EFFECT OF EGG-REPLACER AND COMPOSITE FLOUR ON PHYSICAL PROPERTIES, COLOR, TEXTURE AND RHEOLOGY, NUTRITIONAL AND SENSORY PROFILE OF CAKES

DIPIKA AGRAHAR-MURUGKAR[1], AIMAN ZAIDI, NACHIKET KOTWALIWALE and CHETAN GUPTA

ICAR-Central Institute of Agricultural Engineering, Nabibagh, Bhopal, 462038, India

[1]Corresponding author.
TEL: +91-755-2521070 (O);
FAX: +91-755-2734016;
EMAIL: dipikaagrahar@yahoo.com

ABSTRACT

Eggless cakes were developed using composite flour (CF) of wheat, malted finger-millet, sprouted soy and amaranth and egg-replacers (banana (T1), chia (T2) and soy milk powder (T3)) and were analyzed for physical, textural, rheological, nutritional and organoleptic properties and compared with egg cakes with refined wheat flour (C1) and CF (C2). T1 cake showed no significant difference for batter physical and textural properties with C1. In rheological studies, no significant difference was found for Casson-plastic viscosity, flow-behavior index and consistency-index among T1 and C1 batter. T1 cake had higher volume (437.1 cm^3) as compared to T3 (404.4 cm^3) and T2 (359.4 cm^3). C2 showed highest protein (g/100 g) (14.3) and fat (27), while T3 and T1 cakes contained significantly higher iron contents. On 9-point hedonic scale, T1 cake scored significantly higher values among T cakes. Therefore, CF was a good replacement for refined flour and banana was the best egg-replacer for cake developed.

PRACTICAL APPLICATIONS

Increasing consumer search for healthier food options has led researchers to look for alternatives of traditional bakery items such as eggs, refined wheat flour, and butter in food products. Refined wheat flour with low gluten, eggs with its unique foaming, emulsifying and heat coagulation properties and butter giving tenderness, moistness and flavor are important ingredients in bakery products especially in cakes and thus difficult to replace by any other source. Therefore, our research on different egg-replacers and incorporation of composite flour containing whole wheat, sprouted soybean, malted millet and pseudocereals instead of refined wheat flour in cakes may help manufacturers to produce a healthy product with no sacrifice for its taste and appearance. These alternatives deliver same functional role as that of eggs, butter and flour at much lower cost and can be incorporated into the cakes to obtain desirable organoleptic properties.

INTRODUCTION

Cakes are semidry foam foods with air pockets enclosed in a protein and starch network and are one of the most common bakery products consumed by people. Egg proteins play significant role in foam formation in cakes. However, heath risks associated with consumption of eggs (Shi *et al.* 2011) and consumer preference for vegan diet led researchers to investigate egg-replacers. Many attempts have been made to replace egg with various plant proteins (pea protein and soy protein) and animal proteins (collagen, hydroysates, gelatin, whey protein concentrate, etc.), wheat starch and various hydrocolloids and emulsifiers (Kohrs *et al.* 2010; Tan *et al.* 2015). Soy milk and soy flour have also been identified for partial and full replacement of egg in cake (Rahmati and Tehrani 2015; Zeidanloo *et al.* 2014). Banana is rich in starch, fiber, antioxidants and minerals (Kanazawa and

Sakakibara 2000), has shown good foaming capacity (Alam *et al.* 2014) and has been used in slowly digestible cookies (Aparicio-Saguilána *et al.* 2007), yeast leavened bread (Mohamed *et al.* 2010) etc. Chia (*Salvia hispanica*) seeds contain around 20% protein, high dietary fiber, minerals, vitamins and antioxidants (Ixtaina *et al.* 2008). Chia gum is also an important food ingredient due to its emulsifier and stabilizer potentials.

Fat in baked products imparts tenderness, moistness, lubricity, flavor, color, structure, volume and antistaling qualities. Many efforts have been made to replace fat with extra virgin olive oil (Matsakidou *et al.* 2010), sesame oil (Sowmya *et al.* 2009), inter-esterified palm and cottonseed oils (Dogan *et al.* 2007), owing to the health risk associated with trans fats.

Flour contributes a major portion of cake and replacement of refined flour with nutrient-rich flour enhances nutritional profile but makes product development tricky. The production of cake from wheat, soybeans, cassava flour, maize flour and lupin flour has been reported (Onuegbu *et al.* 2013; Ahmed 2014). Replacing refined wheat flour was attempted initially by us using a wide range of millets and pseudocereals available in India along with whole wheat flour to prepare a cake. After several initial experiments and thorough review of literature, finally a combination of amaranth, finger-millet, soybean and whole wheat were finalized as the base ingredients of the flour mix. Amaranth a pseudocereal is gluten-free and an exceptional source of iron and protein (Bressani 2003). Finger-millet (*Eleusine coracana*) has a dark brown seed coat, rich in polyphenols and minerals (Viswanath *et al.* 2009). To further improve the nutritional and functional quality of the composite mix, malting/sprouting was carried out on finger-millet, amaranth and soybean. Sprouting/malting is a simple technique that improves the nutritive value of foods by increasing protein and dietary fiber, reducing tannin and phytic acid and increasing mineral bioavailability, along with improving the functional quality by increasing nitrogen solubility, water absorption index, improving textural properties, etc. (Agrahar-Murugkar and Jha 2009; Ghavidel and Prakash 2007), and can be incorporated in mixes to enhance nutrient content of diets.

So far, no effort has been made to use composite of millets, pseudocereals, cereals and soybean as ingredients along with sprouting and malting to form base flour and replacing egg with chia seeds/soy milk powder/bananas and yogurt to develop a cake with high nutritional value and taste. The batters and cake were tested for physical, color, rheological, textural, nutritional and organoleptic properties to study the effect of combination of sprouted composite flour (CF) and egg-replacers in comparison to both refined flour egg cakes and CF egg cakes.

TABLE 1. COMPOSITION OF INGREDIENTS IN THE CAKES

Ingredients	C1	C2	T1	T2	T3
Refined wheat flour (g)	120	–	–	–	–
CF (g)	–	120	120	120	120
Egg white (g)	92	92	–	–	–
Egg yolk (g)	45	45	–	–	–
Banana (g)	–	–	160	–	–
Chia seeds powder (g)	–	–	–	6	–
Soya milk powder (g)	–	–	–	–	15
Sunflower oil (mL)	60	60	60	60	60
Baking powder (g)	1	1	5	5	5
Baking soda (g)	–	–	2	2	2
Salt (g)	0.1	0.1	0.1	0.1	0.1
Sugar (g)	100	100	100	100	100
Curd(g)	–	–	100	100	100
Vanilla essence (mL)	2	2	2	2	2
Water (mL)	30	30	–	80	70

C1, Refined flour + egg; C2, composite flour (CF) + egg; T1, CF + banana; T2, CF + chia seeds; T3, CF + Soy milk powder with CF.

MATERIALS AND METHODS

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

Preparation of CF

Finger-millet, amaranth and soybean were cleaned thoroughly, surface sterilized with 0.1% (w/v) potassium permanganate solution, rinsed, soaked in distilled water for 4 h at room temperature (RT) and extra water drained-off and rinsed again. The grains were spread as a single layer on filter paper on sterile petri dishes and germination carried out in relative humidity chamber (Remi Scientific, India) at 25C, 90% Rh. The period of sprouting was 48–72 h for soybean (Agrahar-Murugkar and Jha 2009) and for malting of finger-millet and amaranth it was 12–24 h (Agrahar-Murugkar *et al.* 2013). After sprouting, the seeds were dried overnight in an oven at 60C and cooled to RT. All whole grains were then powdered using analytical mill (Cole Parmar, IL) at high speed (10,590 G) and sieved through mesh size 300 μm. The ingredients used for the preparation of CF were malted finger-millet flour (50 g), whole wheat flour (40 g), sprouted amaranth flour (20 g) and sprouted soy flour (10 g).

TABLE 2. PHYSICAL PROPERTIES, TEXTURE AND COLOR FOR CAKE BATTERS

Batter	Moisture (%, wet basis)	Physical properties Specific gravity	Firmness (N)	Texture Consistency (N.s)	Cohesiveness (N)	Index of Viscosity (N.s)	Color L*	a*	b*	ΔE1	ΔE2
C1	30.8 ± 0.34^c	0.89 ± 0.002^c	0.44 ± 0.05^{bc}	10.62 ± 1.56^{bc}	−0.29 ± 0.06^{ab}	−5.19 ± 1.79^a	65.39 ± 0.41^a	1.81 ± 0.33^d	25.20 ± 2.62^a	–	–
C2	29.5 ± 2.05^c	0.84 ± 0.016^d	0.31 ± 0.01^c	7.46 ± 0.51^c	−0.18 ± 0.03^a	−2.29 ± 0.54^a	45.05 ± 0.38^d	6.76 ± 0.46^a	19.48 ± 1.57^b	21.74 ± 0.55^b	–
T1	38.6 ± 0.24^a	1.04 ± 0.01^c	0.59 ± 0.08^{bc}	15.23 ± 2.40^{bc}	−0.39 ± 0.06^{ab}	−8.38 ± 1.36^{bc}	50.42 ± 1.2^b	6.88 ± 0.23^a	16.80 ± 0.21^c	17.91 ± 1.11^c	6.03 ± 1.12^a
T2	34.2 ± 0.23^b	1.13 ± 0.01^a	2.37 ± 0.56^a	57.48 ± 12.42^a	−1.40 ± 0.32^c	−24.70 ± 5.26^e	44.16 ± 0.55^e	5.12 ± 0.48^{bc}	13.98 ± 0.44^c	24.25 ± 0.56^a	5.81 ± 0.59^b
T3	33.1 ± 1.19^b	1.07 ± 0.006^b	0.85 ± 0.16^b	21.76 ± 4.13^b	−0.58 ± 0.13^b	−12.71 ± 2.36^b	46.94 ± 0.35^c	4.81 ± 0.04^c	14.21 ± 0.04^b	21.68 ± 0.36^b	5.94 ± 0.02^b

C1, Refined flour + egg; C2, composite flour (CF) + egg; T1, CF + banana; T2, CF + chia seeds; T3, CF + Soy milk powder with CF.

ΔE1 and ΔE2 are with reference to C1 and C2, respectively.

Values are expressed as mean ± standard deviation. Means having different letters with in the same column differ significantly at $P < 0.05$ ($n = 3$).

Preparation of Cake Batters

Formulations presented in Table 1 were used to produce control cakes (C) and test cakes (T). Cake with refined flour and CF with eggs served as control cakes C1 and C2, respectively. The T cakes were made using overripe bananas, chia seeds and soy milk powder as egg-replacers. First, all dry ingredients were sifted thrice for uniform mixing. For C cake, egg-white was whipped to obtain soft peaks. Egg yolk, oil and castor sugar were whipped and folded in with dry ingredients. This mixture was then folded with whipped egg-white. For the T cakes, egg-replacers were mixed with sugar using electric mixer (Philips, India, Model HR 1071 at 170 W) at 1 speed until complete dissolution of sugar occurred, and then speed was increased to 3 for 1 min to make mixture smooth and uniform, followed by speed 1 for 30 s. Vegetable oil, yogurt, vanilla essence (1 mL) and water were added into the mixture and whipped to obtain creamy consistency. All dry ingredients were gradually mixed to this cream using cut and fold method. Grounded chia seeds and soy milk powder were kept soaking in sufficient water for 10 min prior to mixing with sugar. Finally, batter (300 g) was poured into cake mold of 13.1 cm × 13 cm × 4.5 cm size and baked at 180C for 50 min. After baking, cakes were allowed to cool on cooling racks at RT for 1 h and used for further analysis. All batters and cakes were prepared thrice and measurements taken in triplicates for each cake and batter.

Physical Properties of Batters and Cakes

Specific gravity of cake batter was measured by dividing weight of certain volume of batter to weight of same volume of distilled water (Turabi *et al*. 2008). Cake density was calculated as the ratio between weight of 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 was measured with digital calliper according to AACC method 10-91 (AACC 1983).

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

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

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 spectrocolorimeter (Hunter Associate Laboratory Virginia, ModelLX16244) 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 cm × 4 cm × 1.5 cm was taken from the center of the cake. An average of three readings were reported for each sample.

TABLE 3. PHYSICAL PROPERTIES AND TEXTURE PROFILE OF CAKES

Cake	Physical properties					Texture				
	Moisture (%)	Volume of cake (cm³)	Volume index (mm)	Cake density (g/cm³)	Weight loss (%)	Hardness (N)	Springiness	Resilience	Cohesiveness	Chewiness (N)
C1	29.26 ± 0.57^d	551.32 ± 23.39^a	126.60 ± 4.46^b	0.47 ± 0.02^c	14.59 ± 0.97	5.30 ± 0.27^a	0.91 ± 0.01^a	0.51 ± 0.01^a	0.84 ± 0.01^a	4.03 ± 0.14^a
C2	28.26 ± 0.69^d	582.27 ± 14.94^a	133.19 ± 3.50^a	0.44 ± 0.01^c	15.20 ± 1.10	3.47 ± 0.07^c	0.84 ± 0.02^b	0.41 ± 0.01^b	0.79 ± 0.01^b	2.32 ± 0.05^b
T1	37.83 ± 1.54^a	437.12 ± 12.44^b	86.20 ± 3.75^c	0.59 ± 0.02^b	14.80 ± 0.17	3.93 ± 0.48^{bc}	0.85 ± 0.02^b	0.48 ± 0.01^b	0.80 ± 0.01^b	2.69 ± 0.34^b
T2	34.14 ± 0.68^b	359.43 ± 26.51^c	73.19 ± 1.53^c	0.71 ± 0.06^a	15.00 ± 1.48	4.22 ± 0.40^b	0.76 ± 0.02^d	0.36 ± 0.02^c	0.72 ± 0.02^c	2.32 ± 0.26^b
T3	31.44 ± 0.48^c	404.39 ± 6.32^b	67.79 ± 2.94^c	0.63 ± 0.01^b	15.62 ± 1.20	3.29 ± 0.20^c	0.82 ± 0.02^{bc}	0.43 ± 0.00^b	0.77 ± 0.01^b	2.07 ± 0.14^b

C1, Refined flour + egg; C2, composite flour (CF) + egg; T1, CF + banana; T2, CF + chia seeds; T3, CF + Soy milk powder with CF.
Values are expressed as mean ± standard deviation. Means having different letters with in the same column differ significantly at $P < 0.05$ (n = 3).

Rheological Properties of Cake Batters

Batter Flow Behavior. Steady shear properties were obtained at constant temperature (25C) 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 1/s, 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. Data were fitted to Casson (Eq. 1) and Herschel-Bulkley (Eq. 2) rheological models:

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

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

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

where σ is shear stress (Pa) and γ is shear rate (1/s). σ_{0H} is yield stress calculated from Casson model (Eq. 1), K_H is consistency index (Pa s^n) and n_H is flow behavior Index of the model (Rao 2014).

Batter Viscoelastic Behavior. Small amplitude oscillatory shear flow measurements of the storage modulus, G′, loss modulus, G″, and loss tangent, tan $\delta = G''/G'$ were obtained using 50-mm-diameter parallel plates. Batter was placed between plates and gap was adjusted to 2 mm. 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 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 25C ± 0.1C 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 sample container, was used to measure the textural properties of cake batters using TA-XT plus Texture Analyser of Stable Micro Systems, U.K., equipped with a 50 kg-f load cell and operated through software program Texture Expert (Texture Technologies Corp., New York). During the test, disc penetrated to a depth of 30% (of sample height) at 1 mm/s test speed and returned to its original position. Data were recorded at a rate of 200 points per second. Texture quality parameters viz. firmness, consistency, cohesiveness and index of viscosity were
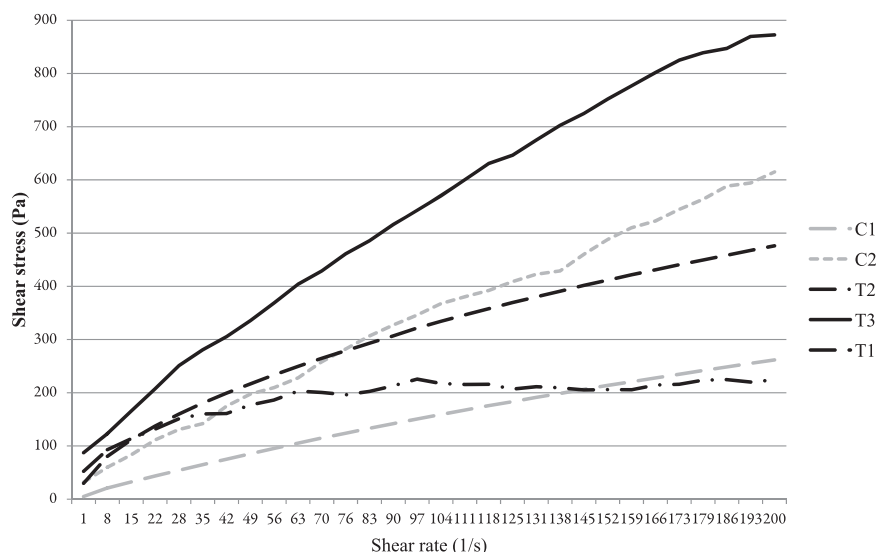
FIG. 1. FLOW CURVE SHOWING SHEAR RATE–SHEAR STRESS RELATIONSHIP OF CAKE BATTERS
C1: Refined flour + egg; C2: composite flour (CF) + egg; T1: CF + banana; T2: CF + chia seeds; T3: CF + Soy milk powder.

estimated using the procedure defined by Angioloni and Collar (2009). All measurements were taken in triplicates.

Cake Texture. Textural characteristics of the cakes were assessed by the above Texture Analyser and the test was performed through two bite compression test before which 1 cm of the crust was removed to make the surface leveled off and crumb piece of size $4 \times 4 \times 1.5$ cm^3 was cut from the center of the cake. Texture Profile Analysis (TPA) was done at pretest speed of 5 mm/s, test and posttest speed of 0.25 mm/s, time interval of 10 s and deformation of 25% using an aluminum 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) (Kotwaliwale *et al.* 2007).

Proximate Analysis

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

Statistical Analysis

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 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 DISCUSSION

Physical Properties of Batter

Batters of control and test cakes were analyzed for physical characteristics (Table 3). Significant difference ($P < 0.05$) was observed among batters for moisture and specific gravity. Among test batters, T1 was found to have highest moisture content which could be due to the addition of banana and yogurt. Specific gravity of T batters was found to be significantly ($P < 0.05$) higher than C batters. Low specific gravity is desired in batter since it indicates more air incorporated, higher foaming ability of egg white proteins compared to egg-replacers. High specific gravity and viscosity of eggless batters made air incorporation difficult as has also been reported by Rahmati and Tehrani (2014). T2 was found to have significantly higher specific gravity probably due to viscous dense nature of chia seeds, which swell considerably after absorbing water, whereas T1 showed lower values indicating better capacity to incorporate air as compared to all egg-replacers.

Batter Texture

The fluid flow properties of cake batter's firmness, consistency, cohesiveness and index of viscosity were analyzed by back extrusion process (Table 2). From the results, it was observed that T batters had significantly ($P < 0.05$) higher value for all textural attributes compared with C batters. T2 batter had significantly ($P < 0.05$) higher value for firmness, consistency, cohesiveness and index of viscosity followed by T3 and T1, which were not significantly different. This increase in attributes may be due to higher batter density of T2 batter as
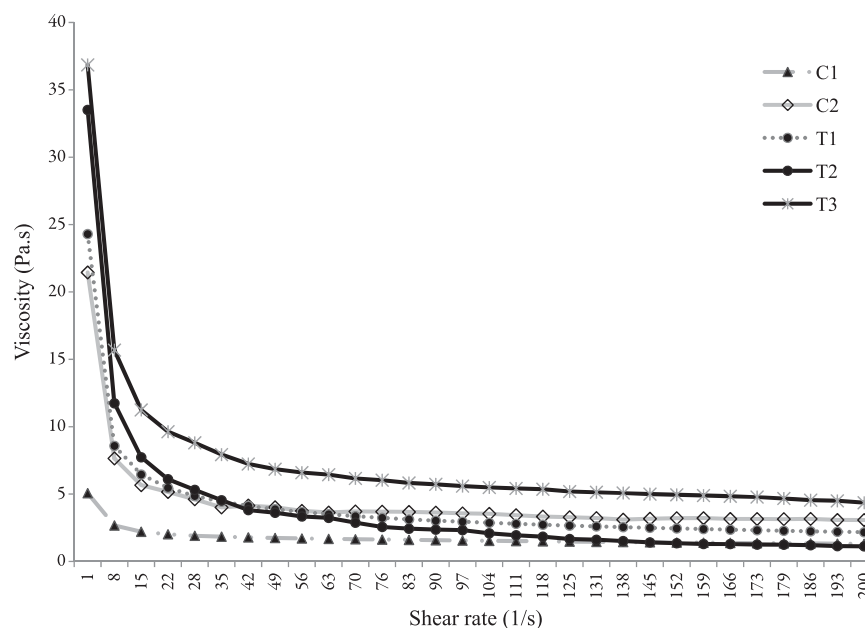
FIG. 2. FLOW CURVE SHOWING SHEAR RATE–APPARENT VISCOSITY RELATIONSHIP OF CAKE BATTERS
C1: Refined flour + egg; C2: composite flour (CF) + egg; T1: CF + banana; T2: CF + chia seeds; T3: CF + Soy milk powder with CF.

well as high water-holding and water-absorption capacity enhancing swelling ability in chia gum resulting in higher viscosity of batter (Segura-Campos *et al.* 2014). Texturally, T1 was closest to both C batters where there was no significant difference (similar superscripts) in parameters between T1 and C1 and C2.

Batter Color Values

Color values of batters represented by *L*, a* and b** values showed significant ($P < 0.05$) difference in values for all batters (Table 3). L* values of T batters and C2 were significantly ($P < 0.05$) lower compared with C1 batter due to the dark color of the CF. Among T batters and C2, T1 had the highest L* value showing a lighter color batter due to addition of yogurt and banana, both light cream in color. T batters also had lower a* and b* value than C2. Carotenoids present in egg yolk

might have contributed in higher a* and b* value of C2 batter. T1 had significantly higher b* value among the test batters, due to banana present in the formulation. However, no significant difference was observed in b* value for T2 and T3.

Rheological Properties of Batters

Flow Behaviour. According to flow curves (Figs.1 and 2), it was observed that the shear stress (Pa) increased with shear rate while apparent viscosity decreased. Curve shape indicated pseudoplastic behavior of cake batters with presence of yield stress. Figure 1 showed that at all shear rate values and shear stress values of T3 sample were higher than other batters. The presence of soy milk powder and CF in T3 could have increased frictional resistance offered by batter in a flow field resulting in increased shear stress. The shear stress values of T2 and C1 were lower than other batters, especially at

TABLE 4. CASSON MODEL AND HERSCHEL BULKLEY MODEL CONSTANTS FOR CONTROL AND TEST CAKE BATTERS

Cake batter	Casson model			Herschel Bulkley model		
	Yield stress (Pa)	Casson plastic viscosity (Pa s)	r^2	Flow behavior index	Consistency index (Pa s^n)	r^2
C1	3.26 ± 0.27[c]	1.09 ± 0.28[b]	1.00 ± 0.00[a]	0.92 ± 0.04[a]	2.20 ± 0.85[b]	0.99 ± 0.02[a]
C2	12.57 ± 6.20[c]	2.27 ± 0.24[a]	1.00 ± 0.01[a]	0.75 ± 0.10[ab]	11.36 ± 6.25[b]	0.98 ± 0.02[a]
T1	29.87 ± 6.95[bc]	1.28 ± 0.07[b]	0.99 ± 0.01[a]	0.71 ± 0.05[ab]	9.88 ± 3.50[b]	1.00 ± 0.00[a]
T2	90.13 ± 28.55[a]	0.30 ± 0.45[c]	0.46 ± 0.48[b]	0.56 ± 0.36[b]	7.55 ± 4.92[b]	0.52 ± 0.44[b]
T3	48.73 ± 16.06[b]	2.72 ± 0.03[a]	1.00 ± 0.01[a]	0.69 ± 0.12[ab]	24.13 ± 12.47[a]	0.97 ± 0.03[a]

C1, Refined flour + egg; C2, composite flour (CF) + egg; T1, CF + banana; T2, CF + chia seeds; T3, CF + Soy milk powder with CF.
Values are expressed as mean ± standard deviation. Means having different letters with in the same column differ significantly at $P < 0.05$ ($n = 3$).
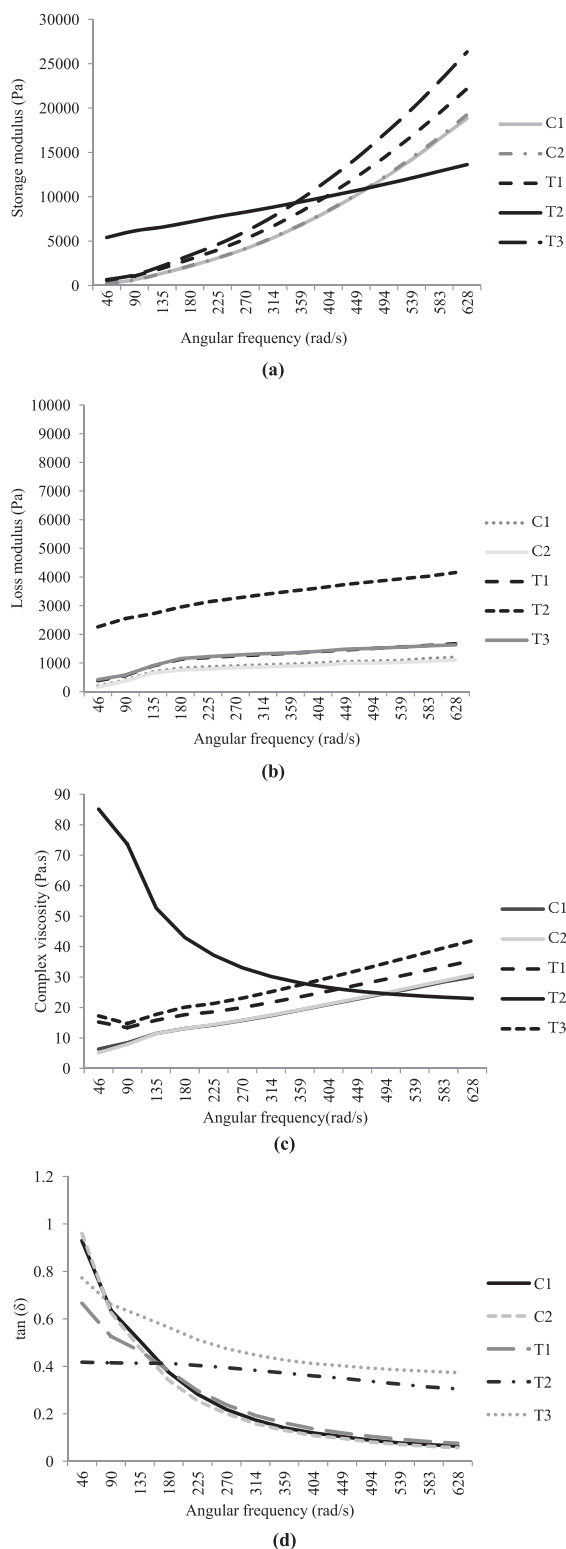r^2: coefficient of determination.

FIG. 3. (A) STORAGE MODULUS, (B) LOSS MODULUS, (C) COMPLEX VISCOSITY AND (D) TAN (δ) PARAMETERS OF CAKE BATTERS
C1: Refined flour + egg; C2: composite flour (CF) + egg; T1: CF + banana; T2: CF + chia seeds; T3: CF + Soy milk powder with CF.

higher stress rates, indicating a lower degree of shear thickening in T2 and C1.

Shear stress (σ) versus shear rate (γ) data obtained for different cake batters were fitted to Casson (Eq. 1) and Herschel Bulkley models (Eq. 2) and are shown in Table 4. Both models fitted poorly for T2 sample as is evident from low values of coefficient of determination ($r^2 = 0.46$ and 0.52). Therefore, in our subsequent explanations, we will disregard the values in T2. Flow behavior index (n_H) of batters ranged from 0.69 to 0.92 which indicated shear thinning behavior due to alignment of microstructure with flow direction and breaking up of agglomerated particles into the smaller ones resulting in increased fluidity (Song *et al*. 2006; Singh and Heldman 2009). Consistency index (K_H) gives an indication of capacity of batter for retaining air (Tan *et al*. 2011). T3 sample had significantly higher value for consistency index than other batters. However, no significant difference was found among C and T1 batters.

Viscoelastic Behaviour. In our study, frequency sweep test was conducted, measuring at 15 different frequencies for storage modulus (G′), loss modulus (G″) and complex viscosity ($\eta^\star$) and have been presented in Figs. 3a–d.

G′ value is a measure of elastic behavior of a sample, while G″ value represents viscous behavior of a sample (Mezger 2002). At lower angular frequencies, T2 showed higher value for G′ and G″ indicating more viscous and elastic behavior whereas C1 and C2 showed lower value indicating less viscous and less elastic behavior. However, at higher angular frequencies, G′ value was found to be higher than G″ value for all batters indicating more elastic behavior. C1 and C2 followed the same trend for G′ and G″. For all the batters, values of G′ were higher than G″ at all frequencies indicating that the cake batter behaved like a gel (Giuseppe *et al*. 2009). Investigation of tan (δ) values (Fig. 3d) for all batters revealed that although G′ and G″ of all samples increased at higher frequency, tan (δ) decreased. This according to Tan *et al*. (2015) suggested that the solid-like property of batter increases at higher frequencies. The phenomenon is more prominent in case of samples C1, C2 and T1. Tan *et al*. (2015) had also observed that batters made from egg also seemed to be more solid and elastic like with higher G′ values than G″ which resulted in lower value of tan (δ). In the current study also C1 and C2 samples containing egg and having lower tan (δ) values have shown more solid like behavior. It is noteworthy that the trends in case of sample T2 are distinctly different from those of other samples. The reason has been explained in the previous section.

Physical Properties of Cakes

Physical properties of T cakes (Table 3) were significantly ($P < 0.05$) higher for moisture, being highest for T1. C cakes

TABLE 5. COLOR PARAMETERS OF CAKE CRUST AND CRUMB AND NUTRIENT CONTENT

Cake	Crust Color					Crumb Color					Nutrient content				
	L^*	a^*	b^*	$\Delta E1$	$\Delta E2$	L^*	a^*	b^*	$\Delta E1$	$\Delta E2$	Protein %	Fat %	Ash %	Phosphorus (mg/100 g)	Iron (mg/100 g)
C1	52.27 ± 1.54[a]	13.66 ± 1.16[a]	31.51 ± 1.01[a]	—	—	63.80 ± 0.51[a]	0.81 ± 0.27[c]	23.84 ± 1.66[a]	—	—	12.9 ± 0.57[b]	20.9 ± 0.43[bc]	0.87 ± 0.01[e]	110.64 ± 3.52[d]	3.14 ± 0.16[e]
C2	41.77 ± 1.18[b]	13.01 ± 0.33[ab]	24.35 ± 1.24[b]	14.89 ± 3.75[b]	—	41.62 ± 0.19[b]	4.69 ± 0.15[b]	15.72 ± 0.81[b]	23.94 ± 0.43[c]	—	14.3 ± 0.21[a]	27.0 ± 2.24[a]	1.70 ± 0.01[d]	207.26 ± 5.30[bc]	6.36 ± 0.49[b]
T1	24.93 ± 1.15[d]	14.09 ± 0.26[a]	17.95 ± 0.77[c]	30.55 ± 1.33[a]	18.06 ± 1.17[a]	32.92 ± 0.86[c]	6.54 ± 0.18[a]	14.24 ± 0.44[b]	32.85 ± 0.81[b]	9.03 ± 0.84[a]	8.8 ± 0.09[d]	19.2 ± 0.14[c]	2.28 ± 0.00[b]	201.55 ± 4.23[c]	5.41 ± 0.08[c]
T2	32.16 ± 1.73[c]	9.25 ± 1.14[c]	14.71 ± 1.30[c]	26.20 ± 2.27[a]	14.15 ± 2.17[a]	32.12 ± 1.91[d]	4.93 ± 0.20[b]	10.79 ± 0.36[d]	34.52 ± 1.62[a]	10.76 ± 1.50[a]	8.3 ± 0.24[e]	21.2 ± 0.23[b]	2.09 ± 0.01[c]	243.25 ± 3.53[a]	4.71 ± 0.27[d]
T3	30.78 ± 1.09[e]	11.50 ± 0.55[b]	15.99 ± 0.70[c]	30.51 ± 6.73[a]	13.90 ± 1.14[a]	32.17 ± 1.01[d]	5.09 ± 0.10[b]	12.51 ± 0.48[c]	33.87 ± 1.08[a]	9.99 ± 1.08[a]	11.9 ± 0.06[c]	22.1 ± 0.18[b]	2.44 ± 0.01[a]	213.30 ± 2.93[b]	8.36 ± 0.39[a]

C1, Refined flour + egg; C2, composite flour (CF) + egg; T1, CF + banana; T2, CF + chia seeds; T3, CF + Soy milk powder with CF.
$\Delta E1$ and $\Delta E2$ are with reference to C1 and C2, respectively.
Values are expressed as mean ± standard deviation. Means having different letters with in the same column differ significantly at $P < 0.05$ ($n = 3$).

had significantly ($P < 0.5$) higher volume, volume index and lower density than T cakes mainly due to unique foaming, emulsifying and heat coagulation properties of egg proteins and water-vaporization during baking. Steam produced during baking helps to form more air cells and to bake cakes of desirable porous internal texture having low density (Rahmati and Tehrani 2015). Therefore, higher ability of soy milk and chia seeds in water absorption, as observed from viscosity values (Table 1), may have reduced the amount of water available to produce steam and therefore, decreased air cells produced in cake crumb. T2 had significantly ($P < 0.05$) lower value for volume and volume index among T cakes. T1 had highest volume with corresponding decrease in cake density which could be attributed to presence of starch, pectin and maltodextrins in banana (Giese 1996). When moist heat is applied to starch, granules gelatinize, forming a mixture of thick, soft and creamy consistency. The gel formed mimics the smooth texture and bland flavor of shortening. An ability of these high-molecular weight carbohydrates is to bind water, which builds body in baked goods better than other simple carbohydrates (Nonaka 1997).

Cake Textural Properties

Textural analysis results for cakes (Table 3) showed that there was significant ($P < 0.05$) difference observed in all cakes for all textural properties. Among controls, C2 showed lower values for all textural attributes when compared with C1, probably due to replacement of refined flour to CF which has less gluten content. Generally, best cakes are obtained from low-protein flour (7–9%) as high protein flour promotes the production of gluten which makes the cake tougher (Al-Dmoor 2013). Our results of decrease in texture attributes value coincide with the findings of Ahmad *et al*. (2010). There was significant difference ($P < 0.5$) in hardness (N) values of C1 and C2 due to CF. Generally, denser masses with lower numbers of gas cells obtain lower resilience values, implying that it will take more time for the structure of cake to recover after compression. T2 had lowest values for resilience indicating more time required to recover its structure after compression.

Cohesiveness quantifies internal resistance of food structure wherein larger the amount of entrapped air in cakes, greater the number of air channels resulting in a less cohesive structure (Matsakidou *et al*. 2010) as seen in T cakes probably due to egg-replacers used in formulation. Chewiness value also followed the same trend as of hardness value for all cakes. Among T cakes, T1 had all textural attributes values closer to C2 indicating high potential of banana to be used as an alternative to egg in cakes.

Cake Color Values

Color values of crust and crumb of cakes are shown in Table 5. The color of crust is generated due to the Maillard reaction which occurs at higher temperature due to caramelization of sugars. Crust of cakes containing CF showed lower L⋆, b⋆ and a⋆ value compared to those obtained for C1 indicating darker, reddish and less yellowish color. The ΔE1 values showed highly significant ($P < 0.5$) differences between C1 and rest of the crusts probably due to malted finger-millet which has a reddish color. In ΔE2, differences in color between C2 and T crusts are due to eggs-replacers used. Cake crumb does not reach temperatures above 100C, so Maillard or caramelization reaction by sugars does not take place to a large extent. Therefore, crumb color must be the result of raw materials colors and their interactions (Gómez *et al*. 2008). Cakes containing CF had lower L⋆ and b⋆ value and higher a⋆ value than C1 indicating more dark, reddish and less yellowish crumb. ΔE1 values showed significant differences between C1 and other crumbs for same reasons explained above; ΔE2 also showed significant differences between C2 and test batter showing that egg-replacers used played a significant role in lower L⋆ and b⋆ and higher a⋆ values. In T1, presence of banana and yogurt lightened the color of crumb.

Nutritional Analysis

Nutritional analysis results have been depicted in Table 5. Protein content was found to be significantly higher for C as compared to T cakes, due to protein-rich egg albumen in formulation. Similarly, T3 had significantly higher protein content followed by T1 and T2, due to inclusion of protein-rich soy milk powder (49% protein) as egg-replacer. Fat content was also found to be highest in C2, due to combined effect of high fat ingredient like egg yolk and CF followed by T2 and T3, due to combined effect of CF with chia seeds (Segura-Campos *et al*. 2014) and soy milk powder (18%), respectively. T1 and C1 obtained lowest value for fat content. Ash content of test and C2 was significantly ($P < 0.05$) higher as compared to C1, which could be due to sprouted finger-millet and amaranth present in CF (Agrahar-Murugkar *et al*. 2015).

CONCLUSIONS

Different types of cakes made using different egg-replacers viz. banana, chia seeds and soy milk powder showed significantly ($P < 0.05$) different values for physical, textural, rheological and organoleptic attributes as compared to cakes made using eggs. For rheological studies, Casson and Herschel Bulkley models were fitted to batters which showed shear thinning behavior of batters. No significant ($P < 0.05$) difference was observed for physical and textural properties of batter between banana and refined flour egg cake. Among test cakes, significantly ($P < 0.05$) higher values for minerals were obtained by soy milk cake and banana cake. Among all

cakes with egg-replacers, banana was at par with control cakes in terms of overall acceptability on 9-point hedonic scale. Thus, it can be concluded that cake made with CF and banana as egg-replacer has high potential to be used as an alternative to refined flour and eggs in cakes.

REFERENCES

AACC International Press. 1983. *Approved Methods of the American Association of Cereal Chemists*, 8th Ed., St. Paul, MN.

AOAC. 1990. *Official Methods of Analysis*, 14th Ed., Association of Official Agricultural Chemists, Washington DC.

AGRAHAR-MURUGKAR, D. and JHA, K. 2009. Effect of sprouting on nutritional and functional characteristics of soybean (*Glycine max* L). J. Food Sci. Technol. *46*, 240–243.

AGRAHAR-MURUGKAR, D., KOTWALIWALE, N., KUMAR, M. and GUPTA, C. 2013. Effect of roasting parameters on soy-butter product quality. Int. J. Food Sci. Technol. *48*, 1359–1365.

AGRAHAR-MURUGKAR, D., GULATI, P., KOTWALIWALE, N. and GUPTA, C. 2015. Evaluation of nutritional, textural and particle size characteristics of dough and biscuits made from composite flours containing sprouted and malted ingredients. J. Food Sci. Technol. *52*, 5129–5137.

AHMAD, I., HAQ, I., ASHRAF, M. and SAEED, M.K. 2010. Profile analysis (tpa) of cakes supplemented with soy flour. Pak. J. Sci. *62*, 22–27.

AHMED, A.R. 2014. Influence of chemical properties of wheat-lupine flour blends on cake quality. Am. J. Food Sci. Technol. *2*, 67–75.

ALAM, M.U., ISLAM, M.Z., HOQUE, M.M. and MONALISA, K. 2014. Effects of drying on the physicochemical and functional properties of green banana (*Musa sapientum*) flour and development of baked products. Am. J. Food Sci. Technol. *2*, 128–133.

AL-DMOOR, H.M. 2013. Cake flour: Functionality and quality (review). Eur. Sci. J. *9*, 1857–7881.

ANGIOLONI, A. and COLLAR, C. 2009. Small and large deformation viscoelastic behaviour of selected fibre blends with gelling properties. Food Hydrocoll. *23*, 742–748.

APARICIO-SAGUILÁNA, A., SÁYAGO-AYERDIB, S.G., VARGAS-TORRESA, A., TOVARC, J., ASCENCIO-OTEROB, T.E. and BELLO-PÉREZA, L.A. 2007. Slowly digestible cookies prepared from resistant starch-rich lintnerized banana starch. J. Food Compost. Anal. *20*, 175–181.

BRESSANI, R. 2003. Amaranth. In *Encyclopedia of Food Sciences and Nutrition*, 2nd Ed. (B. Caballero, ed.) pp. 166–173, Elsevier, Maryland.

CELIK, I., YILMAZ, Y., ISIK, F. and USTUN, O. 2007. Effect of soapwort extract on physical and sensory properties of sponge cakes and rheological properties of sponge cake batters. Food Chem. *101*, 907–911.

DOGAN, I.S., JAVIDIPOUR, I. and AKAN, T. 2007. Effects of inter esterified palm and cotton seed oil blends on cake quality. Int. J. Food Sci. Technol. *42*, 157–164.

GHAVIDEL, R.A. and PRAKASH, J. 2007. The impact of germination and de-hulling on nutrients, anti-nutrients in vitro iron and calcium bioavailability and in vitro starch and protein digestibility of some legume seeds. LWT Food Sci. Technol. *40*, 1292–1299.

GIESE, J. 1996. Fats, oils, and fat replacers. Food Technol. *50*, 78–83.

GIUSEPPE, E.D., FUNICIELLO, F., CORBI, F., RANALLI, G. and MOJOLI, G. 2009. Gelatins as rock analogs: A systematic study of their rheological and physical properties. Tectonophysics *473*, 391–403.

GÓMEZ, M., OLIETE, B., ROSELL, C.M., PANDO, V.C. and FERNANDEZ, E. 2008. Studies on cake quality made of wheat and chickpea flour blends. LWT Food Sci. Technol. *41*, 1701–1709.

HERA, E., RUIZ-PARÍS, E., OLIETE, B. and GÓMEZ, M. 2012. Studies of the quality of cakes made with wheat-lentil composite flours. LWT Food Sci. Technol. *49*, 48–54.

IXTAINA, V.Y., NOLASCO, S.M. and TOM, M.C. 2008. Physical properties of chia (Salvia hispanica L.) seeds. Ind. Crops Prod. *28*, 286–293.

KANAZAWA, K. and SAKAKIBARA, H. 2000. High content of dopamine, a strong antioxidant, in Cavendish banana. J. Agric. Food Chem. *48*, 844–848.

KOHRS, D., HERALDS, T.J., ARMANOUNI, F.M. and ABU GHOUSH, M. 2010. Evaluation of egg-replacers in a yellow cake system. J. Food Agric. *22*, 340–352.

KOTWALIWALE, N., BAKANE, P. and VERMA, A. 2007. Changes in textural and optical properties of oyster mushroom during hot air drying. J. Food Eng. *78*, 1207–1211.

MATSAKIDOU, A., BLEKAS, G. and PARASKEVOPOULOU, A. 2010. Aroma and physical characteristics of cakes prepared by replacing margarine with extra virgin olive oil. LWT Food Sci. Technol. *43*, 949–957.

MEZGER, T.G. 2002. In *The Rheology Handbook: For Users of Rotational and Oscillatory Rheometers* (U. Zorll, ed.), Vincentz Network, Hannover, Germany.

MOHAMED, A., XU, J. and SINGH, M. 2010. Yeast leavened banana-bread: Formulation, processing, colour and texture analysis. Food Chem. *118*, 620–626.

NONAKA, H.H. 1997. Plant carbohydrate derived products as fat replacers and calorie reducers. Cereal Food World *42*, 377–378.

ONUEGBU, N.C., IHEDIOHANMA, N.C., ODUNZE, O.F. and OJUKWU, M. 2013. Efficiency of wheat: Maize composite flour as affected by baking method in bread and cake production. Sky J. Food Sci. *2*, 5–13.

RAHMATI, N.F. and TEHRANI, M.F. 2014. Influence of different emulsifiers on characteristics of eggless cake containing soy milk: Modelling of physical and sensory properties by mixture experimental design. J. Food Sci. Technol. *51*, 1697.

RAHMATI, N.F. and TEHRANI, M.F. 2015. Replacement of egg in cake: Effect of soy milk on quality and sensory characteristics. J. Food Proc. Preserv. J. Food Proc. Preserv. *30*, 574–582.

RAO, M.A. 2014. Flow and functional models for rheological properties of fluid foods. In *Rheology of Fluid, Semisolid, and Solid Foods*, 3rd Ed. (G.V. Barbosa-Canovas, ed.) pp. 27—57, Springer Science + Business Media, New York.

RODRÍGUEZ-GARCÍA, J., PUIG, A., SALVADOR, A. and HERNANDO, I. 2013. Functionality of several cake ingredients: A comprehensive approach. Czech J. Food Sci. Technol. *31*, 355–360.

SEGURA-CAMPOS, M.R., CIAU-SOLÍS, N., ROSADO-RUBIO, G., CHEL-GUERRERO, L. and BETANCUR-ANCONA, D. 2014. Chemical and functional properties of chia seed (Salvia hispanica L.). Int. J. Food Sci. *2014*. doi:10.1155/2014/241053.

SHI, Z., YUAN, B., ZHANG, C., ZHOU, M. and HOLMBOE-OTTESEN, G. 2011. Egg consumption and the risk of diabetes in adults, Jiangsu, China. Nutrition *27*, 194–198.

SINGH, M., LIU, S.X. and VAUGHN, S.F. 2012. Effect of corn bran as dietary fiber addition on baking and sensory quality. Biocatal. Agric. Biotechnol. *1*, 348–352.

SINGH, R.P. and HELDMAN, D.R. 2009. *Introduction to Food Engineering*, 4th ed., pp. 65–185, Elsevier, San Diego, CA.

SONG, K.W., KIM, Y.S. and CHANG, G.S. 2006. Rheology of concentrated xanthan gum solutions: Steady shear flow behavior. Fibers Polym. *7*, 129–138.

SOWMYA, M., JEYARAN, I.T., JYOTSNA, R. and INDRANI, D. 2009. Effect of replacement of fat with sesame oil and additives on rheological, microstructural, quality characteristics and fatty acid profile of cakes. Food Hydrocoll. *23*, 1827–1836.

TAN, M.C., CHIN, N.L. and YUSOF, Y.A. 2011. Power ultrasound aided batter mixing for sponge cake batter. J. Food Eng. *104*, 430–437.

TAN, M.C., CHIN, N.L., YUSOF, Y.A., TAIP, F.S. and ABDULLAH, J. 2015. Improvement of eggless cake structure using ultrasonically treated whey protein. Food Bioprocess Technol. *8*, 605.

TURABI, E., SUMNU, G. and SAHIN, S. 2008. Rheological properties and quality of rice cakes formulated with different gums and an emulsifier blend. Food Hydrocoll. *22*, 305–312.

VISWANATH, V., UROOJ, A. and MALLESHI, N.G. 2009. Evaluation of antioxidant and antimicrobial properties of finger millet polyphenols (Eleusine coracana). Food Chem. *114*, 340–346.

ZEIDANLOO, M.H., GHAVIDEL, R.A. and AFSHAR, S.E. 2014. The evaluation of egg replacement with soy flour and guar gum in oil cake. Int. J. Biosci. *4*, 222–227.