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Physical Properties of Gluten Free Sugar Cookies Containing Teff and Functional Oat Products

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Abstract

Teff-oat composites were developed using gluten free teff flour containing essential amino acids with oat products containing β-glucan known for lowering blood cholesterol and improving texture. The teff-oat composites were used in sugar cookies for improving nutritional and physical properties. Teff and its composites had higher water holding capacities compared to wheat flour. The pasting properties were not significantly influenced by 20% oat product replacements in teff-oat composites. The pasting viscosities of teff-OBC and teff-WOF 4:1 composites were similar to teff flour, but they were all higher than wheat flour. The elastic properties of teff-OBC (oat bran concentrate) and teff-WOF (whole oat flour) doughs were slightly higher than teff dough. Differences were also found in geometrical and textural properties of the doughs and cookies. Overall, the teff-oat cookies were acceptable in colour, flavour, and texture.

Keywords: cookies, oats, texture, functional food, nutrition, elasticity/viscosity

1. Introduction

The important ancient grain Teff (*Eragrostis tef*) is finding resurgence in the modern age. Teff has an excellent nutritional profile with significant levels of minerals including calcium, iron, magnesium, phosphorus, potassium, and zinc. Also, teff is rich in vitamins, such as thiamin (B1), riboflavin, B2), vitamin A and K (USDA Nutrient Database, 2014). Furthermore, teff is high in proteins with an excellent amino acid composition including all 8 essential amino acids for humans that is superior in lysine than wheat or barley along with its high carbohydrates and fiber contents (Taha et al., 2012).

In Egypt, red teff grains are highly recommended for improving of osteoporosis and bone healing. Chemical studies of the red teff seeds reported the isolation of seven compounds from its ethanol extract, namely β-sitosterol , β-amyrin-3-*O*-(2′-acetyl)-glucoside , β-sitosterol-3-*O*-β-D-glucoside , naringenin , naringenin-4′-methoxy-7-*O*-α-L-rhamnoside, eriodictyol-30,7-dimethoxy-4′-*O*-β-D-glucoside and isorhamnetin-3-*O*-rhamnoglucoside. This was the first report on the isolation of compounds β-amyrin-3-*O*-(2′-acetyl)-glucoside and eriodictyol-30,7-dimethoxy-4′-*O*-β-D-glucoside in nature (Taha et al., 2012). A proximate analysis revealed the high nutritive value of the seeds: carbohydrates (57.27%), protein (20.9%), essential amino acids (8.15%) with major leucine and lysine (1.71 and 1.35%, respectively), vitamin B1 (1.56 mg/100 g), and potassium and calcium (32.4 and 9.63%, respectively). The seeds yielded 22% w/w of oil containing 72.46% of unsaturated fatty acids in which oleic acid was predominant (32.41%) following by linolenic acid (23.83%). The ethanolic extract and fixed oil of the seeds exhibited anti-hyperlipedaemic and antihyperglycaemic activities. Oral administration of the fixed oil for 10 days resulted in a rise in serum calcium levels in rats (Taha et al., 2012).

Oat products, such as whole oat flour (WOF) and oat bran concentrate (OBC), contain β-glucan that has beneficial health effects on reducing serum cholesterol and postprandial serum glucose levels (Klopfenstein, 1988). Also, oat products have high viscosities and water holding capacities. In addition, the phenolic and other antioxidant compounds in oats provide health benefits (Madhujith & Shahidi, 2007). Nutrim, oat hydrocolloid with 15% β-glucan, was prepared by steam jet-cooking OBC, sieving, and drum-drying (Inglett, 2000 & 2011). Nutrim containing β-glucan has numerous functional food applications to reduce fat content and calories in a variety of foods (Lee et al., 2004); control the rheology and texture of food products (Rosell et al., 2001); modify starch gelatinization and retrogradation (Rojas et al., 1999; Lee et al., 2005); and also provide freezing/thawing stability (Lee et al., 2002). Rheological and other physical evaluation of jet-cooked oat bran were studied in low calorie cookies by replacing 20% of the shortening with oat β-glucan hydrocolloids. The cookies containing oat hydrocolloid (20% β-glucan), exhibited reduced spreading characteristics and increased elastic properties compared with the control (Lee & Inglett, 2006).

The suitability of teff flour in bread, layer cakes, cookies, and biscuits has been studies (Coleman et al., 2013). However, none of the prior studies included both teff and oat products. Although there are many cookie recipes using teff flour, none were scientifically studied and reported. Thus, oat products containing β-glucan and teff with its distinctive protein profile and gluten free uniqueness were used to produce teff-oat composites, and used in cookies for this research.

In this exploratory study, the teff-oat composites (4:1) were used and evaluated in sugar cookies. The objectives of this study were to evaluate the physical properties of teff-oat composites along with their formulated dough and cookies; to determine if the textures of dough and cookie will be changed by replacing teff with 20 % of oat products; and to determine if the teff-oat cookies are acceptable in the texture, colour, and flavor compared to wheat flour. The physical properties of teff-oat composites and cookies could provide useful information for functional food applications.

2. Materials and Methods

2.1 Ingredients

Teff flour was purchased from Bob's red mill, Milwaukie, OR, USA. OBC (oat bran concentrate) was supplied by Quaker Oats, Chicago, IL, USA. Nutrim (β-glucan hydrocolloid, 15 g/100g) was provided by VDF FutureCeuticals (Momence, IL, USA). Organic whole oat flour colloidal fine (WOF) was provided by Grain Millers (Eugene, OR, USA).

Ingredients were used for cookie: sugar (C&H sugar company, Crockett, CA, USA), brown sugar (C&H sugar company, Crockett, CA, USA), nonfat dry milk (Carnation, Nestlé, Vevey Switzerland), sodium bicarbonate (Arm & Hammer, Church and Dwight, Co., Inc., Princeton, NJ, USA), shortening (Crisco, the J.M. Smucker company, Orrville, OH, USA), ammonium bicarbonate (Calumet, Kraft, Northfield, IL, USA).

2.2 Preparation of Teff-Oat Composites

Teff flour was mixed with Nutrim, OBC, or WOF (4:1, w/w) using a mixer (KitchenAid, St Joseph, MI, USA) for 2 min, respectively. The mixtures were passed through a 20 mesh sieve followed by additional mixing in a mixer for 1 min to obtain the desired consistency.

2.3 Water Holding Capacity of Composites

The water holding capacity (WHC) of the samples was determined by a previous procedure with minor modifications (Ade-Omowaye et al., 2003). Each sample (2 g, dry weight) was mixed with 25 g of distilled water and vigorously mixed for 1 min to a homogenous suspension using a Vortex stirrer, held for 2 h, and centrifuged at 1,590 *g* for 10 min. Each treatment was replicated twice. Water-holding capacity was calculated by the difference between the weight of water added and decanted on dry basis (g of water absorbed /100 g of dry sample).

2.4 Pasting Property Measurement of Composites

The pasting properties of teff, oat composites, and wheat flour were evaluated using a Rapid Visco Analyzer (RVA-4, Perten Scientific, Springfield, IL). Samples (2.24 g, dry basis) were made up to a total weight of 28 g with distilled water in a RVA canister (8% solids, w/w). The viscosity of the suspensions was monitored during the following heating and cooling stages. Suspensions were equilibrated at 50°C for 1 min, heated to 95°C at a rate of 6.0°C/min, maintained at 95°C for 5 min, and cooled to 50°C at rate of 6.0°C/min, and held at 50°C for 2 min. For all test measurements, a constant paddle rotating speed (160 rpm) was used throughout the entire analysis except for 920 rpm in the first 10s to disperse sample. Each sample was analyzed in duplicate. The results were expressed in Rapid Visco Analyser units (RVU, 1 RVU = 12 centipoises).

2.5 Cookie Formulation and Preparation

Cookie flour formulations are teff flour; teff -Nutrim composites 4:1; teff-OBC composites 4:1; teff-WOF composites 4:1; and wheat flour. Cookies were prepared following AACC method 10-52 for sugar cookie as described by an earlier study with modifications (AACC International, 2000; Lee & Inglett, 2006). Sugar (72 g), brown sugar (22.5 g), Nonfat dry milk (2.3 g), salt (2.8g), and sodium bicarbonate (2.3 g) were mixed using a whisk in a bowl. The mixture was placed on top of shortening (100 g), and blended with a paddle beater in a mixing bowl using a KitchenAid mixer (St Joseph, MI, USA) at speed 2 for 3 min, scraping down every minute. The mixture of water (49.5 g) containing ammonium bicarbonate (1.1 g) was added and mixed for 1 min at speed 1. After scraping down, they were mixed for another minute at speed 2. Teff, or teff-oat composites (4:1), or wheat flour (225 g) were added while mixing at speed 1, and continued mixing for 2 min at speed 2 with scraping every 30 s. Dough was flattened by using a rolling pin on a board with 7 mm gauge strips, and cut by a cookie cutter of 6 cm diameter. Cookies were baked at 205 °C in a convention oven (XAF-113 LineChef Stefania, Cadco, Ltd. Winsted, CT, USA) for 10 min, and cooled. The cookies were stored in a sealed plastic bag before measurements were taken.

2.6 Rheological Properties of Dough

A sample was loaded on a 2 cm diameter X-hatch parallel stainless plate with a 2 mm gap using a rheometer (AR 2000, TA Instruments, New Castle, DE, USA). The outer edge of the plate was sealed with a thin layer of mineral oil (Sigma Chemical Co., St Louis, MO, USA) to prevent dehydration during the test. All rheological measurements were carried out at 25°C using a water circulation system within ± 0.1°C. A strain sweep experiment was conducted initially to determine the limits of linear viscoelasticity; then a frequency sweep test was carried out to obtain storage modulus (G') and loss modulus (G") at frequencies ranging from 0.1 to 100 rad s^{-1}. A strain of 0.5 within the linear viscoelastic range was used for the dynamic experiments. All rheological measurements for samples were performed in duplicate.

2.7 Water Loss, Moisture Content, and Water Activity

Water losses during baking were measured by the weight of the difference before and after baking. After grinding three cookies with a pestle in a mortar, moisture content and water activity were measured. Moisture contents of cookies were determined by drying 5 g of sample at 105 °C to a constant weight (about 3-4 h). The water activity was measured using an Aqua Lab water activity meter (Decagon Devices Inc., Pullman, WA, USA).

2.8 Geometrical Properties

Six cookies were placed next to each other and the total diameter was measured. They were rotated by 90° and measured three more times. The average of four measurements was divided by six to calculate the average diameter of a cookie. To measure the height, six cookies were stacked, measured, restacked in different order, and measured again. The average cookie height was the mean of three readings divided by six. The spread ratio was calculated by dividing the diameter by the height. Nine measurements for each replicate were taken.

2.9 Colour

The colour of the cookies was measured with a Hunter Lab spectrocolorimeter (Labscan XE, Hunter Associates Laboratory Inc., Reston, VA, USA). The colorimeter was calibrated using a standard white plate. The colour values $L*$, $a*$, $b*$ were measured with a C illuminant and a 10° standard observer. The dimension $L*$ means lightness with 100 for white and 0 for black. The value $a*$ indicates redness when positive and greenness when negative. The value $b*$ indicates yellowness when positive.

2.10 Texture Analysis

Dough hardness was measured using a TA-XT2 Texture Analyzer equipped with 5 kg load cell in compression mode by penetrating with a flat probe of 5 mm diameter. The cookie dough (110 g) was gradually and evenly placed in a dough cell while compressing and flatting the surface by a plunger to avoid randomly distributed air pockets as a potential cause of variability in consistency measurements. The test was conducted at a pre-test speed of 2.00 mm s^{-1} and test speed of 3 mm s^{-1}, post-test speed of 10.0 mm s^{-1}, and distance of 20 mm.

Cookie hardness was measured using a recommended method of TA-XT2 Texture Analyzer (Texture Technology Crop., Scarsdale, New York, USA) equipped with 30 kg loading cell. The cookie hardness measurement was conducted by a cutting force using a three-point bending method with sharp-blade probe (6 cm long and 1 mm thick). The hardness of the cookies was indicated by the maximum peak force required to break the cookies. The slotted inserts were adjusted and secured on the Heavy Duty Platform to fit sample size and position centrally under the knife edge. The cookie was rested on two supporting beams spaced at a distance of 3 cm. The instrument was set to ‘return to start’ cycle, a pre-test speed of 1.5 mm s^{-1}, test speed of 2.0 mm s^{-1}, post-test speed of 10 mm s^{-1}, and a distance of 5.0 mm.

2.11 Sensory Evaluation

Cookies were evaluated by 26 untrained consumers. A scorecard was evaluated for attributes including surface colour, texture, flavour, and overall quality. The panelist assigned scores for each parameter using a 9-point hedonic scale.

2.12 Statistical Analysis

All data from replicated samples were analyzed with analysis of variance using Duncan’s multiple comparison to determine significant differences ($P< 0.05$) between treatments (SAS Institute, 1999, Rayleigh, North Carolina, USA).

3. Results and Discussion

3.1 Nutritional Composition

Teff has endured the ages from early civilizations as an important food of a highly nutritious gluten-free grain. Teff contains the highest levels of sugar, calcium, iron, potassium, and zinc whereas oat contains the highest magnesium and phosphorus contents among products (Table 1). Also, teff contains protein (13.3%) that is similar to protein in oat (13.7%) but higher than protein in whole wheat flour (13.2%), rice (5.95%) and corn (9.42%). In addition, teff and oat are rich in vitamins. Teff contains the highest vitamin B2 while oat has the highest thiamin (B1) among all products in the Table 1. All B vitamins help the body to convert carbohydrates into energy. Vitamin B2 is important for normal vision along with other nutrients. Some early evidence shows that vitamin B2 (riboflavin) might help prevent cataracts which can lead to cloudy vision (University of Maryland Medical Center, 2013). Vitamin B1 helps the body metabolize fats and protein, and is required for healthy skin, hair, eyes, and liver. It also helps the nervous system and brain function properly (University of Maryland Medical Center, 2013). Remarkably, only teff and oat contain vitamin K among all products in Table 1. Vitamin K is a fat-soluble vitamin that the body stores it in fat tissue and liver. It is best known for its role in helping blood clot and bone health (University of Maryland Medical Center, 2013). Oat was selected in this study because of its β-glucan content that is helpful for lowering blood cholesterol and improving food texture. Moreover, oat has high quality lipids including monounsaturated and polyunsaturated fatty acid. Therefore, the nutritional value of gluten free baked products could be improved by adding the ancient grain teff and oat products to recipes compared to cookies with wheat flour.

3.2 Water Holding Capacities (WHC)

Nutrim had the highest water-holding capacity (603.0 g /100g) while wheat flour had the lowest water-holding capacity (93.8g/100g) among all the starting materials (Figure 1). Nutrim was produced by jet-cooking technology using thermal-shearing forces to promote molecular breakdown that probably contributed to increased water absorption (Inglett, 2000; Lee & Inglett, 2006). The trend of WHC for wheat flour (93.8 g/100g), WOF (158.2 g/100g), OBC (339.5 g/100g), and Nutrim (603.0 g/100g) appeared to be related to their β-glucan contents (wheat flour, 1.2 g/100g; WOF, 3.9-7.5 g/100g; OBC,12.0 g/100g; Nutrim,15.5 g/100g; Kim, Inglett, & Liu, 2008), suggesting β-glucan may be an important factor for WHC.

In general, the WHC of 4:1 composites for teff-Nutrim (135.3g/100g), teff-OBC (139.3g/100g), and teff-WOF (137.7g/100g) were all higher than wheat flour (93.8 g /100 g). Also, the actual WHC values of teff-Nutrim (135.3 g/100g), teff-OBC (139.3 g/100g), and teff-WOF (137.7 g/100g) were all much lower than theoretical WHC values that were calculated by using the actual WHC values of the starting materials (teff-Nutrim, 228.5 g/100g; teff-OBC, 175.8g/100g; teff-WOF 158.2 g/100g), respectively. Teff flour contains 13.3% protein and is rich in calcium and magnesium (Table 1). It is possible that the calcium and magnesium in teff reacted with protein causing precipitation that resulted in a reduction in WHC. It could be a similar mechanism involved in making tofu by coagulating proteins in soymilk with calcium or magnesium sulfate. The proteins coagulate when bonding occurs between the positively charged calcium ions and negatively charged anionic groups of the protein molecules resulting in protein clumping and the removal of insoluble material from solution. Nutrim was produced by jet-cooking that may possibly produce anionic groups on the surface that could allow interactions with protein and calcium in teff. Those results suggested an interaction between Nutrim and OBC with teff. Teff-oat composites could be widely used in different applications in the food industry because of improved WHC compared to wheat flour alone. These composites are notable for thickening properties, syneresis control, and emulsion stabilization along with their nutrients.

Table 1. Comparison of teff composition with other cereals

Nutrient	Unit	teff	rice	corn	whole wheat	oat
		per 100 g	per 100 g	per 100 g	per 100 g	per 100 g
Proximates						
Water	g	8.82	11.89	10.37	10.74	9.37
Energy	kcal	367	366	365	340	371
Protein	g	13.3	5.95	9.42	13.21	13.7
Total lipid (fat)	g	2.38	1.42	4.74	2.5	6.87
Carbohydrate, by difference	g	73.13	80.13	74.26	71.97	68.18
Fiber, total dietary	g	8	2.4	7.3	10.7	9.4
Sugars, total	g	1.84	0.12	0.64	0.41	1.42
Minerals						
Calcium, Ca	mg	180	10	7	34	47
Iron, Fe	mg	7.63	0.35	2.71	3.6	4.64
Magnesium, Mg	mg	184	35	127	137	270
Phosphorus, P	mg	429	98	210	357	458
Potassium, K	mg	427	76	287	363	358
Sodium, Na	mg	12	-	35	2	3
Zinc, Zn	mg	3.63	0.8	2.21	2.6	3.2
Vitamins						
Thiamin (vitamin B1)	mg	0.39	0.138	0.385	0.502	0.54
Riboflavin (vitamin B2	mg	0.27	0.021	0.201	0.165	0.12
Niacin	mg	3.363	2.59	3.627	4.957	0.82
Vitamin B-6	mg	0.482	0.436	0.622	0.407	0.1
Folate, DFE	µg		4	19	44	32
Vitamin B-12	µg	-	-	-	-	-
Vitamin A, RAE	µg	-	-	11	-	-
Vitamin A, IU	IU	9	-	214	9	-
Vitamin E (alpha-tocopherol)	mg	0.08	0.11	0.49	0.71	0.7
Vitamin K (phylloquinone)	µg	1.9	-	-	-	3.2
Lipids						
Fatty acids, total saturated	g	0.449	0.386	0.667	0.43	1.11
Fatty acids, total monounsaturated	g	0.589	0.442	1.251	0.283	1.98
Fatty acids, total polyunsaturated	g	1.071	0.379	2.163	1.167	2.3

Data were selected from USDA nutrient data base. Teff : uncooked; rice: white, flour; corn: grain, yellow; whole wheat: whole wheat grain flour; oat: Quick Oats, dry.

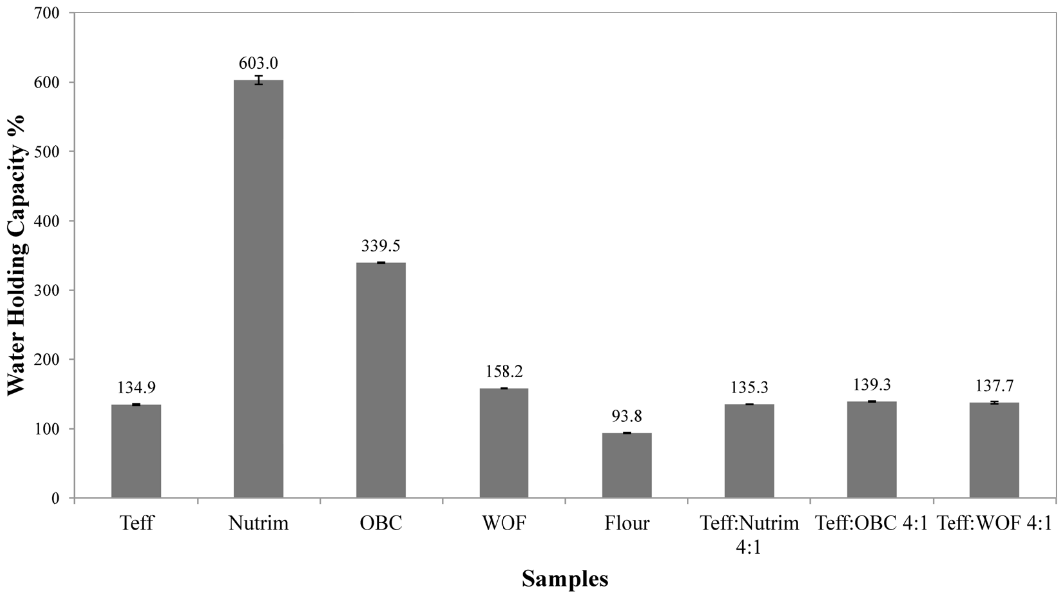

Figure 1. Water holding capacities of starting ingredients and teff-oat composites

3.3 RVA Pasting Properties of Composites

The pasting curves of all starting materials showed dissimilar patterns (Figure 2). The pasting viscosity curve of Nutrim increased sharply (~23 RVU/min) and showed a significantly high initial peak (~250 RVU) at 11 min (90°C), followed by a rapid decrease in viscosity to ~ 25 RVU during continued heating. The Nutrim viscosity slightly increased during cooling showing a considerably low final viscosity (~58 RVU) that was slightly higher than teff flour (~50 RVU). It is known that the viscosity of a completely gelatinized starch slurry decreases during heating (Guha et al., 1998). These characteristics are common for pregelatinized flour (Lai & Cheng, 2004) and typical for Nutrim since it had undergone jet-cooking during preparation where starch gelatinization occurred. The viscosity of OBC increased gradually (~7 RUV/min) to the initial peak (~100 RVU) after temperature reaching 95°C, remained almost constant viscosity during continued heating and shearing, and then increased sharply (~10 RVU/min) during cooling resulting in a considerably high final viscosity (~210 RVU). This high viscosity could be due to starch gelatinization resulting in an entanglement of molecules during cooling to form a matrix with greater stability under heating and shearing. WOF had a lower initial viscosity peak (~ 50 RVU) than Nutrim and OBC at 95°C, showing a small breakdown (peak viscosity minus the lowest point of viscosity after peak), and then slowly increased to a final viscosity (~89 RVU) that was lower than OBC but higher than the rest of the starting materials. The viscosity of teff showed a lower initial peak (~26 RVU) than all oat products but slightly higher than wheat flour (~16 RVU), and remained constant during heating and shearing, and reached a final viscosity (~50 RVU) similar to Nutrim during cooling. The wheat flour showed the lowest initial peak (~16 RVU) and final peak (~17 RVU) among all samples. The trend of initial peaks from wheat flour (~16 RVU), WOF (~48 RVU), OBC (~100 RVU), and Nutrim (~250 RVU) appeared to be related to their β-glucan contents (1.2 g/100g, 8 g/100g, 12 g/100g and 15 g/100g) as shown for water holding capacity.

In general, teff-OBC and teff-WOF 4:1 composites showed similar viscosities of initial and final peak compared to teff, indicating they would have similar viscosity properties after shearing and cooking (Figure 3). The initial peak of teff-Nutrim 4:1 (~17 RVU) was tremendously lower than Nutrim (~250 RVU). Also, the initial peak viscosity of teff-Nutrim 4:1 (~17 RVU) was lower than the teff-OBC (~22 RVU), teff-WOF 4:1 (~29 RVU) composites, and teff (~27 RVU). It suggested possible interactions between teff with Nutrim as showed by WHC. Overall, all teff-oat composites had higher final viscosities than wheat flour. It may be due to the protein of teff bonded with beta-glucan from oat products after heating. Higher initial peak viscosity was related to starch gelatinization whereas higher final peak viscosities suggested stability after heating and shearing. All teff-oat composites showed increased water holding and pasting viscosities with increasing oat contents compared to wheat flour. However, they were only significantly influenced by 80% oat products in teff-oat composites in a previous study (Inglett et al., 2015). Improvement in the textural properties of food using oat β-glucan hydrocolloids has been reported (Lee & Inglett, 2006). The RVA data were useful for providing information on food products.

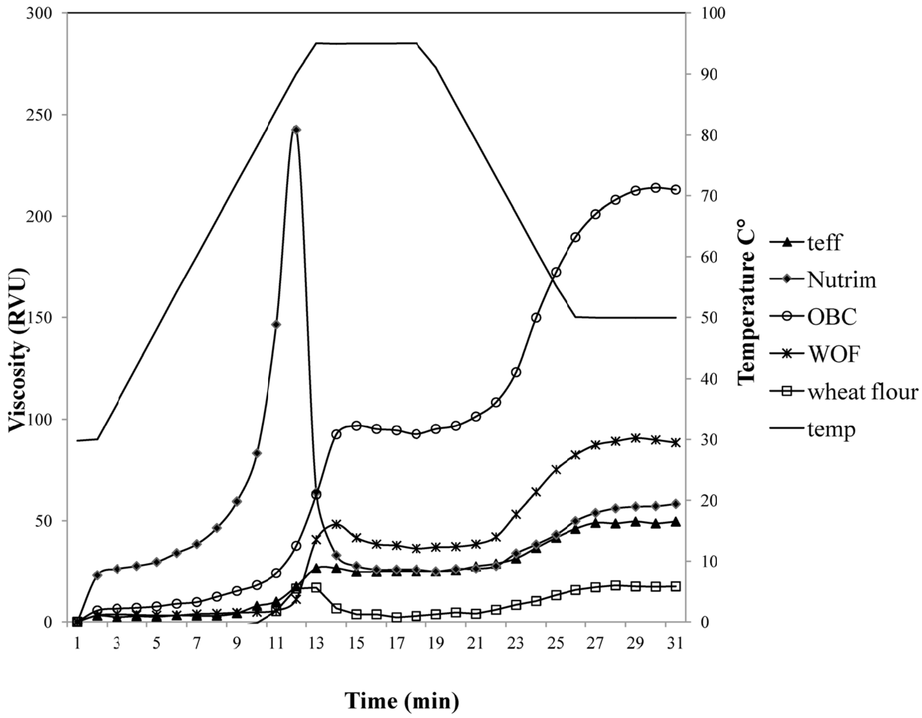

Figure 2. Pasting properties of starting ingredients

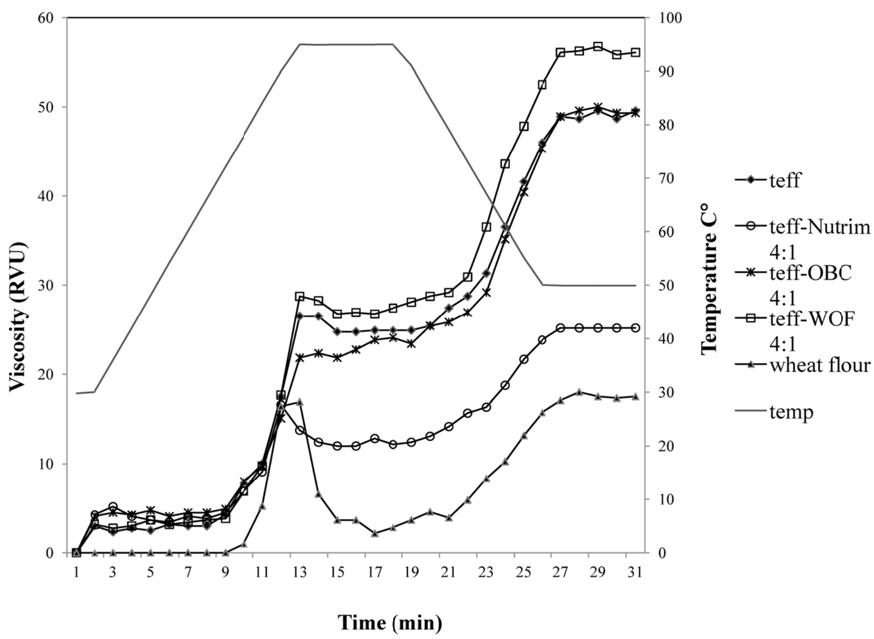

Figure 3. Pasting properties of teff-oat composites

3.4 Rheological Properties of Dough

The dynamic viscoelastic properties of product have been related to the quality of food products (Lee & Inglett, 2006). The G' elastic (storage) and G" viscous (loss) moduli against frequencies for all the doughs are displayed in Figure 4. Both moduli (G' and G") for all samples were increased with increasing frequencies, showing frequency dependence. Furthermore, elastic moduli G' were greater than viscous G" throughout the frequency range for all samples at different levels with the exclusion of dough containing teff-OBC composite. The storage modulus of the sample was higher than the loss modulus, indicating that the sample could be classified rheologically as having a higher predominance of the elastic properties versus the viscous properties (Lai & Liao, 2002). In contrast, the viscous modulus G" of dough containing teff-OBC composites was higher than the elastic modulus G' suggesting a more viscous than elastic nature was predominant in teff-OBC dough. It is probably due to the components and structures of OBC since corn bran in OBC that could not easily form elastic dough before heating. The highest elastic G' and loss G" moduli were observed for dough containing teff-WOF composites, followed by dough with teff and then teff-Nutrim. However, G' values for dough containing teff, teff-WOF, and teff-Nutrim were similar indicating related properties. The values of storage G' and loss G" moduli for wheat flour dough were considerably lower than other doughs. It suggested that dough containing teff or teff-WOF and teff-Nutrim composites could have higher elastic properties than wheat flour dough.

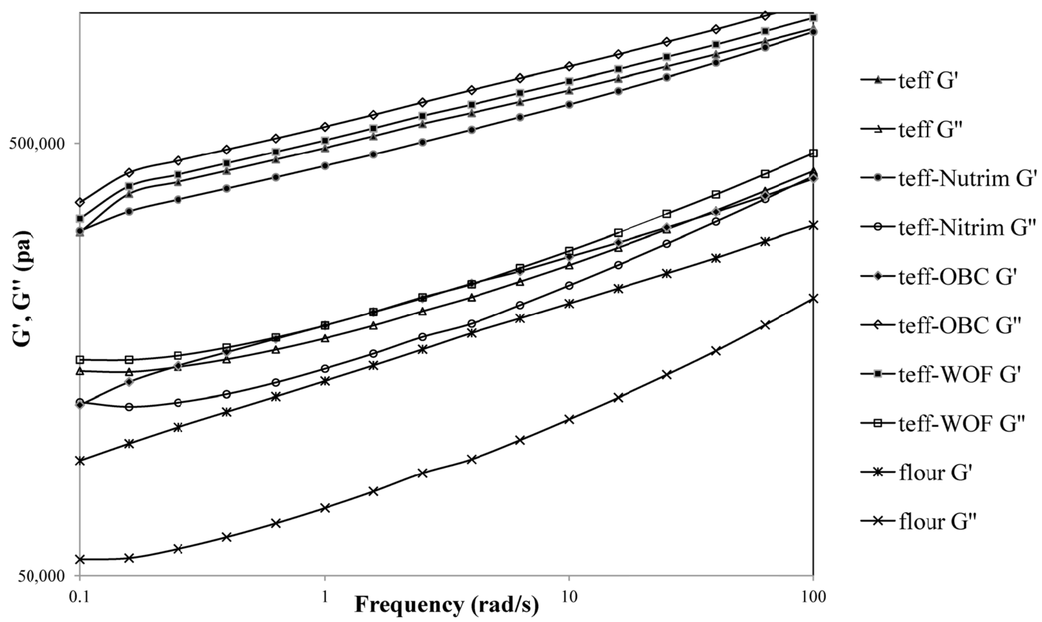

Figure 4. Dynamic viscoelastic properties of cookie doughs containing teff, teff-oat 4:1 composites, and wheat flour

Furthermore, these rheological patterns of the doughs were also confirmed by the tan δ values (loss modulus G"/storage modulus G') (Fig. 5). The values of tan δ clearly describe the ratio of energy lost to the amount of energy stored during a test cycle. The phase shift δ is defined by $\delta = \tan^{-1}(G''/G')$ which indicates whether a material is solid (δ= 0°), liquid (δ= 90°), or between (0° < δ< 90°). Therefore, the values of tan δ are from zero to infinity; and tan δ = 1 means G' = G", tan δ <1 represents G'>G", and tan δ >1 indicates G'<G". With the exception of teff-OBC, the tan δ values for all doughs were less than 1 representing G'>G". The tan δ values for doughs containing teff, teff-Nutrim, and teff- WOF composites were very similar across the entire frequency spectrum ranging from 0.33 to 0.49. The tan δ for wheat flour dough had a similar behavior that was 0.1 higher than the doughs containing teff, teff-Nutrim, and teff-WOF. It indicated wheat flour dough had slightly more viscous properties than the dough containing teff, teff-Nutrim, and teff-WOF. Interestingly, the tan δ values for teff-OBC dough ranged from 2.5 to 2.9. Also, the slightly decreased tan δ trend was observed with the increased frequency for teff-OBC dough. It demonstrated that loss modulus G" of teff-OBC dough was decreased with frequency showing more viscous property which may be attributed to some components and structures of OBC. These rheological data appeared to indicate that the cookie dough containing the teff and teff-Nutrim or teff-WOF had more elastic nature than wheat flour whereas teff-OBC dough had more viscous properties than wheat flour.

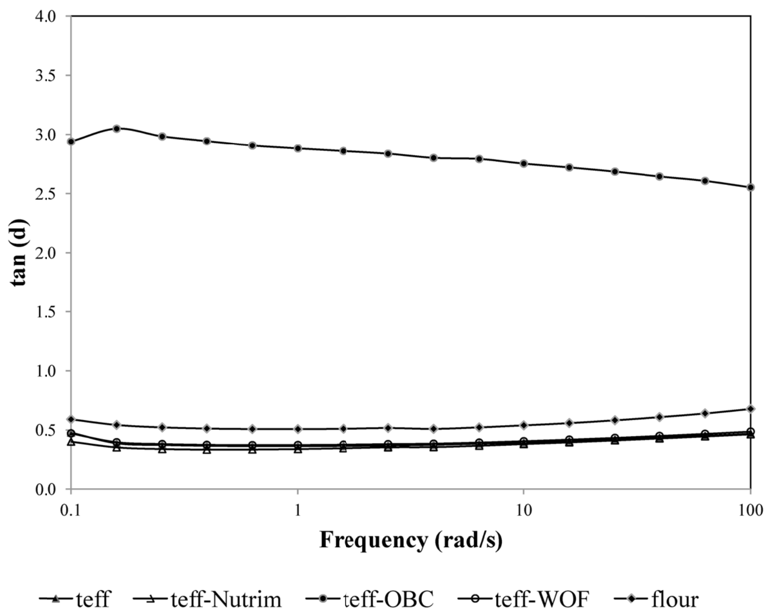

Figure 5. Values of tan (δ) versus frequencies (rad/s) for cookie doughs containing teff, teff-oat 4:1 composites, and wheat flour

3.5 Geometrical Properties of Cookies

Cookie qualities were determined by width, thickness, and cookie spread factor. It was evident from the results that the width was affected by the addition of teff flour. The largest diameter (6.57 cm) was observed for wheat flour cookies and the smallest diameter (5.92 cm) for teff-Nutrim cookies (Table 2). Baking powder released carbon dioxide gas into a batter or dough through an acid-base reaction, causing bubbles in the wet mixture to expand the volume. The smallest diameter value of cookies using teff-Nutrim may be attributed to high WHC that makes dough less expandable compared to the dough with wheat flour. The cookies using teff-OBC composites had the highest thickness (1.28 cm) whereas the cookie containing teff-Nutrim composites had the lowest thickness (1.12 cm, Table 2). The results showed that the width of the cookies using teff, teff-Nutrim, teff-OBC, and teff-WOF decreased ~6, 9, 6, 4 % while the thickness of the cookies using teff, teff-Nutrim, teff-OBC, and teff-WOF decreased ~6, 10, 0, 2% compared to cookies with wheat flour, respectively. The thickness of the cookies using teff-OBC was slightly increased compared with wheat flour cookies probably because oat bran in OBC expanded after heating and absorbing water. The differences were also found in the spread factor. Teff-Nutrim composites had the highest spread ratio (5.30) while the cookie containing teff-OBC composite had the lowest (4.83). In general, higher cookie spread factor indicates higher quality cookies. It was clear from the results that diameter, thickness, and spread factor were not greatly influenced by the use of teff flour and its oat composites compared to cookies with wheat flour.

Table 2. The geometrical properties of cookies

	Width		Thickness		Spread factor
	before bake Cm	after bake cm	before bake cm	after bake cm	width/thickness
Teff	6	6.18 ± 0.01 c	0.7	1.19 ± 0.01 d	5.21 ±0. 05 b
Teff: Nutrim 4:1	6	5.92 ± 0.00 d	0.7	1.12 ± 0.00 e	5.30 ± 0.00 a
Teff: OBC 4:1	6	6.18 ± 0.02 c	0.7	1.28 ± 0.01 a	4.83 ± 0.02 d
Teff :WOF 4:1	6	6.30 ± 0.02 b	0.7	1.24 ± 0.01 c	5.08 ± 0.04 c
Wheat flour	6	6.57 ± 0.01 a	0.7	1.26 ± 0.01 b	5.23 ± 0.03 b

Means ± standard deviation; n=3; means followed by the same letter within the same column are not significantly different (*P>0.05*).

3.6 Colour of Cookies

The cookies containing teff were dark in colour (L^*: 35.2) compared with the other cookies since the dimension L^* means lightness with 100 for white and 0 for black (Table 3). The value a^* indicates redness when positive and greenness when negative. All the cookies showed the redness in different degrees. The a^* value (14.09) of wheat flour cookies was the highest indicating more redness than the other cookies. All the cookies also showed the yellowness in different degree since b^* indicates yellowness when positive. All the cookies showed the yellowness in different degrees. Wheat flour cookies (b^*: 32.49) had the highest value of yellowness among the cookies. In general, ground cookie powders were lighter with less redness and more yellowness compared to the surface colour of cookies with some exceptions.

Table 3. The colour profile of cookies

	Colour (surface)		
	*L**	*a**	*b**
Teff	35.20± 0.97 d	8.08 ±0.15 c	15.98 ± 0.33 d
Teff: Nutrim 4:1	36.19 ± 0.80 cd	7.90 ± 0.52 c	17.72 ± 0.34 c
Teff: OBC 4:1	37.22 ±0.32 bc	9.18 ± 0.36 b	19.09 ± 0.25 b
Teff :WOF 4:1	37.77 ± 0.57 b	9.10 ± 0.34 b	18.97 ±0.18 b
Wheat flour	52.30± 1.58 a	14.09 ± 0.49 a	32.49 ± 0.55 a
	Colour (ground powder)		
	*L**	*a**	*b**
Teff	34.05 ± 0.90 e	8.84 ±0.19 b	19.91 ± 0.61 e
Teff: Nutrim 4:1	45.62 ± 0.49 b	7.29 ± 0.20 d	24.85 ± 0..47 b
Teff: OBC 4:1	38.41 ±0.12 d	8.96 ± 0.09 b	22.36 ± 0.74 d
Teff :WOF 4:1	43.10 ± 0.67 c	8.12 ± 0.31 b	23.35 ±0.44 c
Wheat flour	56.64 ± 0.23 a	10.20 ± 0.11 a	30.39 ± 0.22 a

Means ± standard deviation; n=3; means followed by the same letter within the same column are not significantly different ($P>0.05$).

3.7 Water Loss, Moisture Content, and Water Activity

Cookies with teff flour had the lowest water loss (9.95%) that was similar to cookies with teff-Nutrim (10.05%) and teff-WOF (10.11%) composites but they were lower than cookies with teff-OBC (10.44%) and wheat flour (10.32%, Table 4). Water losses during cooking ranged from 9.95% to 10.47%. All the cookies had similar moisture contents from 3.55% to 3.84%. Moisture is an important aspect of food stability and shelf-life. The growth and metabolic activities of bacteria, molds, and yeasts are retarded and eventually inhibited as the water activities (aw) of foods are decreased. Water activity of the cookies ranged from 0.246 to 0.298 (Table 4). They were much lower than the limit of *water activity* for spoilage *by bacteria,* yeasts and molds, approximately 0.90, 0.85-0.88, and 0.80, respectively. The rate of chemical reactions in food decreases much more slowly with reduced moisture content. Also, the enzymatic activity in foods may be significant at water activities as low as 0.30 (Smith, 2007). Additionally, water activity level affects lipid oxidation rates. Lipid oxidation is typically lowest when almond water activity (a_w) was ~0.25 to 0.35 (~3–4% moisture content), and increased above or below that water activity range (Huang, 2014). Overall, the differences were not intensive in water losses, moistures, and water activities among all cookies.

Table 4. The water loss during baking, moisture, and water activity

Products	Water loss during baking %	moisture %	Water activity (a_w)
Teff	9.95 ± 0.03 d	3.69 ±0.005 c	0.275±0.005 b
Teff: Nutrim 4:1	10.08 ± 0.04 cd	3.99 ±0.03 a	0.298±0.003 a
Teff: OBC 4:1	10.47 ± 0.05 a	3.86± 0.03 b	0.279 ±0.014 b
Teff :WOF 4:1	10.12 ± 0.01 c	3.70 ±0.05 c	0.268 ± 0.008 b
Wheat flour	10.35 ± 0.03 b	3.55 ±0.05 d	0.246 ± 0.006 c

Means ± standard deviation; n=3; means followed by the same letter within the same column are not significantly different (*P>0.05*).

3.8 Texture of Dough and Cookies

The texture evaluations of dough and cookies were presented in Table 5. The cookie dough containing teff-Nutrim had the highest texture value (6.28 N), followed by cookie dough containing teff-OBC (4.51 N) tested by a penetrating force using a 5 mm diameter probe. The cookie dough using teff flour had the lowest hardness value (2.55 N). The dough hardness from teff-WOF composites (3.73 N) was higher than both doughs with wheat (3.14 N) and with teff flour (2.55 N). The cookie dough hardness appeared to be related to WHC. The highest dough hardness value was from cookies containing teff-Nutrim composites with the highest WHC. In contrast, the cookies containing teff-Nutrim required the least cutting force (28.44 N) to break the cookies. The cookies containing wheat flour required the maximum cutting force (94.34 N) to break the cookies. It indicated that dough texture properties were greatly changed after heating. Hoseney and Rogers reported that hardness of the cookies was caused by the interaction of proteins and starch by hydrogen bonding (Hoseney & Rogers, 1994).

Table 5. The texture of cookies and dough

Products	Dough hardness Penetrating Force (N)	Cookie hardness Cutting force (N)
Teff	2.55 ± 0.10 e	64.33 ± 2.45 b
Teff: Nutrim 4:1	6.28 ± 0.10 a	28.44 ± 0.39 d
Teff: OBC 4:1	4.51 ± 0.20 b	57.27 ± 5.20 c
Teff :WOF 4:1	3.73 ±0.10 c	55.90 ± 3.92 c
Wheat flour	3.14 ±0.10 d	94.34 ± 4.41 a

Means ± standard deviation; n=3; means followed by the same letter within the same column are not significantly different (*P>0.05*).

3.9 Sensory Evaluation

The score for colour, texture, flavour, and overall ranged from 6.2 to 7.4, 6.4 to 7.2, 6.0 to 6.8, and 6.2 to 7.2, respectively based on the panelist assigned scores for each parameter using a 9-point hedonic scale (Table 6). The statistical results indicated that no significant differences were found in texture, flavour, and overall quality among cookies (Table 6). These results may be due to the fact that only a small portion (20%) was replaced by oat products, and also both teff and oat apparently had no distinct difference in flavour compared to wheat flour. In addition, the same formulation was used for all cookies. However, the scores of colour preference for wheat flour cookies were higher than cookies with teff and teff-oat composites. It may be due to the difference in colour between teff and wheat flour. Teff flour has brown colour while wheat flour has the light tan colour. If cocoa powder is used in the cookie formula for chocolate flavored cookies, it will make the colour of teff-oat cookies more attractive. Overall, sensory evaluation suggested that the cookies using teff-oat composites were acceptable in all respects.

Table 6. Sensory evaluation

Products	Colour	Texture	Flavour	Overall
Teff	7.17 ± 0.57 b	7.33 ± 0.56 a	7.17 ± 0.54 a	7.33 ± 0.53 a
Teff: Nutrim 4:1	6.83 ± 1.00 b	7.17 ± 1.15 a	6.83 ± 1.03 a	7.00 ± 1.15 a
Teff: OBC 4:1	7.83 ± 1.73 b	7.67 ± 1.08 a	7.50 ±1.31 a	7.67 ± 1.09 a
Teff :WOF 4:1	7.00 ± 0.58 b	7.50 ± 0.51 a	7.00 ± 0.53 a	7.17 ± 0.55 a
Wheat flour	8.33 ± 1.13 a	7.83 ± 0.57 a	7.67 ± 0.54 a	7.83 ± 0.58 a

Means ± standard deviation; n=26; means followed by the same letter within the same column are not significantly different. The number 1 referred to dislike extremely; 2 to dislike very much; 3 to dislike moderately; 4 to dislike slightly; 5 to neither like nor dislike; 6 to like slightly; 7 to like moderately; 8 to like very much; and 9 to like extremely.

4. Conclusion

These composites improved nutritional value, water holding capacity, and the pasting properties along with gluten free quality. In general, teff-oat composites are very suitable for preparing cookies that were acceptable in colour, flavour and texture qualities compared to the cookies with wheat flour. OBC and WOF probably are more suitable to use for cookies by cost. Information on the physical properties of these innovative cookies provides useful information for new functional foods.

References

AACC International. (2000). *Approved Methods of the American Association of Cereal Chemists* (10th ed.) Methods I0-50D and 10-52. AACC International, St. Paul, MN, U.S.A.

Ade-Omowaye, B. I. O., Taiwo, K. A., Eshtiaghi, N. M., Angersbach, A., & Knorr, D. (2003). Comparative Evaluation of the Effects of Pulsed Electric Field and Freezing on Cell Membrane Permeabilisation and Mass Transfer during Dehydration of Red Bell Peppers. *Innovative Food Science & Emerging Technologies, 4*, 177-188. http://dx.doi.org/10.1016/S1466-8564(03)00020-1

Coleman, J., Abaye, A. O., Barbeau, W., & Thomason, W. (2013). The suitability of teff flour in bread, layer cakes, cookies and biscuits. *International Journal of Food Sciences and Nutrition, 64*, 877-881. http://dx.doi.org/10.3109/09637486.2013.800845

Guha, M., Zakiuddin ALI, S., & Bhattacharya, S. (1998). Effect of barrel temperature and screw speed on rapid viscoanalyser pasting behaviour of rice extrudate. *International Journal of Food Science and Technology, 3*, 259-266. http://dx.doi.org/10.1046/j.1365-2621.1998.00189.x

Hoseney, R. C., & Rogers, D. E. (1994). Mechanism of sugar functionality in cookies: the science of cookie and cracker production. In H. Faridi (ed.), *American Association of Cereal Chemists* (Ist ed., pp. 203-225). St. Paul, MN.

Huang, G. (2014). *Almond shelf life factor*s. Technical summary. Almond Board of California.

Inglett, G. E. (2000). Soluble hydrocolloid food additives and method of making. U. S. Patent Number 6,060,519.

Inglett, G. E. (2011). Low-Carbohydrate Digestible Hydrocolloidal Fiber Compositions. U. S. Patent Number 7,943,766B2.

Inglett, G. E., Chen, D., & Liu. X. S. (2015). Functional properties of teff and oat composites. *Food and Nutrition Science, 6*, 1591-1602. http://dx.doi.org/10.4236/fns.2015.67065.

Kim, S., Inglett, G. E., & Liu, S. X. (2008). Content and molecular weight distribution of oat β-glucan in oatrim, nutrim, and C-trim products. *Cereal Chemistry, 85*, 701-705. http://dx.doi.org/10.1094/CCHEM-85-5-0701

Klopfenstein, C. F. (1988). The role of cereal beta-glucans in nutrition and health. *Cereal Food World, 33*, 865-869.

Lai, H. M., & Cheng, H. H. (2004). Properties of pregelatinized rice flour made by hot air or gum puffing. *International Journal of Food Science and Technology, 39*, 201-212. http://dx.doi.org/10.1046/j.0950-5423.2003.00761.x

Lai, L. S., & Liao, C. L. (2002). Steady and dynamic shear rheological properties of starch and decolorized Hsian-tsao leaf gum composite systems. *Cereal Chemistry, 79*, 58-63. http://dx.doi.org/10.1094/CCHEM.2002.79.1.58

Lee, S., & Inglett, G. E. (2006). Rheological and physical evaluation of jet-cooked oat bran in low calorie cookies. *International Journal of Food Science and Technology, 41*, 553-559. http://dx.doi.org/10.1111/j.1365-2621.2006.01161.x

Lee, M. H., Baek, M. H., Cha, D. S., Park, H. J., & Lim, S. T. (2002). Freeze-thaw stabilization of sweet potato starch gel by polysaccharide gums. *Food Hydrocolloids, 16*, 345-352. http://dx.doi.org/10.1016/S0268-005X(01)00107-2

Lee, S., Inglett, G. E., Carriere, C. J. (2004). Effect of nutrim oat bran and flaxseed on rheological properties of cakes. *Cereal Chemistry, 81*, 637-642. http://dx.doi.org/10.1094/CCHEM.2004.81.5.637

Lee, S., Warner, K., & Inglett, G. E. (2005). Rheological properties and baking performance of new oat β-glucan-rich hydrocolloids. *Journal of Agricultural and Food Chemistry, 53*, 9805-9809. http://dx.doi.org/10.1021/jf051368o

Madhujith, T., & Shahidi, F. (2007). Antioxidative and antiproliferative properties of selected barley (Hordeum vulgare L.) cultivars and their potential for inhibition of low-density lipoprotein (LDL) cholesterol oxidation. *Journal of Agricutlural and Food Chemistry, 55*, 5018-5024. http://dx.doi.org/10.1021/jf070072a

Rojas, J. A., Rosell, C. M., & Benedito de Barber, C. (1999). Pasting properties of different wheat flour-hydrocolloid systems. *Food Hydrocolloids, 13*, 27-33. http://dx.doi.org/10.1016/S0268-005X(98)00066-6

Rosell, C. M., Rojas, J. A., & Benedito de Barber, C. (2001). Influence of hydrocolloids on dough rheology and bread quality. *Food Hydrocolloids*, *15*, 75-81. http://dx.doi.org/10.1016/S0268-005X(00)00054-0

SAS Institute INC. (1999). The SAS® system for Windows®, version 8e. Cary, NC.

Smith, P. G. (2007). *Applications of Fluidization to Food Processing Introduction* (pp. 116-117). Wiley-Blackwell.

Taha S. E., Shahira M. E., & Amani, A. S. (2012). Chemical and biological study of the seeds of Eragrostis tef (Zucc.) Trotter, *Natural Product Research*: *Formerly Natural Product Letters, 26*, 619-629. http://dx.doi.org/10.1080/14786419.2010.538924.

University of Maryland Medical Center. (2013). Retrieved from http://umm.edu/health/medical/altmed/supplement/vitamin-k#ixzz33t70aIeT

USDA Nutrient Database. (2014). Retrieved from http://ndb.nal.usda.gov/ndb/search/list

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