed as a partial replacement for bread flour in yeast bread,” Int. J. Food Sci. Technol., vol. 41, no. s2, pp. 95–101, Dec. 2006.

[23] A. Costa, A. C. Baraúna, R. L. Bertin, and L. B. B. Tavares, “Flaxseed flour addition on fatty acid profile and sensory properties of brazilian cheese roll,” Ciência e Agrotecnologia, vol. 36, no. 4, pp. 431–438, Aug. 2012.

[24] Ö. Menteş, E. Bakkalbaşşi, and R. Ercan, “Effect of the Use of Ground Flaxseed on Quality and Chemical Composition of Bread,” Food Sci. Technol. Int., vol. 14, no. 4, pp. 299–306, Aug. 2008.

[25] Y. Xu, C. Hall III, and C. Wolf-Hall, “Fungistatic Activity of Heat-Treated Flaxseed Determined by Response Surface Methodology,” J. Food Sci., vol. 73, no. 6, pp. M250–M256, Aug. 2008.

[26] Y. XU, C. HALLIII, C. WOLFHALL, and F. MANTHEY, “Fungistatic activity of flaxseed in potato dextrose agar and a fresh noodle system,” Int. J. Food Microbiol., vol. 121, no. 3, pp. 262–267, Feb. 2008.

[27] R. AB, S. SM, and S. RV, “Effect of Hydrocolloid (guar gum) Incorporation on the Quality Characteristics of Bread,” J. Food Process. Technol., vol. 03, no. 02, 2012.

[28] A. Wirkijowska, P. Zarzycki, A. Sobota, A. Nawrocka, A. Blicharz-Kania, and D. Andrejko, “The possibility of using by-products from the flaxseed industry for functional bread production,” LWT, vol. 118, no. January 2020, p. 108860, Jan. 2020.

[29] J. Wang, C. M. Rosell, and C. Benedito de Barber, “Effect of the addition of different fibres on wheat dough performance and bread quality,” Food Chem., vol. 79, no. 2, pp. 221–226, Nov. 2002.

[30] S. Gill, T. Vasanthan, B. Ooraikul, and B. Rossnagel, “Wheat Bread Quality as Influenced by the Substitution of Waxy and Regular Barley Flours in Their Native and Extruded Forms,” J. Cereal Sci., vol. 36, no. 2, pp. 219–237, Sep. 2002.

[31] G. Mazza, and C. G. Biliaderis, "Functional properties of flax seed mucilage," J. Food Sci., vol. 54, no. 5, pp. 1302–1305,1989.

[32] P. Kajla, A. Sharma, and D. R. Sood, “Flaxseed—a potential functional food source,” J. Food Sci. Technol., vol. 52, no. 4, pp.1857—1871, Apr.2015.

[33] C. G. Biliaderis, “Thermal analysis of food carbohydrates,” in Development in carbohydrate chemistry, R. Alexander and H. Zobel, Eds. New York: American Association of Cereal Chemist, 1992, pp. 168–220.

[34] P. D. Ribotta, A. E. León, and M. C. Añón, “Effect of freezing and frozen storage on the gelatinization and retrogradation of amylopectin in dough baked in a differential scanning calorimeter,” Food Res. Int., vol. 36, no. 4, pp. 357–363, 2003.