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Development of gluten free eggless cake using gluten free composite flours made from sprouted and malted ingredients and its physical, nutritional, textural, rheological and sensory properties evaluation

Dipika Agrahar-Murugkar¹ · Aiman Zaidi¹ · Shraddha Dwivedi¹

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Abstract The aim of the study was to develop gluten free eggless cake using gluten free composite flour made of finger millet, sprouted soy and amaranth, for patients with celiac disease. Gluten free eggless cake prepared (T2), were analyzed for physical, textural, rheological and nutritional properties and compared with control cake (C) made using refined wheat flour and eggs and eggless composite flour cake made using whole wheat flour, malted finger millet, sprouted soy flour and amaranth (T1). There was no significant difference between T2 and C batter in terms of textural properties, flow behaviour index and consistency index. T2 had higher volume (454.4 cm³) as compared to T1 (437.1 cm³) cake. No significant differences in textural analysis were observed between cakes in terms of springiness, resilience and cohesiveness. The nutritional quality of T2 cake was significantly ($p < 0.05$) higher in case of phosphorous (224.0 mg/100 g) and iron content (7.39 mg/100 g). Therefore, gluten free eggless cake of high nutritional composition with good quality characteristics is a good substitute for refined flour egg and composite flour eggless cake. Higher mineral content due to germinated ingredients also made it a nutritious and palatable naturally gluten free food option for the people with celiac disease.

Keywords Gluten free eggless cake · Texture · Flow behaviour index · Consistency index · Organoleptic properties

Introduction

Cakes are one of the most popular and common bakery products containing gluten and are consumed by people all over the world. Cakes play an important part in festive occasions like marriages, birthdays and special holidays. Cakes are made from a mixture of ingredients like flour, sugar, egg and fat or oil and are characterized by dense, tender crumb with light and delicate structure. Flour is the most important ingredient in cake from which gluten formation takes place when its protein reacts with water. Gluten gives viscoelastic property and is responsible for the final structure of bakery products. In the cake making process, full gluten network formation is not an essential component for the structure.

Nowadays, consumers are looking for a gluten-free food product to reduce the risk of a celiac disease which is a common digestive condition where a person has negative reaction from gluten ingestion. All food products containing gluten from wheat, triticale, barley, kamut, rye and oats or their derivatives may be pernicious to health of gluten sensitive people, if consumed even in small quantity.

Rice, maize and potato flour are common substitutes used for gluten free product preparation, but they are less nutritive as compared to gluten rich cereals. The removal of gluten also often results in a liquid batter, poor colour, problems with texture and other quality defects post baking (Gallagher et al. 2004). Therefore, it is imperative to develop high nutritive value gluten free products with better quality characteristics.

Initially studies on replacement of refined flour with whole wheat flour and millets for an eggless cake were carried out successfully (Agrahar-Murugkar et al. 2016). In a further attempt to remove gluten from the mix several initial experiments and thorough review of literature were

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carried out and finally a combination of amaranth, finger-millet and soybean were finalized as the base ingredients of the flour mix. Among gluten free flour of high nutritional composition that can be used as a replacement of refined wheat flour for cake preparation, finger millet (*Eleusine coracana*) could be a suitable option. Finger millet is a rich source of carbohydrate, protein, dietary fibre and minerals, and an important staple food for people belonging to low socio-economic group. Its dietary fibre is superior to wheat, rice, and it contains fairly well balanced protein. Its calcium content is highest among all the cereals and iodine content is also higher than other food grains (Desai et al. 2010). Amaranth seed, a pseudocereal, is also gluten-free and can be used as a substitute for as it consist of about 19% protein with a better biological value than milk proteins as well as minerals as compared to common cereals, especially in iron, potassium, calcium and magnesium (Bressani 2003).

Soy flour has been considered for gluten free raw material by the researchers Dhen et al. (2015), Man et al. (2014) as it contains 40% high quality protein with excellent digestibility. It is also rich in minerals like calcium and phosphorous and is high in lecithin which is favorable for visco-elasticity. Shahraki et al. (2013) reported that high quality cakes with good textural and nutritional properties were obtained from 25% soybean flour substitution in wheat flour. In recent years, various studies have shown that the sprouts of legumes after germination have higher protein content and dietary fibre; lower tannin and phytic acid content and more mineral bio-availability (Agrahar-Murugkar and Jha 2009). Therefore the sprouting of amaranth and soybean has been incorporated before flour making, to add to the quality of the cake.

Egg impart moistness and renders soft texture; contributes to cake color and aroma due to their unique emulsifying, foaming and gelation properties (Conforti 2014). Recently however, people have had concerns regarding egg consumption due to cholesterol, specific dietary needs and egg protein allergy. Banana and yoghurt can be used as a substitute for egg in cake preparation, as it has shown good foaming capacity, promotes tenderness, retains moistness and has high ability to be used as a substitute for eggs in cakes (Agrahar-Murugkar et al. 2016).

The objective of our study was to develop gluten-free eggless cake of good nutritional value and acceptable sensory properties. Batters and cakes physical, colour, rheological, textural, nutritional and organoleptic properties were also evaluated and compared with refined flour cakes and composite flour cakes containing gluten.

Materials and methods

Materials

Whole finger-millet (*Eleusine coracana*), whole wheat flour (*Triticum aestivum*), amaranth seeds (*Amaranthus hypochondriacus*), soybean (*Glycine max*), refined wheat flour, baking powder (Weikfield Foods Pvt. Ltd., India), sugar, baking soda, salt vegetable oil (Adani Wilmar Ltd., India) and vanilla essence (Gujarat flavours Pvt. Ltd., India) were all purchased from the local markets in Bhopal, India. Bananas (over-ripe), eggs and yoghurt (Sanchi-Madhya Pradesh Cooperative Dairy Federation, Bhopal, India) were procured fresh on the day of experiment.

Preparation of gluten free composite flour

Amaranth and soybean were cleaned thoroughly to remove dust, dirt, stubbles and foreign matter. For germination, cleaned grains were surface sterilized with 0.1% (w/v) potassium permanganate solution and it was followed by soaking in distilled water for 4 h at room temperature (RT). After this process the extra water was drained off and rinsed again. The soaked grains were spread as a single layer on filter paper on sterile petridishes. The grains were germinated in a relative humidity chamber (Remi Scientific, India) at 25 °C, 90% Rh for 12–24 h for amaranth (Agrahar-Murugkar et al. 2013) whereas the period for soybean sprouting was 48–72 h for (Agrahar-Murugkar and Jha 2009). After germination process, the seeds were dried at 60 °C for overnight in an oven and then cooled to RT. All whole grains were then powdered using analytical mill (Cole Parmer, IL, USA) at high speed (10,590 G). All powders were then sieved through mesh of size 300 microns. The ingredients used for the preparation of gluten free composite flour were finger millet flour (85 g), sprouted amaranth flour (25 g) and sprouted soy flour (10 g) whereas for composite flour (CF) ingredients were malted finger millet flour (50 g), whole wheat flour (40 g), sprouted amaranth flour (20 g) and sprouted soy flour (10 g). Refined wheat flour was used instead of composite flour for the control cake.

Preparation of cake batters

Control cake was made using refined flour and eggs whereas the test cakes were made without egg, using over ripe bananas. Firstly, all dry ingredients (flour, 120 g; baking soda, 2 g; baking powder, 1 g for control cake and 5 g for test cake and salt, 0.1 g) were sifted three times for uniform mixing. For the preparation of control cake, egg whites (92 g) were whipped to obtain soft peaks. Egg yolks

(45 g), oil (60 g) and castor sugar (100 g) were whipped well. Dry ingredients were then added in small increments and gently folded into the whipped batter. The mixture obtained was then folded with whipped egg white. For the test cakes, banana (160 g) and sugar (100 g) were mixed together using electric mixer (Philips, India, Model HR 1071 at 170 W) at 1 speed for complete dissolution of sugar and to make the mixture free from all the lumps. Speed of the electric mixer was then increased to 3 for 1 min to get uniform and smooth mixture followed by speed 1 again for about 30 s. Vegetable oil (60 g), yoghurt (100 g), vanilla essence (2 ml) and water were added into the mixture and whipped to gain creamy consistency. All dry ingredients were gradually mixed to this cream using cut and fold method. Finally, batter (300 g) was poured into cake mould of (13.1 × 13 × 4.5 cm) size and baked at 180 °C for 50 min. After baking, cakes were placed on cooling racks, and cooled at RT for an hour and used for further analysis. All the batters and cakes were prepared thrice. For each cake and batter, all the measurements were taken in triplicates.

Physical properties of batters and cakes

Specific gravity of cake batter was determined by dividing the weight of certain volume of batter to the weight of same volume of distilled water (Turabi et al. 2008). Cake density was calculated as the ratio between the weight of the cake and its volume (Hera et al. 2012). Cake volume was measured by rapeseed displacement method (Sowmya et al. 2009). Volume index of cake samples were measured with digital calliper according to the AACC method 10–91 (AACC 1983).

The weight loss (WL %) during baking was calculated by using the following equation (Rodríguez-García et al. 2013):

$$WL (\%) = (W_{\text{batter}} - W_{\text{cake}}/W_{\text{batter}}) \times 100$$

where, W denotes weight in g.

Color analysis of batter and cake

Color values (L^* , a^* , b^* and ΔE) of cake batters and baked cakes were determined by using Lab scan XE spectrophotometer (Hunter Associate Laboratory Virginia, USA, Model LX16244) following the method of Celik et al. (2007). Cake crust of 0.5 cm thickness was removed from surface and crumb piece of size (4 × 4 × 1.5 cm) was taken from the centre of the cake. An average of 3 readings was reported for each sample.

Rheological properties of cake batters

Batter flow behaviour

Steady shear properties were obtained at constant temperature (25 °C) using a parallel-plate rheometer (Anton Paar, Germany: Physica MCR 51). The samples were prepared just before the experiments. The gap between the plates was 1 mm. Shear rate, which was increased linearly between 1 and 200 s⁻¹, was applied to 2–3 g sample for 5 min (Turabi et al. 2008). Throughout the tests, shear rate-shear stress and shear rate-apparent viscosity data were collected. The data were fitted to Casson Eq. (1) and Herschel Bulkley Model Eq. (2) rheological models:

$$\sigma^{0.5} = K_{0c} + K_c(\gamma)^{0.5} \quad (1)$$

Casson yield stress (σ_{0c}) and Casson plastic viscosity (η_{ca}) was determined as the square of the intercept (K_{0c}) and slope (K_c) respectively (Rao 2014).

$$\sigma = \sigma_{0H} + K_H(\gamma)^{n_H} \quad (2)$$

where σ is the shear stress (Pa) and γ is the shear rate (s⁻¹). σ_{0H} is yield stress calculated from Casson Model Eq. (1), K_H is consistency index (Pa sⁿ) and n_H is the flow behaviour index of the model (Rao 2014).

Batter viscoelastic behaviour

Small amplitude oscillatory shear flow measurements of the storage modulus, G' , the loss modulus, G'' , and the loss tangent, $\tan \delta = G''/G'$ were obtained using 50 mm diameter parallel plates. Batter was placed between the plates and the gap was adjusted to 2 mm. The batter was rested between plates for 1 min before testing so that residual stresses, if any, would relax. Oscillatory shear tests were carried out in controlled-strain mode over the frequency range of 0.1–100 Hz (0.63–628 rad/s) at 0.1% strain value. Storage, G' and loss, G'' moduli were determined. The temperature was controlled at 25 ± 0.1 °C using a Peltier controller, and humidity covers were used to prevent drying of the sample (Singh et al. 2012).

Textural properties of batters and cakes

Back extrusion test of batter

Back extrusion cell, consisting of a container of 50 mm diameter with 35 mm disc positioned centrally over the sample container, was used to measure the textural properties of cake batters using TA-XT plus Texture Analyser of Stable Micro Systems, UK equipped with a 50 kg-f load cell and operated through software program Texture Expert (Texture Technologies Corp., New York, USA). During the

test, the disc penetrated to a depth of 30% (of sample height) at 1 mm/s test speed and at this point or the 'peak' or maximum force was taken as a measurement of firmness (N) after which the probe returned to its original position. The area under the curve up to this point was taken as an indication of consistency (Ns). The negative region of the graph, drawn on probe return, was the result of the weight of sample which was lifted primarily on the upper surface of the disc on return, i.e. due to back extrusion and hence gave an indication of the viscosity (Ns) (resistance to flow off the disc). The maximum negative force was taken as an indication of the cohesiveness (N) of the sample. All parameters of back extrusion were estimated using the procedure defined by Angioloni and Collar (2009). Data was recorded at a rate of 200 points per second. The measurements were carried out at room temperature (25 °C). The analyses were performed in triplicate with six replicates in all.

Cake texture

Textural characteristics of the cakes were assessed by means of a texture Analyzer (TA-XT2, Stable Micro Systems Ltd., Surrey, UK). Texture Profile Analysis (TPA) test was performed through two bite compression test before which 1 cm of the crust was removed to make the surface levelled off and crumb piece of size (4 × 4 × 1.5 cm) was cut from the centre of the cake. TPA was done at pre-test speed of 5 mm s⁻¹, test and post-test speed of 0.25 mm s⁻¹, time interval of 10 s and deformation of 25% using an aluminium cylindrical probe of 75 mm diameter. Hardness/firmness was obtained as a maximum force of the first bite of TPA test (F1); the ratio of areas (A2/A1) from force distance curves indicated cohesiveness and springiness being determined by dividing the second peak time by the first peak time (t2/t1); resilience was calculated by dividing the area of upstroke energy of the first compression by the area of downstroke energy of the first compression (A4/A3) while chewiness is Hardness × Cohesiveness × Springiness (Agrahar-Murugkar et al. 2016).

Proximate analysis

The moisture, fat, protein, ash, phosphorus and iron contents of the batters and cakes of control as well as test cakes were estimated using standard methods (AOAC 1990).

Statistical analysis

The experiments were carried out in triplicate and results are presented as mean values with standard deviations. Different mean values were analyzed by one way analysis

of variance (ANOVA) and Duncan test using Microsoft Excel 2010. A probability level of $p < 0.05$ was considered to be significant for all statistical procedures.

Results and discussions

Physical properties of batter

Batters physical properties of control and test cakes are shown in Table 1. Moisture content of T1 and T2 batters were higher in comparison to C batter due to the inclusion of banana and yoghurt in their formulations. The specific gravity of batter determines how much air has been incorporated into the batter during mixing. Generally, lower specific gravity of batter results in higher finished cake volume (Des Rochers et al. 2003). To get low specific gravity, density of batter should be lower which can be achieved by higher incorporation of air. Specific gravity of all batters were not significantly ($p < 0.05$) different though the specific gravity of test batters were higher than control batter.

In case of control batter, presence of egg played important role as its protein assisted in entrapping large air quantities and produced better foaminess and fluffiness in the batter as compared to eggless test cakes. As a consequence, batter densities of test cakes were higher than control batter which resulted in their higher specific gravity.

Batter texture

Batter textural properties are considered important quality parameters as they are closely related to the final quality of cake. The fluid flow properties of cake batters, firmness, consistency, cohesiveness, and index of viscosity were analyzed by back extrusion process (Table 1). In all the textural attributes T2 batter was similar to the Control while the T1 batter showed significantly ($p < 0.05$) higher values for firmness, consistency and cohesiveness. In T2 batters good hydration properties due to the presence of banana may have played an important role in the determining the ability to hold water as they have more affinity for water and oil than cereal derivatives (Grigelmo-Miguel et al. 1999; Singh et al. 2016). In addition to the combination of banana and yoghurt which has moisture retention properties, presence of sprouted soybean flour and sprouted amaranth flour may be responsible for conferring similar textural properties to the T2 batter in comparison to C batter. Soy protein has the ability to impart texture to the food products, whereas amaranth flour along with its high quality protein content has good water holding capacity which increases the viscosity of batter and has the potential

Table 1 Physical properties, texture and colour of cake batters

Batter	Physical properties			Texture			Color			
	Moisture (% basis)	Specific gravity	Firmness (**N)	Consistency (**N.s)	Cohesiveness (**N)	Index of viscosity (**N.s)	L*	A*	B*	ΔE1
¹ C	30.8 ^a ± 0.34	0.89 ± 0.00	0.44 ^a ± 0.05	10.62 ^a ± 1.56	- 0.29 ^a ± 0.06	- 5.19 ^a ± 1.79	65.4 ^c ± 0.41	1.8 ^a ± 0.33	25.2 ^b ± 2.62	-
² T1	38.6 ^b ± 0.24	1.04 ± 0.01	0.59 ^b ± 0.08	15.23 ^b ± 2.40	- 0.39 ^b ± 0.06	- 8.38 ^b ± 1.36	50.4 ^b ± 1.20	6.9 ^b ± 0.23	16.8 ^a ± 0.21	17.9 ^a ± 1.11
³ T2	39.6 ^b ± 0.43	1.01 ± 0.03	0.48 ^a ± 0.06	12.25 ^a ± 1.60	- 0.29 ^a ± 0.04	- 5.84 ^a ± 1.01	47.5 ^a ± 0.49	7.85 ^b ± 0.26	15.5 ^a ± 0.23	21.3 ^b ± 0.40

¹C, Refined flour + egg; ²T1, composite flour + banana and yoghurt; ³T2, gluten free flour + banana and yoghurt

ΔE1 is with reference to C

Values are expressed as mean ± standard deviation. Means having different letters as superscripts within the same column differ significantly at $p < 0.05$ (n = 9)

**N Newton; **N.s Newton per second

to improve the texture of gluten free food products as suggested by Inglett et al. (2014). Whole wheat flour in T1 batter comprised of higher protein content which has higher water binding capacity that increased batter viscosity and contributed to the increase in its firmness, consistency and cohesiveness (Bhaduri 2013).

Batter colour values

Colour values of cake batters represented by L*, a*, and b* values are given in Table 1. L* and b* value of T1 and T2 batters were lower than C batter whereas a* value were higher due to the dark colour of flour itself.

Higher L* value is related to whiter colour which is more appealing colour. The white colour of bleached refined flour and carotenoids present in egg yolk might have contributed in higher L* and b* value of C batter than test batters. T1 batter had significantly ($p < 0.05$) higher L* and b* value and significantly ($p < 0.05$) lower a* value than T2 batter. T2 had higher content of ragi flour than T1 which is of brick red to dark colour and contributed darker colour to the batter. Absence of whole wheat flour in T2 flour might also be the reason of its lower L* and b* value as whole wheat flour contains carotenoid pigment giving little yellowish colour to T2 batter.

Rheological properties of batters

Flow behaviour

The shear stress (σ) versus shear rate ($\dot{\gamma}$) data obtained for different cake batters were fitted to Casson Eq. (1) and Herschel Bulkley model Eq. (2) and are shown in Table 2. Flow behavior index (n_H) of batters ranged from 0.71 to 0.92 which indicated shear thinning behavior due to alignment of microstructure with the flow direction and breaking up of the agglomerated particles as explained by Singh and Heldman (2009). Consistency index (K_H) is related to the capacity of the batter for retaining air. T1 sample had significantly highest value for consistency index and lowest value for flow behavior index compared to C and T2 batters. This may be due to higher gluten content in T1, which has the ability to absorb water up to twice of its dry weight (Day et al. 2006) that may have reduced the availability of free water to facilitate movement of particles in the batter. This indicated that higher amount of the proteins in the batter enhanced its viscoelasticity (Shevkani et al. 2015). T1 also contained malted finger millet flour which resulted in the increase in viscosity as compared to T2 which comprised of plain finger millet flour with lower water holding capacity. No significant difference was found among C and T2 batters for consistency index as well as flow behavior index. For

Table 2 Casson model and Herschel Bulkley model constants for cake batters

Casson model				Herschel Bulkley model		
Cake batters	Yield stress (Pa*)	Casson plastic viscosity (Pa.s)	r ²	Flow behaviour index	Consistency index (Pa.s ^{n**})	r ²
¹ C	3.26 ^a ± 0.27	1.09 ^b ± 0.27	1.00 ± 0.00	0.91 ^b ± 0.04	2.36 ^a ± 0.85	0.99 ± 0.01
² T1	29.87 ^c ± 6.94	1.28 ^c ± 0.07	0.99 ± 0.00	0.72 ^a ± 0.05	9.87 ^b ± 3.49	1.00 ± 0.00
³ T2	17.90 ^b ± 1.90	0.69 ^a ± 0.07	0.98 ± 0.01	0.90 ^b ± 0.01	2.28 ^a ± 0.19	0.95 ± 0.01

¹C, Refined flour + egg; ²T1, composite flour + banana and yoghurt; ³T2, gluten free flour + banana and yoghurt

Values are expressed as mean ± standard deviation. Means having different letters as superscripts with in the same column differ significantly at $p < 0.05$ (n = 9)

r²: coefficient of determination

*Pa Pascal; **Pa.s Pascal second

preparation of good quality cakes, the batter should be optimally viscous for trapping gas bubbles during mixing and retaining them during baking. On the contrary, a too highly viscous batter can restrict its expansion during baking (Rahmati and Tehrani 2014).

Viscoelastic behaviour

In our study, frequency sweep test was conducted by measuring at 15 different frequencies for storage modulus (G'), loss modulus (G'') and complex viscosity (η^*). G' represents the elastic (solid) behaviour in batter and is a measure of deformation energy stored in the sample during shear process. On the other hand, G'' represents the viscous (liquid) behaviour of the batter and is a measure of deformation energy used up and lost during shearing (Mezger 2002). The $\tan(\delta)$ is the ratio of viscous to elastic property (Fig. 1) and can be measured as G''/G' (Crockett et al. 2011). At lower angular frequencies, all the batters showed lower value for G' and G'' indicating less viscous and less elastic behaviour. However at higher angular frequencies, G' value was found to be higher than G'' value for all batters indicating more elastic behaviour.

For all the batters, values of G' were higher than G'' at all frequencies indicating that the cake batter behaved like gel (Giuseppe et al. 2009). $\tan(\delta)$ value for all the batters were lower than 1 which confirmed that the elastic properties predominated over viscous properties. T1 batter showed higher value for $\tan(\delta)$ compared to C and T2. The values of $\tan(\delta)$ of T2 and C were close to each other, though C was slightly lower than T1, showing more solid and elastic like behaviour. Tan et al. (2015) had also reported that batters made from egg resulted in more solid and elastic-like liquids with higher G' values than G'' resulting in a lower value of $\tan(\delta)$.

Physical properties of cake

Physical properties of cakes have been depicted in Table 3. Moisture content of test cakes were higher as compared to C cakes which might be due to the presence high water content ingredients like banana and yoghurt which helped in retaining of moisture during baking process. C cakes had significantly ($p < 0.05$) higher volume, volume index and lower density than T2 cakes mainly due to unique foaming, leavening, and heat coagulation properties of egg proteins and water vaporization during baking. No significant differences were obtained in physical parameters of T1 and T2 cakes. Higher quality cakes are associated to light, porous structure, high volume and low density. The higher the number of air pockets the higher the volume. Starch gelatinization and protein denaturation together with carbon dioxide formation gives cake its porous and soft structure. High volume with a fine homogeneous moist crumb is the characteristic of good quality cake. Gómez et al. (2010) observed an increase in batter density with increase in the level of different fibers. Ronda et al. (2011) have also reported that the amount of air incorporated was lower in a batter of high density and consistency. T1 and T2 cakes consisted of sprouted soy flour, sprouted amaranth flour and ragi flour in their formulations which resulted in higher batter density and lower cake volume as compared to control cakes. However, presence of starch, pectin and malto-dextrins in banana may have counteracted this effect (Giese 1996) to a certain extent as the granules get gelatinized during heating and swell to form the 'building bricks' of the cake crumb (Donovan 1977) improving volume.

Cake textural properties

The texture parameters values of cakes are shown in Table 3. There were no significant differences between

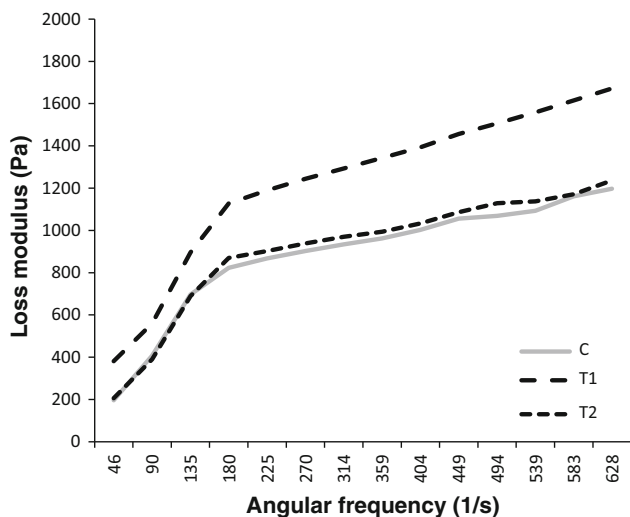


Fig. 1 Loss modulus parameter of cake batters. C, refined flour + egg; T1, composite flour + banana and yoghurt; T2, gluten free flour + banana and yoghurt

cakes in terms of springiness, resilience and cohesiveness. This shows that all the cakes were similar in elasticity, ability to spring back after compression and resilient enough to recover back to their position after compression. However in terms of hardness and chewiness C cakes showed significantly higher values as compared to test cakes which were softer and less chewy. The best cakes are obtained from a low-protein flour (7–9%) to give soft cakes. The larger amounts of gluten proteins are not preferable for cake preparation as it hampers spread of dough and inhibit dough moulding to specific dimension and shape. The final moisture content of cake is also one of the important factors in analysing cake quality. Lower values of hardness in test cakes as compared to control cake was due to the high moisture content in test cakes which was attributed due to the addition of banana and yoghurt and low protein content. Among all the three cakes, T2 was softer due to its gluten free nature and higher moisture content.

Chewiness is related with hindrance in chewing the sample and developing a bolus before swallowing. Chewiness value of cakes showed similar trend with the protein content of cakes, having highest value for control cake and lowest value for gluten free cake. This is explained by the protein content in the batter which forms a network and helps to retain incorporated air in cake leavening. Batter with high foaming capacity produced highly aerated cake (Tan et al. 2015).

Cake colour analysis

Table 4 presents the colour parameters of cakes. During baking process at high temperature, heat and mass transfer

takes place between the product and environment; as a consequence the cake surface dehydrates and there is a development of crust colour as a result of Maillard reaction between sugar and amino acid and caramelization reaction of sugar. Crust of gluten free cake and cake made with composite flour showed lower L^* , b^* and a^* value compared to control cake indicating darker, reddish and less yellowish colour. The $\Delta E1$ values showed highly significant ($p < 0.05$) differences between C cake and T1 and T2 cakes crusts probably due to the finger millet flour which has a reddish colour.

Maillard or caramelization reactions by sugars fail to take place because cake crumb does not reach temperatures above 100 °C during baking. Hence, crumb colour must be the consequence of the modifications to colours of raw materials (Barcenilla et al. 2015). In the crumb colour measurement, T1 and T2 cake showed lower L^* and b^* value and a higher a^* value than the C cake indicating dark, less reddish and less yellowish crumb. Higher L^* value of C crumb is related to whiter colour which is more appealing to the consumer. $\Delta E1$ values showed no significant differences between the test cake crumb samples for the same reasons explained above. Presence of malted ragi flour in T1 and T2 cakes may have been the cause of dark colour of cake crumb.

Nutritional analysis

Table 4 shows the nutrition analysis of cakes and Table 5 depicts the correlation between iron content of cakes and colour. The protein content was found to be significantly ($p < 0.05$) higher in C cakes as compared to Test cakes probably due to the protein rich albumin present in egg used in the formulation. Similarly, T1 cakes had significantly ($p < 0.05$) higher protein content as compared to T2 cakes due to the inclusion of whole wheat flour in the formulation. The fat content of C and T1 cakes was significantly ($p < 0.05$) higher as compared to T2 cakes due to the presence of fat rich ingredients egg yolk and wheat flour which were absent in T2 cakes. Ash content of test cakes were significantly ($p < 0.05$) higher as compared to C cake which could be due to the presence of germinated soy flour, germinated amaranth flour and banana. The mineral content (phosphorus and iron) were significantly higher ($p < 0.05$) in T2 cakes as compared to C and T1 cakes due to the presence of mineral rich ingredients like finger millet and amaranth flour.

Table 3 Physical properties and texture profile of cakes

Cake	Physical properties				Texture					
	Moisture (%)	Volume of cake (cm ³)	Volume index (mm)	Cake density (g/cm ³)	Weight loss (%)	Hardness (*N)	Springiness	Resilience	Cohesiveness	Chewiness (*N)
¹ C	29.3 ^a ± 0.57	551.3 ^b ± 23.39a	126.6 ^b ± 4.46	0.47 ^a ± 0.02	14.6 ± 0.97	5.3 ^b ± 0.23	0.91 ± 0.012	0.51 ± 0.01	0.84 ± 0.01	4.03 ^b ± 0.14
² T1	37.8 ^b ± 1.54	437.1 ^a ± 12.44	86.2 ^a ± 3.75	0.59 ^b ± 0.02	14.8 ± 0.17	3.9 ^a ± 0.48	0.85 ± 0.02	0.48 ± 0.01	0.80 ± 0.01	2.69 ^a ± 0.34
³ T2	39.0 ^b ± 0.38a	454.4 ^a ± 19.31	88.4 ^a ± 1.79	0.56 ^b ± 0.02	14.8 ± 0.17	3.7 ^a ± 0.22	0.86 ± 0.02	0.49 ± 0.01	0.82 ± 0.00	2.58 ^a ± 0.21

¹C, Refined flour + egg; ²T1, composite flour + banana and yoghurt; ³T2, gluten free flour + banana and yoghurt

Values are expressed as mean ± standard deviation. Means having different letters as superscripts within the same column differ significantly at $p < 0.05$ (n = 9)

*N Newton

Table 4 Colour parameters of cake crust and crumb and nutrient content

Cake	Crust color				Crumb colour						Nutrient content					
	L*	A*	B*	ΔE1	L*	ΔE1	A*	B*	ΔE1	Protein (g/100 g)	Fat (g/100 g)	Ash (g/100 g)	Phosphorus (mg/100 g)	Iron (mg/100 g)		
¹ C	52.3 ^b ± 1.54	13.7 ± 1.16	31.5 ^b ± 1.01	-	63.8 ^b ± 0.51	-	0.8 ^a ± 0.27	23.8 ^c ± 1.66	-	12.9 ^c ± 0.57	20.9 ^b ± 0.43	0.9 ^a ± 0.01	110.6 ^a ± 3.52	3.14 ^a ± 0.16		
² T1	24.9 ^a ± 1.15	14.1 ± 0.26	18.0 ^a ± 0.77	30.5 ± 1.14	32.9 ^a ± 0.86	30.5 ± 1.14	6.5 ^b ± 0.18	14.2 ^b ± 0.44	32.8 ^a ± 0.8	8.8 ^b ± 0.09	19.2 ^b ± 0.14	2.3 ^b ± 0.00	201.6 ^b ± 4.23	5.41 ^b ± 0.08		
³ T2	26.3 ^a ± 1.55	12.5 ± 0.19	15.7 ^a ± 0.30	30.5 ± 1.4	30.3 ^a ± 1.74	30.5 ± 1.4	6.5 ^b ± 0.10	11.9 ^a ± 0.16	36.0 ^b ± 1.6	7.3 ^a ± 0.32	17.3 ^a ± 0.11	2.3 ^b ± 0.01	224.0 ^b ± 8.19	7.39 ^c ± 0.70		

¹C, Refined flour + egg; ²T1, composite flour +banana and yoghurt; ³T2, gluten free flour + banana and yoghurt

ΔE1 is with reference to C

Nutrient contents are expressed in dry matter basis. Values are expressed as mean ± standard deviation. Means having different letters in superscripts within the same column differ significantly at $p < 0.05$ (n = 9)

Table 5 Correlation between colour parameters of cake crust and crumb and iron content

Parameters	Crumb				Crust			
	L	A	B	Iron	L	A	B	Iron
L*	1	-0.98	0.98	-0.93	1	0.63**	0.98	-0.94
a*		1	-0.97	0.87		1	0.726	-0.49**
b*			1	-0.92			1	-0.86
Iron content				1				1

The values indicated by * are not significant at $p < 0.05$

Conclusion

Overall results showed that healthy and tasty gluten free eggless cake of acceptable quality characteristics can be obtained using ragi, sprouted amaranth and soyflour, banana and yoghurt, which could be able to meet celiac patients desires and demands. Gluten free eggless cakes showed no significant difference for batter textural properties compared to control cakes made using eggs. For rheological studies, Casson and Herschel Bulkley model were fitted to all batters which showed shear thinning behaviour of batters. There were no significant difference observed for flow behaviour index and consistency index among gluten free and control batters. Gluten free cake had significantly lower cake volume and volume index in comparison to control cake whereas no significant differences were determined among gluten free and composite flour eggless cakes. Textural properties of gluten free cakes were similar to control cakes. Protein and fat content was higher in control cakes as compared to gluten free cakes. Gluten free cakes showed higher values for minerals especially iron as compared to control cakes. Higher density and darker colour as compared to standard control cake did not impair the sensory properties gluten free cakes. Thus, it can be concluded that cake made with gluten free flour and banana and yoghurt as egg-replacer has high potential to be used as an alternative to refined flour and eggs in cakes with added health benefits.

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