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Flaxseed Characteristics and Using Cake Mucilage in Pan Bread

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ABSTRACT

The main objective of this study was to evaluate the characteristics of flaxseed and to investigate the effects of using different levels of flaxseed cake mucilage (FCM) as a substitute for bread improver (0.5%, 1.0%, and 1.5%) or as a replacement for oil (33.33%, 66.66%, and 100%) on the sensory attributes, physical characteristics, color, texture profile, and freshness of pan bread. The results indicated that the Sakha 5 flaxseed variety had an oil content of approximately 33.37%, with linolenic acid as the primary fatty acid, comprising about 57.47% of the total. Flaxseed cake mucilage (FCM), extracted from the by-product of flaxseed oil production, is composed of natural and acidic sugars, and it exhibits excellent water-binding and rheological properties. Sensory evaluation data revealed that the complete replacement of bread improver with FCM at the 1.0% level enhanced the color, texture, taste, general appearance, and overall acceptability of the pan bread, compared to samples using FCM at 0.5% and 1.5% levels. Additionally, partial replacement of oil with FCM at the 66.66% level improved crumb color and texture without a significant difference in overall acceptability when compared to the control pan bread. The physical characteristics of the bread showed a reduction in volume and specific volume in samples containing FCM compared to the control. However, the inclusion of FCM in pan bread formulation delayed staling and improved freshness due to its ability to retain moisture in the crumb. In conclusion, FCM shows potential as a functional ingredient in pan bread production. Further studies are recommended to explore additional applications of FCM in various baked products.

1. Introduction

Flaxseed, *Linum usitatissimum L.*, is a versatile crop primarily cultivated for its fiber, oil, food, and animal feed. Its rising significance is attributed to its unique components, which have a wide range of applications, particularly in the production of functional foods (Elsorady, 2016; Hady and Elsorady, 2020; Mueed et al., 2022). The functional properties of flaxseed are closely linked to its chemical composition, including omega-3 fatty acids, lignans, and dietary fiber. These bioactive components are vital for enhancing the nutritional value of food products. For instance, α-linolenic acid, an essential omega-3 fatty acid, cannot be synthesized by the human body and must be obtained through diet. The food industry is increasingly focused on enhancing both the sensory and functional properties of foods to meet consumer demands (Elsorady, 2020).Flaxseed cake mucilage (FCM), derived from the by-product of flaxseed oil extraction, is known for its excellent water-binding capabilities. It has been successfully used in the food industry to enhance stability, increase viscosity, improve emulsifying ability, and provide desirable rheological and foaming properties (Mueed et al., 2022). FCM is extracted from flaxseed meal, a by-product of the oil industry, and consists of a complex polysaccharide mixture including xylose, arabinose, galactose, glucose, galacturonic acid, rhamnose, and fructose, along with

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associated proteins. It is easily obtained by soaking the meal in warm water, yielding a product with 50-80% carbohydrates and 4-20% proteins. Despite its beneficial properties, limited data on its detailed structure and functional characteristics have restricted its widespread use. FCM can act as a thickening agent, stabilizer, and water-holding component (Elsorady, 2016). When mixed with water, flaxseed mucilage forms a highly effective hydrocolloid gel. This gel is valuable not only in food products but also in pharmaceutical and cosmetic applications due to its high viscosity. FCM is made up of two types of polysaccharide fractions: acidic and neutral (Rocha et al., 2021). It constitutes about 8-10% of the total weight of the flaxseed, with its unique polysaccharide profile contributing to its health benefits as a soluble dietary fiber. FCM has been shown to help prevent chronic conditions such as diabetes, obesity, cardiovascular diseases, and colon cancer. It has been successfully incorporated into a variety of food products, including juices, dairy items, and flour-based goods (Bongartz et al., 2022). Flaxseed cake mucilage (FCM) is primarily composed of arabinoxylan (neutral polysaccharide) and pectic-like material (acidic polysaccharide). Due to its excellent water-binding capacity and rheological properties, FCM functions similarly to gum arabic and can be effectively used as a substitute ingredient in food products (Puligundla and Lim, 2022).

Baking is a major sector within the processed food industry. The widespread popularity of baked goods is attributed to their convenience, affordability, ready-to-eat nature, ease of transport, and diverse taste options. Pan bread, in particular, offers a valuable medium for delivering functional ingredients to consumers (Al-Hassawi et al., 2023). Bread is a staple food consumed worldwide, with an average daily intake of about 250 grams per person. In developing countries, bread consumption rates are even higher. The typical composition of bread includes 70-80% carbohydrates, 10-14% proteins, 0.7-1.35% fats, 2-3% dietary fiber, and 0.5-0.8% minerals (Makowska et al., 2023). Maintaining the freshness of bread is a priority for consumers, and various additives are used to enhance quality and delay staling (Al-Shammari et al., 2022). Bread staling is a complex process characterized by changes in bread quality, such as crust softening, crumb hardening, and loss of freshness (Curti et al., 2014). The primary factor contributing to staling is water migration within the bread matrix, which affects texture (Ding et al., 2019). Staling reduces consumer acceptability, as modern consumers demand high-quality and healthier bread products (Foschia et al., 2013; Vasileva et al., 2018). Recent trends in bread enhancement involve incorporating natural antioxidants and mucilage derived from herbs, fruits, and by-products of flaxseed oil extraction. Flaxseed cake mucilage, rich in phenolic compounds, has shown promise due to its effective water-binding properties, which help maintain bread freshness (Dziki et al., 2014; Mueed et al., 2022).

The present study aimed to evaluate the characteristics of flaxseed and to explore the potential use of FCM as a replacement for conventional bread improvers or oil in pan bread production. The effects of FCM on the sensory attributes, physical characteristics, and freshness of the produced pan bread were investigated to determine its suitability as a functional ingredient in baked products.

2. Materials and Methods

Materials

Golden flaxseed (Sakha 5 cultivar, season 2022-2023) (Figure 1) was sourced from the Sakha Agricultural Research Station, Sakha, Egypt. Wheat flour (72% extraction rate) was obtained from South Cairo Mills Company, Giza, Egypt. Other ingredients including corn oil, sugar (sucrose), bread improver, dry yeast, and salt (NaCl) were purchased from the local market in Giza, Egypt. Chemicals and reagents were supplied by Sigma Chemical Co. (St. Louis, USA) and El-Gomhoria Co. for Pharma-

Figure 1. (A): Golden flaxseed (Sakha 5 cv) (B): flaxseed cake

Proximate Composition of Flaxseed and FCM

Moisture, protein, oil, fiber, and ash contents of flaxseed, flaxseed cake and flaxseed cake mucilage (FCM) were determined according to the methods described by AOAC (2010). Carbohydrates were calculated by difference.

Extraction of Flaxseed Oil

Flaxseeds were pressed using a mechanical pressing method at room temperature. The extracted oil was filtered, stored in amber bottles, and kept at -18ºC until further analysis.

Chemical Characteristics of Flaxseed Oil

Free fatty acid (FFA) content, peroxide value (PV), conjugated dienes (CD), conjugated trienes (CT), and thiobarbituric acid (TBA) number were assessed following the AOAC (2010) protocols.

Fatty Acid Composition of Flaxseed Oil

Methylation of Fatty Acids

Approximately 10mg of saponified and acidified flaxseed oil was dissolved in 2mL of hexane. Then, 0.4 mL of 2N KOH in anhydrous methanol was added (Elsorady et al., 2022). After 3 minutes, 3 mL of water was added. The organic phase was separated via centrifugation, dried over anhydrous sodium sulfate, and concentrated under a nitrogen stream to approximately 0.5 mL for gas chromatography (GC) analysis of fatty acid methyl esters (FAME).

Fatty Acid Analysis

Fatty acid analysis was performed using an Agilent 6890 GC system equipped with a DB-23 column (60 m × 0.32 mm × 0.25 µm). The oven temperature program started at 150°C, ramping up to 195°C at 5°C/min, and then to 220°C at 10°C/min. The flow rate was maintained at 1.5mL/min. FAME standards were used as references for identification and quantification.

Extraction of Flaxseed Cake Mucilage (FCM)

Flaxseed cake mucilage (FCM) was extracted from the by-product of oil extraction using the method outlined by Elsorady et al. (2024). Briefly, the flaxseed cake was soaked in water at a ratio of 1:8 (w/w) at 90°C with continuous gentle stirring on a magnetic plate for 4 hours. The mixture was then filtered, and the water containing dissolved mucilage (Figure 2) was collected for further use in pan bread production.

Figure 2. Flaxseed cake mucilage solution (FCM)

Determination of Neutral and Acidic Sugars

Neutral and acidic sugar concentrations in FCM were measured using colorimetric assays as per Kaewmanee et al. (2014) at 480, 525 nm, respectively. Results were expressed as milligrams of D-xylose (neutral sugars) and D-galacturonic acid (acidic sugars) per milligram of mucilage powder.

Total Phenolic Content (TPC)

Total phenolic content was determined using the Folin–Ciocalteu reagent. Absorbance was measured at 725 nm with a UV–visible spectrophotometer (Hitachi U-3210, Hitachi, Ltd., Tokyo, Japan), following the method of Elsorady et al. (2024). Results were expressed in milligrams of gallic acid equivalent (GAE) per 100 grams of sample.

Lignans Extraction

Lignans were extracted from defatted flaxseed meal following the method of Zhang et al. (2007). Briefly, 200 grams of the defatted meal was mixed with 1.2 L of an ethanol-water solvent (50-100% v/v) and allowed to stand at room temperature for 24 hours. The mixture was then filtered using a sand core funnel and concentrated at 40°C using a rotary evaporator at 90 rpm. The concentrated syrup was hydrolyzed with 1M NaOH for 16 hours at room temperature. After hydrolysis, the syrup was acidified with 1M HCl to pH 6, cooled to 15°C, and centrifuged at 2000 rpm for 10 minutes. The precipitate was freeze-dried, and the lignan content was quantified using the following formula:

$$\text{Acquired ratio of lignans (\%)} = \frac{\text{Weight of freeze} - \text{dried lignans}}{\text{Weight of defatted flaxseed powder}} \times 100$$

Antioxidant activity

The antioxidant activity of flaxseed cake mucilage (FCM) was determined using the DPPH (1,1-Diphenyl-2-picrylhydrazyl) radical scavenging method. A DPPH solution (2.5 mL, 60 µM) in methanol (0.2 mL) was mixed with 3 mL of FCM powder solution (10 mg/L in MeOH). The mixture was kept in the dark at room temperature for 30 minutes. During this period, the deep violet DPPH solution is reduced to a yellow form, indicating scavenging of free radicals. The absorbance of a 200 µL aliquot from the reaction mixture was measured at 517 nm using a Hitachi U-3210 spectrophotometer (Hitachi, Ltd., Tokyo, Japan) as per El-sorady et al. (2024). The DPPH radical scavenging activity was calculated using the following formula: Where A_0 was the absorbance of the blank and A1 was the absorbance of the sample or standard. All analyses were performed in triplicate. The data were recorded as mean values.

$$\text{DPPH radical scavenging activity (\%)} = \frac{A_0 - A_1}{A_0} \times 100$$

Preparation of pan bread

The pan bread was prepared using a modified straight dough method based on AACC (2010). The formulation used was as follows:

- Wheat flour (72% extraction rate): 350 g
- Salt: 3.5 g
- Dry yeast: 5.25 g
- Sugar: 10.5 g
- Corn oil: 15.75 g
- Bread improver: 3.5 g
- Required amount of water

Various substitution levels for bread improver and oil using FCM were tested. However, samples where both bread improver and oil were replaced did not achieve satisfactory sensory evaluation results. The acceptable formulas are listed in Table 1. All dry ingredients were mixed thoroughly for 1 minute in a laboratory mixer, after which the liquid ingredients were added and mixed for an additional 6 minutes. The dough was rounded manually by folding, left to rest for 15 minutes, then cut and shaped into rolls. The rolls were placed in lightly greased metal baking pans and left to ferment in a cabinet at 37°C with 80-85% relative humidity for 60-90 minutes. The bread was baked for 25 minutes at 220 ± 8°C in an electric oven. The baked loaves were removed from the pans, cooled at room temperature (25 ± 2°C) for 60 minutes, and then packed in polyethylene bags for further analysis.

Table 1. Formulation of pan bread

Ingredients \ Sample No.	1	2	3	4	5	6	7
Wheat flour 72% (g)	350	350	350	350	350	350	350
FCM (ml)	-------	1.75	3.50	5.25	5.25	10.50	15.75
Corn oil (ml)	15.75	15.75	15.75	15.75	10.50	5.25	-------
Sugar (g)	10.50	10.50	10.50	10.50	10.50	10.50	10.50
Dry yeast (g)	5.25	5.25	5.25	5.25	5.25	5.25	5.25
Sodium chloride (g)	3.50	3.50	3.50	3.50	3.50	3.50	3.50
Bread improver (g)	3.50	-------	-------	-------	3.50	3.50	3.50
Water (ml)	190.00	187	180	173	183	179	175

Sensory Evaluation of Pan Bread

The sensory evaluation of the pan bread samples was conducted by a panel of ten trained staff members from the Food Technology Research Institute, Agricultural Research Center, Giza, Egypt. The samples were assessed for crust color, crumb color, texture, taste, flavor, general appearance, and overall acceptability following the method of Gelinas and Lachance (1995).

Physical Measurements of Pan Bread

- **Bread Loaf Weight:** Recorded after cooling for 1 hour.

- **Bread Loaf Volume:** Determined by the rapeseed displacement method as described by AACC (2010).
- **Specific Volume:** Calculated by dividing the volume (cm^3) by the weight (g).
- **Specific Gravity:** Determined by dividing the weight (g) by the volume (cm^3).
- **Moisture Content:** Measured in fresh baked bread samples.

Water Activity (aw)

Water activity (aw) of different pan bread samples was measured using a Rotronic Hygro Lab EA10-SCS water activity meter (Switzerland) according to El-Gohery, (2020) method. Each sample was analyzed in triplicate.

Texture Profile Analysis (TPA)

The texture profile analysis (TPA) of the pan bread was carried out using a CT3 Texture Analyzer (Version 2.1, Brookfield Engineering Laboratories, Inc., USA), according to method 74-09 (AACC, 2000). A 25 mm thick slice of bread was prepared, with the three end slices discarded, and the crusts left intact. A 36 mm diameter cylindrical probe was set up at a test speed of 2 mm/s. The testing location was the center of the bread slices, avoiding areas that were not representative of the crumb. The sample was subjected to 40% deformation with a trigger load of 5 g. Parameters including hardness (N or g), cohesiveness, gumminess (N), chewiness (mJ), and springiness (mm) were recorded. Each treatment was tested using three samples, and the results were averaged across these replicates.

Color measurements of pan bread

The crust and crumb color of the pan bread samples were assessed using a Chroma Meter (CR-400 model, Konica Minolta, Japan) according to Khan et al. (2020) method. The measurements were recorded in the CIE *L*, a*, b** color space:

- *L** indicates lightness (0 = black, 100 = white).
- *a** indicates the green-red spectrum (negative values = green, positive values = red).
- *b** indicates the blue-yellow spectrum (negative values = blue, positive values = yellow).

Each measurement was performed in triplicate, and the reported values represent the average.

Determination of staling rate

The staling rate of pan bread samples was monitored over storage periods of 0, 24, 48, and 72 hours at room temperature using the Alkaline Water Retention Capacity (AWRC) method, as described by Yamazaki (1953) and modified by Kitterman and Rubenthaler (1971). The AWRC was calculated using the following formula:

$$AWRC\ \% = [(W_2 - W_1)/ W_3] \times 100$$

W_1= Weight of empty tube (g), W_2= Weight of tube with sample after centrifugation (g), W_3= Weight of sample (g).

Statistical Analysis

The experimental data were statistically analyzed using SPSS software (Version 16.0). Descriptive statistics were used to determine means and standard deviations. One-way analysis of variance (ANOVA) was applied, followed by multiple range tests to compare the means. Statistical significance was defined at a level of $P \leq 0.05$

3. Results and Discussions

Chemical Composition of Flaxseed and Flaxseed Cake Mucilage (FCM)

The chemical compositions of the flaxseed (Sakha 5 cultivar) and flaxseed meal after oil extraction, as well as the characteristics of the extracted oil, were presented in Table 2. The results were consistent with those reported by Elsorady et al. (2022) for the same cultivar in a different season. The proximate composition of FCM revealed (Table 3):

- Moisture content: 5.14%
- Protein content: 8.76%
- Total carbohydrates: 78.22%

These findings align with those reported by Barbary et al. (2009) and Kaushik et al. (2017). The composition of FCM can vary based on factors such as flaxseed cultivar, extraction conditions, pH, and temperature (Wannerberger et al., 1991). The sugar composition analysis showed that neutral sugars were predominant (71%) compared to acidic sugars (25%), resulting in a neutral to acidic sugar ratio of 2.86. This result agrees with Kaewmanee et al. (2014). High temperature during extraction was found to negatively affect the monosaccharide content, possibly due to degradation of starch and proteins in the extracted gum (Barbary et al., 2009).

Table 2. Chemical composition of Sakha5 flaxseed, flaxseed cake, oil characteristics and fatty acid composition

Chemical composition		
	Flaxseed	Flaxseed cake
Moisture	6.75±0.10	6.11±0.08
Crude oil	33.37±0.15	8.93±0.06
Crude protein	18.34±0.17	36.10±0.13
Fiber	11.38±0.16	18.49±0.17
Ash	3.31±0.02	3.18±0.02
Carbohydrates	26.83±0.42	27.17±0.02
Oil characteristics		
Free fatty acid (% as oleic acid)	0.21±0.01	
Peroxide value (meq O2/kg oil)	1.64±0.01	
Conjugated dienes (CD)	1.66±0.01	
Conjugated trienes (CT)	0.20±0.00	
TBA number (mg malonaldehyde/kg oil)	0.33±0.02	
Fatty acid composition		
Myristic acid ($C_{14:0}$)	0.02	
Palmitic acid ($C_{16:0}$)	5.42	
Palmitoleic acid ($C_{16:1}$)	0.21	
Margaric acid ($C_{17:0}$)	0.03	
Heptadecenoic acid ($C_{17:1}$)	0.06	
Stearic acid ($C_{18:0}$)	3.52	
Oleic acid ($C_{18:1}$)	15.65	
Linoleic acid ($C_{18:2}$)	17.32	
Linolenic acid ($C_{18:3}$)	57.47	
Arachidic acid ($C_{20:0}$)	0.10	
Eicosenoic acid ($C_{20:1}$)	0.11	
Behenic acid ($C_{22:0}$)	0.09	
Saturated fatty acids (SFA)	9.18	
Unsaturated fatty acids (USFA)	90.82	

Table 3. Chemical composition of flaxseed-cake mucilage on dry weight basis

Moisture (%)	5.14±0.10
Oil (%)	0.75±0.04
Protein (%)	8.76±0.19
Fiber (%)	6.21±0.10
Ash (%)	0.90±0.04
Carbohydrates	78.22±0.14
Neutral sugar g/g	0.71±0.07
Acidic sugar g/g	0.25±0.04
Natural/acidic sugar	2.86± 0.18

Bioactive Compounds and Antioxidant Activity of FCM

The total phenolic content of FCM was 15.60 mg GAE/100 g, while the lignan content was 2.05%. The antioxidant activity was measured at 5.97% (Table 4). These results are consistent with those reported by Elsorady et al. (2024). The positive correlation between antioxidant activity and phenolic content is well-documented in the literature (Rajurkar and Hande, 2011; Seçzyk et al., 2017). Lignans, which are co-extracted with FCM, are known to contribute to its antioxidant properties.

Table 4. Bioactive components and antioxidant activity of FCM

Total phenols (mg GAE/100 g)	15.60±0.31
Lignans (%)	2.05±0.05
Antioxidant activity (%)	5.97±0.12

Sensory Evaluation of Pan Bread

Sensory evaluation results for the pan bread samples are shown in Table 5 and Figure 3. The evaluation included parameters such as crust color, crumb color, texture, taste, flavor, general appearance, and overall acceptability. The following observations were made:

Sample No. 3 (bread improver replaced with 1% FCM) received higher scores for crumb color, texture, taste, flavor, general appearance, and overall acceptability compared to samples where bread improver was replaced with 0.5% or 1.5% FCM (samples No. 2 and 4).

The control sample (No. 1) scored the highest in terms of texture, taste, flavor, general appearance, and overall acceptability compared to all samples where the bread improver was replaced with FCM.

The data in Table 5 also showed that the crust and crumb color, as well as the texture of the bread sample produced by replacing 66.66% of the oil with FCM (sample No. 6), had higher scores than the control sample. No significant difference (P≤0.05) was observed in overall acceptability between sample No. 6 and the control sample. The results indicate that the incorporation of FCM as a substitute for bread improver (at 1% replacement level) or oil (at 66.66% replacement level) produces pan bread with acceptable sensory characteristics. These formulations exhibited good quality in terms of crumb color, texture, and overall acceptability, making FCM a promising ingredient for improving the functionality of pan bread without compromising consumer acceptability.

Table 5. Sensory evaluation of pan bread samples

Pan bread samples	Crust Color (10)	Crumb Color (10)	Texture (20)	Taste (20)	Flavor (20)	General Appearance (20)	Overall Acceptability (100)
1	8.60^b±0.98	8.65^b±0.84	18.15^a±1.54	18.35^a±0.94	18.75^a±1.03	18.60^a±1.29	91.10^a±4.78
Bread improver replacement							
2	8.52^c±1.29	8.50^b±1.03	17.20^c±2.78	17.75^c±2.45	18.43^b±1.69	17.40^d±1.99	87.82^d±7.65
3	8.85^a±1.11	9.02^a±1.03	17.86^b±2.20	17.97^b±1.71	17.96^c±2.13	18.50^b±1.59	90.65^b±7.21
4	8.85^a±0.75	8.50^b±0.97	17.80^b±1.38	17.75^c±0.98	17.95^c±1.42	18.25^c±1.27	89.10^c±3.86
Fat replacement							
5	8.53^b±1.63	8.60^b±1.29	17.53^c±2.81	17.85^c±2.06	18.15^b±1.56	17.55^c±2.01	88.21^b±6.99
6	8.70^a±1.07	8.90^a±0.74	18.25^a±2.09	18.05^b±1.67	18.20^b±1.55	17.95^b±1.69	90.05^a±5.23
7	8.73^a±1.29	8.85^a±1.03	18.15^b±2.78	16.85^d±2.45	17.89^c±1.69	17.80^b±1.99	88.27^b±7.65

In which: 1= Control pan bread, 2 =with 0.5% bread improver replacement, 3=with 1.00 % bread improver replacement, 4=with 1.50% bread improver replacement, 5=with 33.33% oil replacement, 6=with 66.66% oil replacement, 7 =with100% oil replacement, Values are means of ten replicates ± standard deviation, number in the same column followed by the same letter are not significantly different at 0.05 levels.

Figure 3. Pan Bread samples

Physical Properties, Moisture Content, and Water Activity of Pan Bread Samples Containing FCM

Table 6 presents the physical properties, moisture content, and water activity of the pan bread samples. Loaf weights ranged from 156.83 g (Sample 1) to 159.44 g (Sample 6). Replacing bread improver or oil with FCM in the bread formulation resulted in increased loaf weights, likely due to FCM's high water-binding capacity (Mueed et al., 2022). Consistent with this, the moisture content of the control sample (29.19%) was lower than that of samples containing FCM, with Sample 6 exhibiting the highest moisture content (30.27%).

Specific volume, a crucial parameter for consumer acceptability, reflects the ratio of volume to weight (Hager et al., 2012). Both loaf volume and specific volume decreased in FCM-containing samples compared to the control. This reduction may be attributed to the sugar and soluble fiber content of FCM, which can disrupt gluten formation (Ragaee et al., 2011). However, specific gravity remained relatively consistent across all samples.

The water activity (aw) of the pan bread samples ranged from 0.883 to 0.908.

Table 6. Physical properties, moisture content and water activity of pan bread samples

Pan bread samples	Loaf weight (g)	Loaf Volume (cm^3)	Loaf Specific volume (cm^3/g)	Specific Gravity (g/cm^3)	Moisture content (%)	Water Activity (aw)
1	$156.83^{b}\pm0.07$	$480.00^{a}\pm0.04$	$3.06^{a}\pm0.02$	$0.33^{a}\pm0.01$	$29.19^{b}\pm0.08$	$0.908^{a}\pm0.002$
3	$158.10^{a}\pm0.03$	$465.50^{c}\pm0.05$	$2.94^{b}\pm0.07$	$0.34^{a}\pm0.02$	$29.36^{b}\pm0.04$	$0.883^{b}\pm0.007$
6	$159.44^{a}\pm0.05$	$470.00^{b}\pm0.07$	$2.95^{b}\pm0.03$	$0.34^{a}\pm0.04$	$30.27^{a}\pm0.07$	$0.906^{a}\pm0.003$

In which: 1= Control pan bread, 3=with 1.00 % bread improver replacement, 6=with 66.66% oil replacement
Values are means of three replicates ± standard deviation, number in the same column followed by the same letter are not significantly different at 0.05 level.

Color Analysis of Crust and Crumb in Pan Bread Samples Containing FCM

Color is a primary factor influencing consumer perception. Table 7 presents the L, a, and b color values for the crust and crumb of the pan bread samples. For the crust, *L, a,* and *b* values ranged from 55.05 to 56.92, 11.47 to 12.08, and 27.05 to 29.64, respectively. For the crumb, the corresponding ranges were 73.06 to 75.11, -0.40 to -0.54, and 16.85 to 17.07. Replacing bread improver or oil with FCM significantly increased the lightness (L) values of both the crust and crumb. The a values of the crust and crumb were higher for the control sample, with significant differences observed compared to other samples, except for Sample 3 in the case of crumb color. No significant differences were observed in the b values of the crumb between the control and other samples.

Table 7. Color values of pan bread samples

Pan bread samples	Crust color			Crumb color		
	L	a	b	L	a	b
1	$55.05^{c}\pm0.05$	$12.08^{a}\pm0.05$	$27.05^{c}\pm0.02$	$73.06^{c}\pm0.01$	$-0.40^{a}\pm0.02$	$16.85^{a}\pm0.06$
3	$55.31^{b}\pm0.02$	$11.52^{b}\pm0.02$	$28.06^{b}\pm0.05$	$74.26^{b}\pm0.02$	$-0.48^{a}\pm0.01$	$17.07^{a}\pm0.02$
6	$56.92^{a}\pm0.04$	$11.47^{b}\pm0.03$	$29.64^{a}\pm0.01$	$75.11^{a}\pm0.04$	$-0.54^{b}\pm0.04$	$17.01^{a}\pm0.04$

In which: 1= Control pan bread, 3=with 1.00 % bread improver replacement, 6=with 66.66% oil replacement
L: The lightness (L=100 for lightness, L= Zero for darkness), a value are measures of redness (+) or greenness (-), b value are measures of yellowness (+) or blueness (-).
Values are means of three replicates ± standard deviation, number in the same column followed by the same letter are not significantly different at 0.05 level.

Texture Profile of Pan Bread Samples Containing FCM

Table 8 presents the texture profile (hardness, chewiness, gumminess, cohesiveness, and springiness) of the pan bread samples. Pan breads containing FCM exhibited lower hardness values compared to the control sample. Lower hardness is generally preferred by consumers as it is associated with freshness (Heitmann et al., 2015). A positive correlation was observed between chewiness and hardness, consistent with findings by Ibrahim (2011) and Nassar et al. (2017).

Gumminess and cohesiveness values were significantly higher in samples containing FCM (Samples 3 and 6). This could be attributed to the water-binding and rheological properties of FCM.

Conversely, the control sample exhibited the highest springiness, which aligns with its higher volume (Table 6).

Table 8. Texture profile of pan bread samples

Pan bread samples	Hardness	Chewiness	Gumminess	Cohesiveness	Springiness
1	20.05^{a}±0.02	68.10^{a}±0.06	10.18^{b}±0.04	0.50^{b}±0.01	6.30^{a}±0.03
3	17.16^{c}±0.05	51.80^{b}±0.01	10.86^{a}±0.03	0.72^{a}±0.04	4.77^{c}±0.02
6	17.33^{b}±0.03	51.80^{b}±0.02	10.81^{a}±0.06	0.73^{a}±0.03	5.09^{b}±0.01

In which: 1= Control pan bread, 3=with 1.00 % bread improver replacement, 6=with 66.66% oil replacement
Values are means of three replicates ± standard deviation, number in the same column followed by the same letter are not significantly different at 0.05 level.

Alkaline Water Retention Capacity (AWRC) of Pan Bread Samples Containing FCM at Different Storage Times

Alkaline Water Retention Capacity (AWRC) is a measure of starch retrogradation, a process linked to bread staling (Fadda et al., 2014). Higher AWRC values indicate greater starch gelatinization and improved bread freshness, while lower values are associated with increased starch crystallization and accelerated staling (Licciardello et al., 2014). Table 9 presents the AWRC of pan bread samples containing FCM at different storage times (0, 24, 48, and 72 hours). Results showed that replacing bread improver or oil with FCM significantly increased AWRC compared to the control sample. Additionally, AWRC decreased significantly with increasing storage time.

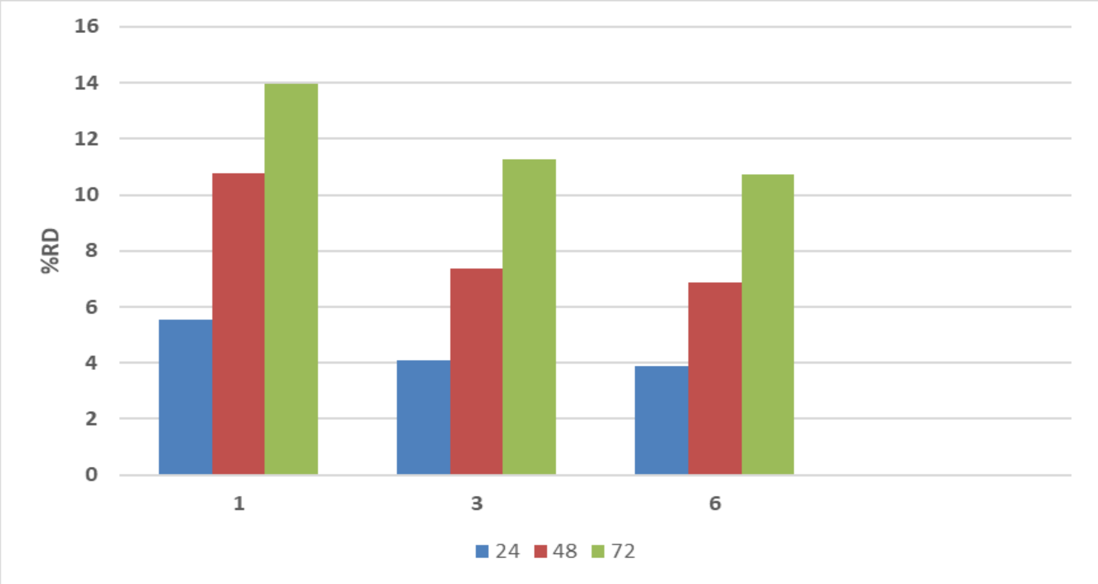
Table 9. Alkaline water retention capacity (AWRC) of pan bread samples

Pan bread samples	Storage time (h)						
	Zero	24	*RD%	48	*RD%	72	*RD%
1	398.82^{c}±0.10	376.78^{c}±0.14	5.53	355.79^{c}±0.12	10.79	343.16^{c}±0.16	13.96
3	403.85^{b}±0.14	387.27^{b}±0.11	4.11	374.08^{b}±0.15	7.37	358.40^{b}±0.13	11.25
6	406.90^{a}±0.12	391.08^{a}±0.15	3.89	378.98^{a}±0.11	6.86	363.22^{a}±0.10	10.73

In which: 1= Control pan bread, 3=with 1.00 % bread improver replacement, 6=with 66.66% oil replacement
*RD (%) = Reduction of freshness, Reduction of freshness = (AWRC in zero time - AWRC in n time / AWRC zero time) × 100
Where n = time of storage.
Values are means of three replicates ± standard deviation, number in the same column followed by the same letter are not significantly different at 0.05 level.

Reduction in Freshness and Staling of Pan Bread

Figure 4 illustrates the reduction in freshness (RD%) of pan bread samples over 72 hours of storage. Sample 6 exhibited the lowest RD%, while the control sample (Sample 1) showed the highest RD%. This can be attributed to the water-binding properties of FCM, which help retain moisture and delay staling. A strong correlation exists between bread staling and moisture content, with higher moisture levels associated with increased freshness (Piazza and Masi, 1995).



Figrue 4. Reduction of freshness in pan breads during storage for 72 hours

Reduction of freshness (RD %) = (AWRC in zero time - AWRC in n time / AWRC zero time) × 100,
Where n = time of storage

4. Conclusion

Flaxseed cake mucilage (FCM) can be effectively used to replace bread improver up to 1% and oil up to 66.66% in pan bread formulations, resulting in acceptable product quality. The incorporation of FCM into pan bread can delay staling, enhance freshness, and reduce reliance on oil.

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