Rheology, fatty acid profile and storage characteristics of cookies as influenced by flax seed (*Linum usitatissimum*)

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Abstract Flaxseed is a versatile functional ingredient owing to its unique nutrient profile. Studies on the effect of substitution of roasted and ground flaxseed (RGF) at 5, 10, 15 and 20% level on the wheat flour dough properties showed that amylograph peak viscosity, farinograph dough stability, extensograph resistance to extension and extensibility values decreased with the increase in the substitution of RGF from 0–20%. The cookie baking test showed a marginal decrease in spread ratio but beyond substitution of 15% RGF the texture and flavour of the cookies was adversely affected. The data on storage characteristics of control and cookies with 15% RGF showed no significant change with respect to acidity of extracted fat and peroxide values due to storage of cookies upto 90 days in metallised polyester pouches at ambient conditions. The gas chromatographic analysis of fatty acid profile indicated that the control cookies contained negligible linolenic acid and the flaxseed cookies contained 4.75 to 5.31% of linolenic acid which showed a marginal decrease over storage. Hence flaxseed could be used as a source of omega-3 fatty acid.

Keywords Cookies · Fatty acids · Flaxseed · Gas chromatography · Rheology · Storage

Introduction

The food industry is facing the challenge of developing new food products with special health enhancing characteristics.

The nutraceuticals come from a wide variety of plant consumable products (Lee et al. 2004). Functional foods are targeted to provide selective protection against some of the most common disease risks such as cardiovascular diseases, cancers, digestive disorders and other disorders associated with lack of adequate nutrients (Oomah and Mazza 1998; Tripathy et al. 2003; Jisha et al. 2009). Flaxseed (*Linum usitatissimum*) has recently gained attention as a functional food because of its unique nutrient profile (EPFSN 1998). Flaxseed has been consumed throughout the world and today flaxseed is recognized as a good source of soluble fibre which helps to lower blood cholesterol, insoluble fibre which promotes laxation, α -linolenic acid an essential omega-3 fatty acid important for cardiovascular health and phytoestrogens with estrogen like activity (Payne 2000). 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 about 16% of total fatty acids, α -linolenic acid about 57% (Morris 2001).

Ground or whole flaxseed can be added to almost any baked product to add a nutty flavour to bread, waffles, pancakes and other products. Flaxseed flour is used commercially in breads in the United States, in muffin, cookie and other mixes (Carter 1993). Studies on the use of flaxseed in the bakery products have been reported (Alpers and Sawyer-Morse 1996; Ramcharitar et al. 2005; Alpaslan and Hayta 2006). The cause of concern is the presence of natural toxicant cyanogenic glycosides in flaxseed. Cunannane and Thompson (1995) reported that total cyanogenic glycoside content measured as hydrocyanic acid (HCN), decreased from 20.8 to 1.0 mg (HCN/100 g seeds) when flaxseed was roasted at 120° C three times. They also stated that bread and bakery mixes containing about 10% flaxseed, had relatively low levels

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of linustatin and traces of linamarin. Flaxseed is not consumed as part of the regular diet in India. Hence, the study was carried out with the objective of using flaxseed as a functional ingredient in cookies, its effect on the rheological properties of wheat flour and also to study the fatty acid profile of flaxseed cookies during storage.

Materials and methods

Wheat flour Commercial wheat flour obtained from the local market was used for the studies. The characteristics of the flour such as moisture (method 44–16), ash (method 08-01), dry gluten (method 38-10), falling number (method 56-81B) SDS sedimentation value (method 56–70) were determined using the methods of AACC (2000).

Flaxseed Flaxseed was procured from the local market. The flaxseeds were roasted in an oven at 180°C for 13 min to get a nutty flavour. The roasted flaxseeds were coarsely ground and sieved through 500 μ sieve. The flaxseed analysis comprising determination of ash (08-01) and proteins (56-81B) were carried out as per AACC method. The fat was extracted in a Soxhlet apparatus using petroleum ether.

Ingredients Marvo brand shortening (Hindustan Lever Ltd., Mumbai, India), Sugar powder procured from local market, vanilla essence (Bush Boake Allen Ltd., Chennai, India) were used in the studies.

Rheological characteristics Effect of replacement of wheat flour with 0, 5, 10, 15 and 20% RGF on amylograph (Model No. 803201, Duisburg, Germany), farinograph (Model No. 810108004, Duisburg, Germany), and extenso-graph (Model No. 996035, Duisburg, Germany) characteristics were studied using standard AACC methods (2000).

Preparation of cookies Cookies were prepared using blends or wheat flour–RGF in the ratio of 100:0, 95:5, 90:10, 85:15 and 80:20 w/w, sugar powder (50 g), shortening (60 g), vanilla (0.3 g) and water (8 ml). The sugar powder, shortening and essence were creamed together in a Hobart N–50 mixer (Ontario, Canada) at 173 rpm for 5 min. Then water was added and mixed for 1 min at 58 rpm and 2 min at 173 rpm. Finally flour was added and mixed for 2 min at 58 rpm followed by addition of RGF and mixing for 2 min at 58 rpm. The cookie dough was sheeted to 10 mm thickness and cut into circular shape using 5 cm diameter cutter. The cookies were then baked at 180°C for 16–17 min. The cookies were thoroughly cooled and packed in metallised polyester pouches.

Evaluation of cookies

1. **Physical characteristics:** The control and cookies with 5, 10, 15 and 20% RGF were analyzed for physical parameters such as weight, diameter (D), thickness (T) and spread ratio (diameter / thickness). Four cookies were analyzed for the above parameters and averages of four values are presented.
2. **Sensory characteristics:** Sensory evaluation was carried out by a panel of six judges with over 10 years of experience in the field of baking science and technology. Sensory analysis of control and flaxseed cookies was conducted for various sensory parameters by assigning scores for surface colour: 1 = dark brown, 10 = golden brown; surface characteristics: 1 = rough surface, 10 = smooth surface; texture: 1 = hard / brittle, 10 = crisp; flavour: 1 = foreign / bland; 10 = pleasant nutty; mouthfeel: 1 = very gritty, 10 = clean mouthfeel / no residue. The overall quality score (50) is the combined score of all the above parameters.
3. **Texture measurement:** The breaking strength of the cookies was measured by following triple beam snap technique using texture analyser (Model Tahdi, Stable Microsystems, UK) according to the method of Gaines (1991). The sample was rested on two supporting beams spread at a distance of 3 cm. Another beam connected to moving part was brought down to break the biscuits at a crosshead speed of 10 mm/min and load cell of 10 kg. Care was taken to see that the point of contact was equivalent from both the supporting beams. The peak force (g) at break, representing breaking strength was recorded and mean values of triplicates are expressed.
- 3a. **Storage studies:** Quality evaluation of cookies at 0, 30, 60 and 90 days of storage (stored at ambient temperature 26–28°C) for moisture, acidity of extracted fat and peroxide value were carried out as per ISI methods (IS: 1011-1981).
- 3b. **Fatty acid analysis by gas chromatography:** The lipid fractions were converted to methyl esters as per the method of Morrison and Smith (1963). The relative percentage of Fatty acids were analysed by gas chromatography (GC) as their methyl esters. GC was carried out for the methyl esters of control and flaxseed cookies at 0, 30, 60 and 90 days of storage. GC was performed with a gas liquid chromatography (Shimadzu, Model No. 15 A, Japan) equipped with a flame ionization detector, using 0.5 mm id $\times$ 10 ft column packed with 12.5% Diethylene glycol succinate (DEGS) on 60/80 mesh chromosorb column, temperature 180°C with a temperature programming of

injection to 220°C and detection at 250°C. Flow rates of nitrogen (carrier gas), hydrogen and air were kept at 40 ml/min. respectively. Peaks were identified by comparing their retention times with those of authentic reference standards (Sigma, U.S.A.). The peaks were integrated by a computing integrator. Figures reported are percent of individual peaks. Duplicates were run for each sample and the average values are reported.

Statistical analysis The data were statistically analysed using Duncan's New Multiple Range Test with different experimental groups appropriate to the completely randomized design with triplicates each as described by Steel and Torrie (1960). The significant level was established at $P \leq 0.05$.

Results and discussion

The wheat flour had 0.5% ash, 7.5% dry gluten, 19 ml Zeleny's sedimentation value and 8% protein. The flaxseed had 4% ash, 39% fat and 24.8% protein.

Effect of RGF on amylograph characteristics of wheat flour The data on the effect of substitution of wheat flour with 0–20% RGF on amylograph characteristics of wheat flour is presented in Fig. 1. The pasting temperature of control was 65.3°C and it varied from 64.7–65.6°C with different levels RGF. The peak viscosity, hot paste viscosity, cold paste viscosity, set back and break down values decreased, as the level of RGF increased. The effect of replacement of wheat flour at 25% level with oilseed flours, peanut (raw and roasted), sunflower seed and full fat soy on the amylograph characteristics was studied by

Mathews et al. (1970). They reported that the peak viscosity, hot paste viscosity and cold paste viscosity decreased with the replacement of oilseed flours when compared with the value of the control wheat flour. Our results are also in line with their observation. Mathews et al. (1970) opined that the variations in viscosity during prolonged heating can reflect enzyme activity and starch properties of the various oilseeds in combination with wheat flour. Carter (1993) reported that flaxseed gum has been shown to enhance viscosity and affect shear rate similar to gum Arabic. Gum like behaviour of ground flaxseed is observed in baking of cookies and muffins. Mazza and Biliaderis (1989) found that solubility, foamability, rheological properties and chemical properties of flaxseed gum resemble those of gum arabic. Ashwini et al. (2009) observed a decrease in peak viscosity and cold paste viscosity of wheat flour with the use of arabic gum. Funami et al. (2005) stated that a decrease in peak viscosity is caused by a reduced amylose leaching prevailed over the increase in viscosity due to gums present in the continuous phase. According to Christianson et al. (1981), gums affect gelatinization and retrogradation of starch through strong association of amylose with gum resulting in a decrease in retrogradation of starch. According to Lee et al. (2002) the increase in breakdown is due to the starch granules becoming less resistant to thermal front and mechanical shearing which means the morphological changes of the starch granules involving a radial expansion of the granules to rupture, were altered by the interaction with hydrocolloids. Payne (2000) reported a total dietary fiber content of 24.5 g per 100 g in flaxseed. Rao and Rao (1991) reported that amylograph peak viscosity gradually decreased when 50% wheat bran was incorporated possibly due to decrease in total starch content. Symons and Brennan (2004) studied the substitution of wheat starch with barley β -glucan fiber fractions at 5% level and reported a decrease in peak viscosity and break down

Fig. 1 Effect of RGF (roasted and ground flaxseed) on amylograph characteristics of wheat flour. PV: Peak Viscosity; HPV: Hot Paste Viscosity; CPV: Cold Paste Viscosity; SB: Set Back; BD: Break Down

values. They stated that these lower values are an indication of a reduction in starch available for gelatinization. This reduction is likely because of water being held from the starch granules by β -glucan and general reduction in starch content of pastes because of replacement of barley glucan fiber.

Effect of RGF addition on the farinograph and extensograph characteristics of wheat flour Effect of substitution of 5, 10, 15 and 20% RGF on the farinograph, and extensograph characteristics of wheat flour is presented in Table 1 and Fig. 2.

The data on the farinograph characteristics showed that with the increase in the level of RGF from 0–20%, the water absorption and dough development time increased whereas dough stability values decreased. Mathews et al. (1970) reported that adding oilseed flours such as cottonseed, peanut, sunflower seed to wheat flour increased water absorption and decreased mixing tolerance of doughs. They also added that narrow farinograph band width at higher levels of replacement showed poor dough stability. Zhang and Moore (1997) studied the effect of different wheat bran particle sizes (609, 415 and 278 μ m) on bread dough rheological properties at replacement level of 0, 50, 100 and 150 g/kg and they reported that there was a decrease in mixing stability. Dervas et al. (1999) stated that the lupin flour at 5% substitution level increased stability and tolerance index of the dough, while a marked weakening was noted at higher levels (15%) of supplementation. Dough mixing studies showed that inclusion of lupin flour blends delayed farinograph arrival time and decreased dough stability when substituted for wheat flour.

The extensograph characteristics with 0–20% RGF showed that resistance to extension, extensibility and area values decreased with the increase in the level of RGF (Fig. 2). Mathews et al. (1970) stated that dough extensibility decreased when wheat flour was replaced with oilseed flour. Dervas et al. (1999) stated that the extensibility decreased as the substituted level of lupin flour increased from 5–15%. They attributed this to the dilution

Table 1 Effect of addition of RGF^a on the farinograph characteristics of wheat flour

RGF (%)	Water absorption (%)	Dough development time (min)	Dough stability (min)
0	59.5	3.0	6.8
5	60.0	4.5	6.3
10	60.8	5.0	5.5
15	61.2	5.5	5.0
20	62.0	6.5	4.0

^a Roasted and ground flaxseed

Fig. 2 Effect of RGF (roasted and ground flaxseed) on extensograph characteristics of wheat flour

of the wheat gluten structure by the added protein. Sudha et al. (2007) also reported that the resistance to extension values gradually increased, extensibility values reduced and area under the curve decreased with the increase in the level of bran in the blends.

Effect of RGF on the quality characteristics of cookies The data on the effect of substitution of RGF on the physical and sensory characteristics of cookies is presented in Tables 2 and 3. The data indicated that there was a decrease in the diameter of cookies as the level of RGF increased. The spread ratio also showed a similar trend. The spread ratio of the control was 9.2 whereas the spread ratio of cookie with 20% RGF was 8.3. The breaking strength increased with the increase in the level of RGF (Table 2). The sensory characteristics of cookies showed that the surface colour, surface characteristics, texture, flavour and mouthfeel were adversely affected beyond 15% level of RGF. The total score showed a decrease with the increase in the level of RGF. The total score was 45 out of 50 for control cookies whereas it ranged from 43.5–34 out of 50 for cookies with 5–20% RGF (Table 3). The cookies with 20% RGF had

Table 2 Effect of RGF^a on the physical characteristics of cookies

RGF (%)	Diameter (cm)	Thickness (cm)	Spread ratio (D/T)	Breaking strength (g)
0	9.2 a	1.0 a	9.2 a	1300 a
5	9.1 a	1.0 a	9.1 c	1330 a
10	8.8 b	1.0 a	8.8 b	1345 b
15	8.6 b	1.0 a	8.6 c	1370 c
20	8.3 c	1.0 b	8.3 d	1420 d
SEM ^b ($\pm$)	0.03	0.05	0.02	10

^a Roasted and ground flaxseed

SEM^b Standard error of means ($n=15$)

Means in the same column followed by different letters differ significantly $P \leq 0.05$

Table 3 Effect of RGF^a on the sensory characteristics of cookies

RGF (%)	Surface colour (10)	Surface character (10)	Texture (10)	Flavour (10)	Mouthfeel (10)	Total score (50)
0	9.0 a	9.0 a	9.0 a	9.0 a	9.0 a	45.0 a
5	8.5 b	8.5 b	9.0 a	8.5 b	9.0 a	43.5 b
10	8.5 b	8.5 b	8.0 b	8.0 b	8.0 b	41.0 bc
15	8.0 b	8.5 b	7.5 b	7.5 b	7.5 b	39.0 c
20	7.5 c	7.5 c	6.5 c	6.5 c	6.0 c	34.0 d
SEM ^b (±)	0.04	0.03	0.02	0.03	0.04	0.35

^a Roasted and ground flaxseedSEM^b Standard error of means ($n=15$)Means in the same column followed by different letters differ significantly $P \leq 0.05$

brownish colour, rough surface, hard texture, dominating foreign flavour, gritty mouthfeel and had the lowest total score (34) and the quality characteristics were affected. Increased hardness in texture of cookies with 20% RGF could be due to the higher content of fibre in flaxseed. These results indicate that RGF substitution at 15% level is optimum. Wills et al. (1984) prepared protein-enriched biscuits with sunflower seed meal and protein isolates. The biscuits containing less than 17.5% sunflower proteins were acceptable. Tyagi et al. (2007) studied the nutritional, sensory and textural characteristics of biscuits prepared by incorporating defatted mustard flour at 5, 10, 15 and 20% levels. They reported that the textural characteristics of biscuits upto 15% of defatted mustard flour were almost similar, but at 20% level the values were significantly different and they recommended use of 15% defatted mustard flour to achieve desirable results. Sugar cookies were prepared with 10, 20 or 30% defatted peanut flours substituted for wheat flour without adversely affecting dough handling, diameter, height, spread and sensory quality. The cookies with 30% peanut flour contained protein twice that of the 100% wheat flour cookies (McWatters 1978).

Storage characteristics of cookies with RGF The control and cookies with 15% RGF were evaluated at 0, 30, 60 and 90 days of storage by determining the moisture, fat acidity, peroxide value, texture and sensory quality. The results (Table 4) showed that there was no significant change in the moisture content of cookies. Also, the changes in the acidity of the extracted fat was insignificant. However, there was some increase in the peroxide value of the control and flaxseed cookies. Cunannane and Thompson (1995) reported that flaxseed either whole or coarsely ground, appears stable to long-term storage at room temperature. Even after 308 days at 22°C there was essentially no change in peroxide value as a measure of oxidation by-products or in the percentage of α -linolenic acid in fat extracted from the stored flaxseed samples. The breaking strength of the control cookies ranged from 1300–1315 g during the 0–90 days of storage whereas the texture of the flaxseed cookies showed slight loss of crispness as shown by the decrease in breaking strength values from 1330 to 1285 g.

Fatty acid profile of flaxseed cookies during storage The data reported represents the relative percentage of fatty

Table 4 Storage characteristics^a of cookies with 15% RGF^b

Cookies	No. of days	Moisture (%)	Fat acidity (%)	Peroxide value (M Eq O ₂ / kg fat)	Breaking strength (g)	Total score ^c (50)
Control	0	1.32	0.38	12.0	1300	45
	30	1.26	0.51	12.9	1320	45
	60	1.34	0.54	13.9	1330	44
	90	1.23	0.54	14.7	1315	43
RGF (15%)	0	1.14	0.41	12.3	1370	39
	30	1.20	0.52	12.7	1360	39
	60	1.13	0.72	15.9	1340	41
	90	1.24	0.77	18.3	1290	40

^a Average of 4 readings^b Roasted and ground flaxseed^c Total score is the combined score of surface colour (10), surface character (10), texture (10), flavour (10) and mouthfeel (10)

acids. The data on the fatty acid profile of the control and flaxseed cookies with 15% RGF showed that there was an increase in the saturated fatty acids i.e. palmitic, stearic and oleic acids during the storage (Fig. 3a). The control cookies did not have any linolenic acid whereas the flaxseed cookies had linolenic acid content varying between 4.75–5.31% (Fig. 3b). Also, there was a marginal decrease in linolenic acid content upon storage. Vicario and Viviana (2003) reported a higher content of saturated fatty acid i.e. palmitic, stearic and oleic acids in butter cookies. Also, palmitic and oleic acid content were dominating than the stearic acid and among the polyunsaturated fatty acids, linoleic acid content was higher and linolenic acid content of cookies was very negligible. Inkpen and Quackenbush (1989) opined that in soft wheat crackers, the % oleic acid was highest followed by palmitic, linoleic and stearic acids respectively. Chen et al. (1994) stated that ground flaxseed does not lose significant amount of α -linolenic acid during baking in muffin mixes and the ground flaxseed readily

absorbs oxygen under typical baking conditions but this did not markedly affect its fatty acid composition.

Conclusions

The substitution of wheat flour with 0–20% RGF decreased peak viscosity, set back, break down, dough stability and extensibility. Beyond 15% level of RGF substitution in cookies adversely affected the quality. Thus acceptable quality cookies with omega-3-fatty acid can be prepared by substituting 15% RGF. The control cookies had negligible content of linolenic acid whereas cookies with 15% RGF had 4.75–5.13% linolenic acid. A marginal decrease in linolenic acid content of cookies with 15% RGF was observed when stored upto 90 days at ambient temperature. Flaxseed with the unique fatty acid profile and a natural source of omega-3-fatty acid needs to be exploited to produce functional foods.

Fig. 3 Saturated and unsaturated fatty acid profile of control and cookies made with 15% RGF ($n=12$)

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