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Rheological and Textural Properties of Gluten Free Cookies based on Pearl Millet and Flaxseed

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Abstract: Gluten is common term refered to proteins found in wheat and related grains which is responsible for elasticity of dough and chewy texture of final product. But gluten causes problems to patients suffering from celiac diseases hence gluten free diet is the only existing treatment for celiac disease today. This study was conducted with an objective to create a dough system composed of pearl millet and flaxseed proteins that would be able to reproduce the same rheological and textural properties as wheat gluten in cookie making. A dough mixture comprising of pearl millet and flaxseed were used to prepare gluten free cookies. Psyllium husk was used to provide gelling property to the gluten free dough. Different dough samples with varying concentrations of flaxseed flour (i.e. 15g, 17g, 20g, and 22.5g) were prepared and thus optimized by rheological testing of dough samples. The cookies formulated from different dough samples with varying flaxseed concentrations were tested for rheological properties and texture profile analysis of the formulations was done. This study indicated that it is feasible to develop gluten free cookies as a commercial snack towards the fast and emerging need of gluten free products for the patients suffering from celiac disease.

Keywords: Gluten free, cookies, rheology, texture, celiac disease

1. Introduction

Gluten is the protein found in wheat that plays a key role in determining the unique baking quality of wheat as it provides water absorption ability, cohesiveness, viscosity and elasticity to wheat dough. Gluten is a viscoelastic mass formed of gliadin and glutenin [1]. Glutenins are responsible for mixing characteristics and elasticity of wheat dough whereas gliadins are responsible for viscosity and softening of dough [2-3]**.** Gliadin to glutenin ratio in wheat varieties is directly related to functional characteristics in cookies, bread, noodles etc [4-5]. Wet gluten contains approximately 65% water content. Wheat gluten mainly comprises protein (75 to 86% dry weight basis) and rest is carbohydrate and lipid which are present in the protein matrix. Gluten is composed of protein components that may be as monomers or, as oligo and polymers linked via inter-chain disulphide bonds [6]. Gluten is the key ingredient/component responsible for functional characteristics in bakery products hence termed as 'heart of bakery'.

Celiac disease or gluten sensitive enteropathy is an autoimmune disease that is associated with small intestine [7]**.** It may occur at any age (often cases in childhood) and it is triggered with the intake of gluten, a storage protein found in wheat, rye, and barley [8].

Worldwide, it is one of the most common lifelong disorders and can lead to long-term complications such as osteoporosis, cancer, and infertility [9]. A high prevalence of celiac disease has been reported in Western countries [10]. Recent studies by the Celiac Disease Foundation have reported that 1 in every 133 Americans is affected by the disease. Furthermore, it has been found that celiac disease has increased in areas of the developing world, such as North Africa, Middle East, and India, contributing to childhood morbidity and mortality [9]. Coeliac disease is caused by various factors such as genetic, immunological and environmental factors. Intake of gluten in the diet comes under environmental factor which causes coeliac disease. Various similar terms used for coeliac disease are celiac disease and gluten sensitive enteropathy and it involves serious pain and critical impairment in the gut of patients suffering from coeliac disease until gluten from the diet of these patients is not excluded [11]. Coeliac disease is considered a permanent inflammatory disease of the gut induced by gluten [12]. In this condition, the mucosa of proximal end of small is damaged and the severity of the damage decreases moderately towards distal end of small intestine. In serious cases, contusion may spread to ileum and colon. The disease is caused by an unusual body defense response to gluten. Individuals who have the disorder produce antibodies to ingested gluten, and these injure villi cells in the small intestine, which are involved with nutrient absorption. The jejunal mucosa in coeliac disease may be flat and featureless but usually presents a mosaic pattern caused by the intersection of deep depressions leaving elevated mounds [13]**.** This condition is also affecting the absorption of nutrients and reduction in absorption of minerals and vitamins. Thus, gluten sensitive enteropathy is a more suitable term as it describes the condition to the maximum extent. The only known and successful treatment for these patients is to give them gluten free diet for whole life. However, the lack of healthy and appetizing gluten-free products has contributed to the patients' difficulty in carrying out their daily and social activities, which negatively impacts their lifestyle [10].

The trend for development of designer food and functional foods is rising among food processor [14-32]. There is an emerging need to develop gluten-free baked foods to enhance food choice of celiac sufferes as well as consumers that demand gluten-free foods to address personal choices. It has been reported that gluten-free food category attained a growth of 136% during the year 2013 to 2015 and reached a value of $11 billion [33]. Novel gluten free food products are not easy to develop as its preparation is associated with several technical hurdles such as impairment of dough mixing properties, sheeting characteristics, leavening characteristics, organoleptic properties etc. All these technical hurdles are important for bakers as well for consumers [34-37]. Keeping in view the present scenario, of celiac disease and increased health awareness of consumers, there is an emerging demand for gluten free products in the market. Therefore,the objective of this research work was to establish process technology for gluten free cookies. In this study wheat was replaced by pearl millet which lacks viscoelasticity and extensibility. In order to achieve viscoelasticity and extensibility in dough flaxseed and psyllium husk were added. Besides, these properties flaxseeds and psyllium husk were selected as they provide various health benefits.

2. Materials and Methods

2.1. Materials.

The raw materials (pearl millet, flaxseed flour, psyllium husk, butter, sugar, salt were purchased from local market Alaknanda, New Delhi. All the chemicals used in the study were of analytical grade procured from local distributors.

2.2. Proximate composition.

Moisture content, carbohydrate, ash & fat content were determined using AOAC methods (2000). Protein content (IS: 7219-1973) and crude fiber content (IS: 11062) were determined using BIS standard methods.

2.3. Dough development.

Gluten free dough sample was prepared in the traditional domestic way. Pearl millet flour (60g), flaxseed flour (35g), sugar (58g), salt (0.95g), sodium bicarbonate (1g) and gel formed from psyllium husk powder, (5g of psyllium husk powder was mixed with 20ml of water to form gel) were mixed with 6ml of dextrose (13.8g in 150ml water) to form dough. Then the dough was mixed thoroughly along with the addition of shortening (36g) in molten form until it reaches a maximum consistency. A similar procedure was used to form different dough samples with varying concentrations of flaxseed flour (15g, 17g, 20g and 22.5g). Formulated dough samples were subjected to rheological testing.

2.4. Rheological analysis of formulated dough.

Dough samples for the rheological tests were prepared as those used in cookie making (they contained different concentrations of flaxseed flour). The rheological properties of gluten-free dough formulations were studied by an oscillating rheometer of Anton Paar using a parallel plate geometry (25mm diameter and 2 mm gap); the temperature was regulated at 25^0C) with an accuracy of $\pm 0.1^0$C. Cookie dough samples were loaded on the plate followed by 30 minutes resting. Trimming off excess dough was performed just before the measurement to avoid moisture loss during the resting period. The tests performed on the dough samples were: strain sweep test, creep test and frequency sweep test. Strain sweep tests in a range of 0.01–100% at 1 Hz frequency. Creep tests were performed by applying constant stress of 10 Pa for 5min on the sample and allowing strain recovery by the sample in 5 min after removal of load of 0 Pa. Creep data, collected under constant stress (σ) over time (t), can be described by a creep compliance (J) function, in terms of shear deformation (γ), using equation:

$$J(t) = \gamma(t) / \sigma.$$

The creep data were analyzed by Burger's model presented by equation:

$$J(t) = J_0 + J_1 \cdot (1 - \exp(-t/\lambda)) + t / \eta_0.$$

The recovery phase data were analyzed using Burger's model presented by equation:

$$J(t) = J_{max} - J_0 - J_1 \cdot (1 - \exp(-t/\lambda)).$$

where J_0 = instantaneous compliance, J_1 = retarded compliance, J_{max} = maximum compliance, λ = mean retardation time and η_0 = Newtonian viscosity [38-40]. Frequency sweep test was carried out by applying oscillating frequencies within the range of 0.1-100 Hz at constant strain of 0.01%. The data of frequency sweeps were plotted as G' and G” in double logarithmic diagram and experimental data of G' v/s frequency (f) was fitted using the following equation:

$$G'=K'f^{n'}$$

Where G' is storage (elastic) modulus, K' is coefficient which represents the storage modulus at 1 Hz [41] and n' is coefficient which represents the slope of the curve in a log-log plot of G' vs frequency [42]. The values of tanδ, which represents the ratio of energy loss or dissipated (G'') to energy stored in the material and recovered from it per cycle of sinusoidal deformation (G') were also reported.

2.5. Formulation and preparation of gluten free cookies.

Gluten free cookies were prepared using Pearl millet flour, flaxseed flour, psyllium husk as per the formulation presented in Table 1. Pearl millet flour, flaxseed flour, psyllium husk were sieved and mixed with other ingredients using planetary mixer. Different dough samples were prepared with varying concentrations of flaxseeds flour. The dough samples formed in the previous step were subjected to sheeting with dough sheet thickness of 5 mm, cut into circular shapes of 4.2 cm diameter, and then transferred on a baking tray. The baking trays containing sheeted cookie dough samples were placed in an oven pre-heated to 200 °C for 10 min. The cookies formed were cooled for some time at room temperature. The cookies formed were packed in polyethylene aluminum laminates in order to enhance shelf life and were stored at room temperature.

Table 1. Formulation of gluten free cookie.

Constituents	Amount used (g)
Pearl millet flour	60
Flaxseed flour	15/17/20/22.5
Psyllium husk powder	5
Sugar	58
Sodium bicarbonate	1
Salt	0.9
Shortening	36
Dextrose	13.8
Water	20 (ml)

2.6. Texture analysis.

The texture of the cookies was measured after baking cookies, using a TA-XT2 texture analyzer (Stable Microsystems, Surrey, UK) fitted with the 'Texture Expert' software. The cookies were broken using the three point bending rig probe (HDP/350). The two adjustable supports of the rig base plate are placed at a suitable distance apart to support the sample. This gap (distance) was noted and remained constant for comparing results. For texture measurement, the base plate was first fixed on heavy duty platform which was locked to facilitate the upper blade/knife to remain at equal distance from lower support. The sample is removed from its place of storage and is placed centrally over the supports just prior to testing. The experimental conditions were supports 30 mm apart, a 20 mm probe travel distance, a trigger force of 5 g and with pre-test speed of 1.0 mm/s, test speed of 2.0 mm/s and post-test speed of 2.0 mm/s. The maximum force (Newton) at break and the displacement (mm) during break were measured during texture analysis. The maximum force at rupture was considered as the hardness of cookies.

2.7. Sensory evaluation of cookies.

Sensory evaluation of formulated gluten free cookies was carried out by 30 semi-trained sensory panelists having past experience of sensory testing and know all the terms used in sensory testing. Age group of the sensory panelists ranged between 20-35 years who performed sensory evaluation of gluten free cookies prepared in this study. Sensory evaluation was performed by panelists after 1 day of baking and the sensory attributes evaluated were appearance, taste, mouthfeel, aroma, texture, crispiness, aftertaste and overall acceptability using nine-point hedonic scale i.e. 9 to 1 (liked extremely to disliked extremely).

3. Results and Discussion

3.1. Proximate analysis.

Proximate analysis results of pearl millet flour, flaxseed flour, psyllium husk and gluten free cookies (GFC) are presented in Table 2. Results revealed that all the parameters of the raw materials and gluten free cookies were significantly different from each other. Moisture content of pearl millet flour and psyllium husk were similar however moisture content of flaxseed flour (6.5) and cookies (4.35) were significantly lower. Flaxseed flour showed the highest fat, ash and protein content and lowest carbohydrate content in comparison to other ingredients and cookies. Psyllium husk exhibited the lowest values of fat and protein content and the highest levels of crude fiber and carbohydrate content. Pearl millet flour also showed second highest protein content among raw material and cookie samples.

Table 2. Proximate analysis of pearl millet flour, flaxseed flour, psyllium husk and gluten free cookies (GFC).

Constituents	Pearl millet flour	Flaxseed flour	Psyllium husk	Gluten free cookies (GFC)
Moisture	10.9 ± 0.1	6.5 ± 0.42	10.985 ± 0.58	4.35 ± 0.95
Ash	1.7 ± 0.28	2.65 ± 0.21	2.1 ± 0.14	2.35 ± 0.35
Fat	4.5 ± 0.42	39.75 ± 1.76	0.4 ± 0.1	20.5 ± 2.12
Protein	11.4 ± 0.56	19.15 ± 0.35	0.52 ± 0.14	7.3 ± 0.90
Crude fibre	1.5 ± 0.14	8.535 ± 0.58	8.7 ± 0.28	4.65 ± 0.21
Carbohydrate	71.5 ± 0.14	31.95 ± 0.58	85.99 ±0.01	60.55 ± 0.01

3.2. Rheological analysis.

3.2.1 Strain sweep test.

In viscoelastic materials, rheological characteristics do not depends on strain upto a specific strain value. Materials behave non-linear above this specific strain value and value of storage modulus also fall down. So, measuring the strain amplitude dependence of the storage (G') and loss moduli (G’’) is the first step taken in characterizing viscoelastic behavior. The viscoelasticity of gluten free dough formulations was examined by oscillatory measurements. Strain sweep experiments on gluten free dough samples were performed to establish its linear viscoelastic region. Fig.1 shows a strain sweep test of gluten free dough samples with varying concentrations of flaxseed flour. In this case, the critical strain Y (%) is 1%. Below 1% strain, the structure is intact, the materials behaves solid like and G' > G’’, indicating that the material is highly structured. Dough network structure gets disrupted when the strain value is beyond the critical strain. The material becomes progressively more fluid like, the moduli declines and G’’ exceeds G' eventually. This shows the breakdown of gluten free dough structure beyond this deformation level (1%). Similarly, it has been previously found that wheat flour- water dough’s exhibit linear viscoelasticity at strain levels lower than 0.1 – 0.25% [43-44]. The strain sweep test shows breakdown of gluten free structure beyond the critical strain in the order of:
15g flaxseed flour >17g flaxseed flour >20g flaxseed flour >22.5g flaxseed flour > control cookie.

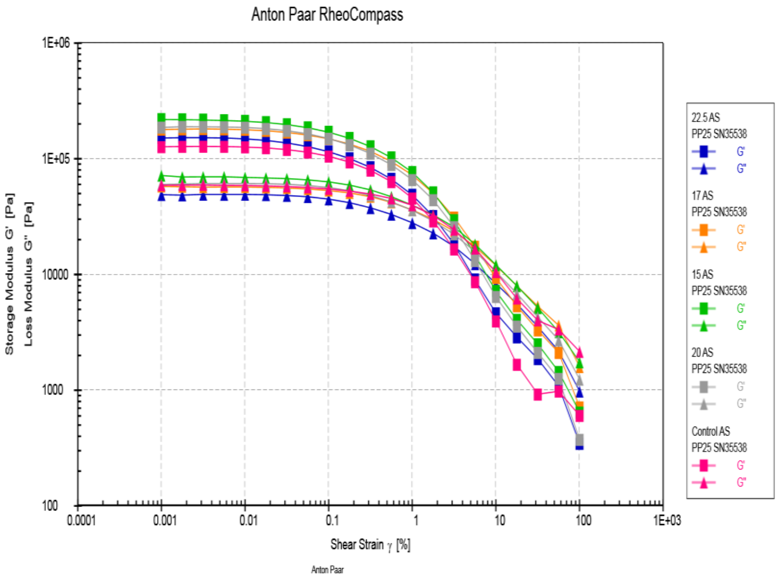

Figure 1. Strain sweep graph of gluten free cookies.

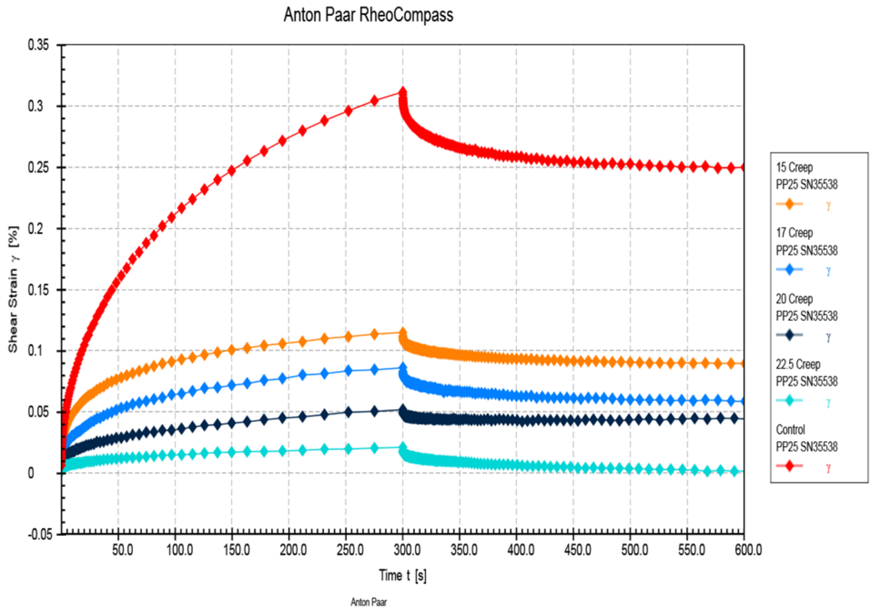

Figure 2. Creep recovery test of gluten free cookies.

3.2.2. Creep recovery test.

Creep-recovery tests were also conducted on the different formulations of gluten-free dough's. The stress of 10 Pa used for the measurements, which exceeded the region of linear viscoelasticity, was applied for 300 s, sufficient for the sample to reach steady-state flow as determined by the instrument software. The results of the creep recovery test reveal that viscoelastic behavior of gluten free dough is achieved via mixing viscous and elastic material similar to the viscoelastic behavior reported in literature of wheat dough [45-47] and of rice flour [42]. Representative creep-recovery curves of all dough samples are presented in (Fig 2) to show the effect of an increase in flaxseed flour content to dough formulation.

The incorporation of the increased percentage of flaxseed flour into dough formulations increased the resistance of dough to deformation as shown by the reduction of maximum creep % strain (strain at the end of creep phase). The resistance to deformation of dough when flaxseed flour percentage was increased followed the order of Control >15g flaxseed flour >17g flaxseed flour >20g flaxseed flour >22.5g flaxseed flour.

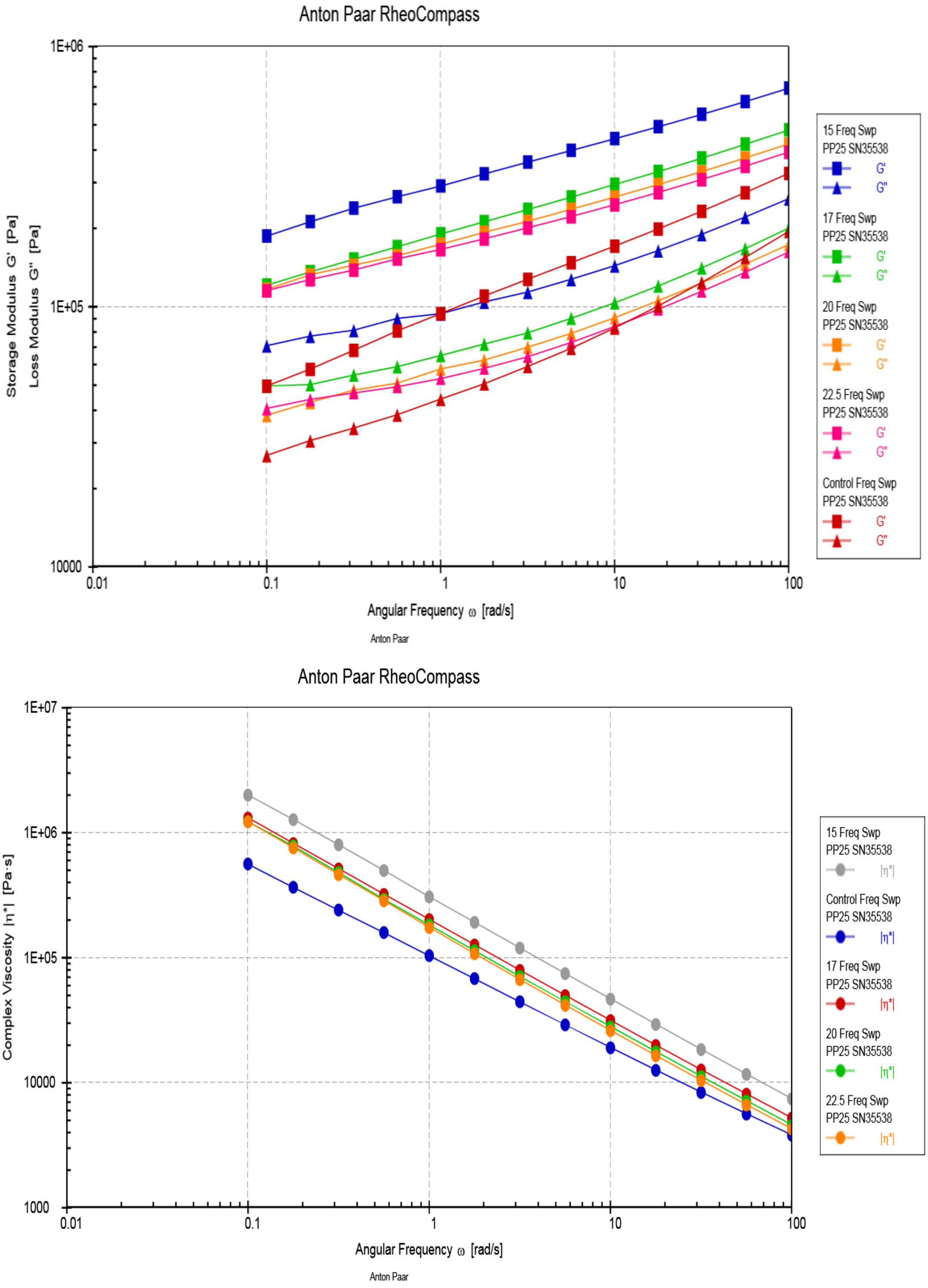

Figure 3. Frequency sweep test of gluten free cookies.

Curves obtained for creep recovery reveals the viscoelastic characteristic of dough which can regain its initial structure partly after stress removal. The influence of flaxseed flour on viscoelastic behavior of the dough samples is presented in Fig 2. Compared to the control sample the compliance for all dough samples with flaxseed flour decreased. Also, an increase in the amount of the flaxseed flour reduced the compliance of the samples.

3.2.3. Frequency sweep test.

Mechanical spectra obtained from frequency sweep test of cookie dough samples reveal that value of G' (storage modulus) was higher as compared to G'' (loss modulus) within the experimental frequency range which indicates the solid-elastic characteristic of gluten free dough samples (tanδ< 1) (Fig.3). The prevalence of elastic properties over viscous has also been reported for gluten free bread dough containing rice flour [42, 48-49]. But, cookie dough has lower moisture content and higher levels of sugar and fat in comparison to bread dough that's why it showed high value of elastic/storage modulus as compared to gluten free bread dough comprising rice and buckwheat flour [49]. According to previously conducted studies, reduction in water level in both gluten-free [48] and wheat [43, 45] dough led to an increase in dough elastic modulus. Frequency sweep test has also shown a frequency dependence of both G' and G" modulus. G' and G" modulus of control dough sample showed the lowest value in the frequency sweep curve in comparison to the dough samples containing flaxseed flour. In order to express the magnitude of the dependence of storage modulus on oscillation frequency, the curves were fitted to power law equation and the obtained mean values of tan δ (G"/G') are represented in Table 3.

Table 3. Mean values of tan δ (G"/G') of cookies.

Dough samples	**tan δ= (G"/G')**
Control	0.598
30% flaxseed flour	0.375
35% flaxseed flour	0.418
40% flaxseed flour	0.410
45% flaxseed flour	0.416

The storage/elastic modulus (G') values were dominating over loss/viscous modulus (G") for all dough samples despite of the levels of flaxseed flour added to gluten free dough samples. This is responsible for the viscoelastic behavior of the dough system [50]. Tan δ value was less than 1 for all the dough samples which reveal that a more elastic component of the dough system was dominating over the viscous component of dough system. An increase in the amount of flaxseed flour reduced the values of tan δ (Table 3), which pointed to higher domination of storage modulus over loss modulus and to a harder dough consistency.

3.3. Texture analysis of gluten free cookies.

Texture (hardness) of cookie is considered as an important characteristic of cookie by researchers [51]. Texture analysis results of gluten free cookies are presented in Table 4.

Table 4. Texture profile of control & gluten free cookies.

Cookie samples	**Hardness (N)**	**Fracturability (mm)**
Control	24.22 ± 2.42	5.72 ± 0.73
C1	43.61 ± 4.08	5.24 ± 0.3
C2	46.27 ± 7.52	4.32 ± 0.44
C3	43.13 ± 3.03	4.61 ± 0.47
C4	61.2 ± 4.0	6.67 ± 0.41

C1-Cookies containing 15g flaxseed, C2- Cookies containing 17g flaxseed,
C3- Cookies containing 20g flaxseed, C4- Cookies containing 22.5g flaxseed

Table 5. Sensory evaluation of gluten free cookies.

Cookie samples	**Texture**	**Taste**	**Appearance**	**Crispiness**	**Mouth feel**	**Aroma**	**After taste**	**Overall acceptability**
C1	6	7	7	8	6	7	8	7
C2	7	8	8	9	8	8	8	8
C3	6	7	6	7	5	6	5	6
C4	6	7	5	7	5	6	6	6

C1-Cookies containing 15g flaxseed, C2- Cookies containing 17g flaxseed,
C3- Cookies containing 20g flaxseed, C4- Cookies containing 22.5g flaxseed

Hardness of the cookies is the maximum force which achieved after the increase in the trigger force until the cracking of cookies into two pieces. Fracturability of cookie samples refers to the distance at the point of break and resistance of cookie to bend before fracture. Low Fracturability of sample means sample fracture at long distance and vice versa. Hardness of the cookies samples containing flaxseed flour was higher as compared to the control cookie sample which showed a hardness value of 24.22 N. Fracturability of cookies sample containing up to 20g of flaxseed flour showed lower fracturability values as compared to control cookie sample. The hardness amongst the cookies samples increases with the increase in flaxseed flour concentration while the fracturability of cookies samples decreases with an increase in flaxseed concentration.

3.4. Sensory properties of gluten free cookies.

Proteins are regarded as most significant components for their functions [52-54]. These proteins also provide functional applications in the products [55]. Proteins due to their functionality and contribution in structure may also interfere sensory characteristics of the food products.Sensory characteristics of cookies are considered very important by researchers [56]. Sensory results of gluten free cookies are presented in Table 5. C3 & C4 cookie samples received the lowest sensory scores. Sensory evaluation of gluten free cookies with varying concentration of flaxseed flour revealed that cookies (C2) containing 17g flaxseed flour was liked very much.

4. Conclusions

This research discovered an economic formulation for the production of dough with suitable handling and processing properties for the preparation of good quality glutenfree cookies. The optimized product was comparable to that of the control wheat cookie indicating that gluten free cookies could be successfully developed from the ingredients used in the study. The significance of this research is mainly for promoting the commercial aspect of developing process technology for ready to eat gluten free cookies and the insights gained may extend to other bakery items that could be used by celiacs. Hence, it can be recommended to add flaxseed flour at the rate of 17g in the given cookie formulation for the development of nutritional and acceptable gluten free cookies.

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Conflicts of Interest

The authors declare no conflict of interest.

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