Meat and Muscle Biology™

Cooking loss, texture properties, and color of comminuted beef prepared with breadfruit (*Artocarpus altilis*) flour[1]

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Abstract: Cooking loss, texture properties, and color of comminuted beef when prepared with breadfruit (*Artocarpus altilis*) flour or other flour sources was evaluated using 2 separate studies. Flour sources tested in these studies (against a negative control with no added flour) were breadfruit flour, soy flour, corn flour, wheat flour, and tapioca flour. Study 1: Finely minced, comminuted beef batters (extra lean beef targeted to 97% lean and 3% fat, salt, and ice/water) prepared with inclusion levels of 0, 1, 2, 3, 4, and 5% flour were evaluated for cooking loss and texture. Cooking loss was reduced ($P < 0.05$) in comminuted beef prepared with breadfruit flour compared with those not prepared with flour and cooking loss decreased as breadfruit flour inclusion level increased (Linear $P < 0.01$). Hardness was not different ($P = 0.49$) in comminuted beef prepared with breadfruit flour compared with soy flour, and was much less ($P < 0.01$) compared with the 3 other flour sources at each inclusion level. Study 2: Comminuted beef (lean beef targeted to 90% lean and 10% fat, salt, and ice/water) with inclusion levels of 0, 2.5, and 5% flour were formed into patties and were evaluated for color over a simulated retail display period. Redness values (a*) of comminuted beef prepared with breadfruit flour were the greatest ($P < 0.05$) during the 7-d simulated retail display compared with all other treatments, including control samples with no flour. Overall, the results indicated that breadfruit flour could be effectively used as an ingredient in comminuted beef to produce similar texture as observed with soy flour, while actually improving redness values beyond that of other flour sources.

Keywords: breadfruit flour, comminuted beef, meat color stability, meat texture properties, processed beef products
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Introduction

Breadfruit (*Artocarpus altilis*) is a traditional staple crop found throughout Oceania that contains high levels of carbohydrates, fiber, some vitamins, and minerals (Jones et al., 2011a, 2013; Turi et al., 2015). Some varieties of breadfruit contain up to 6% protein and the protein found in breadfruit is a complete source of protein, which contains all of the indispensable amino acids (Liu et al., 2015). While most breadfruit is eaten fresh, there is a long history of slicing, sun drying, and grinding the fruit into a flour or porridge. A sample of dried, ground breadfruit prepared in Mauritius around 1830 is deposited in the Economic Botany collection at Kew Gardens in the UK (sample ID 42792; Kew Royal Botanic Gardens, http://apps.kew.org/ecbot/specimen/42792). In February of 2016, breadfruit flour received ‘Generally Recognized as Safe’ status, thus opening the possibility of using the flour as an ingredient for North American food markets (FDA, 2016).

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Breadfruit flour can be used as an alternative source of starch in many different food products (Adebowale et al., 2005; Tan et al., 2017). So far, breadfruit flour has been successfully incorporated into a variety of food products; such as, bread, cake, pancakes, biscuits, stiff porridges, infant formulas, and extruded products (Ayodele and Oginni, 2002; Esparagoza and Tangonan, 1993; Jones et al., 2011a; Mayaki et al., 2003; McHugh et al., 2007; Olaoye et al., 2007).

Currently, no research has been conducted on breadfruit flour as an ingredient in processed meat products. The utilization of functional ingredients in processed meat products with intentions to maintain or improve technological, nutritional, visual, and sensory characteristics is an important area of research for the meat industry. Breadfruit flour as a potential binder in meat has significant economic potential since breadfruit is a high-yielding tropical food crop and breadfruit trees do not require annual planting (Jones et al., 2011b). Another benefit of breadfruit flour is that it is gluten free, which may be useful for people who have Celiac disease or choose not to consume gluten. Gluten free products are often expensive, providing an opportunity for gluten-free flours such as breadfruit to be used as a cheaper alternative (Jones et al., 2011b). Likewise, breadfruit flour could be used in processed meat products as a replacement of soy ingredients, which are allergens and produce products with unfavorable visual and sensory properties when used at high inclusion levels (Rentfrow et al., 2005).

The objectives of this study were to evaluate cooking loss and texture properties of finely, minced beef batters prepared with breadfruit flour, and to evaluate color stability of comminuted beef prepared with breadfruit flour and formed into patties. Two studies with unique model systems were used to address the research objectives. Study 1 used finely minced, comminuted beef batters to determine cooking loss and texture properties of comminuted beef. Study 2 used comminuted beef formed into patties to determine color over a simulated retail display period. Additionally, to make the study more comparable to previous studies, different inclusion levels of breadfruit (*Artocarpus altilis*) flour and more common flour sources, such as soy flour, corn flour, wheat flour, and tapioca flour were compared.

Materials and Methods

Explanation of studies

In each study, beef was procured from the control fed steers (diet consisted of 76.50% high moisture corn, 15.30% alfalfa silage, 6.80% soybean meal, and 1.40% vitamin and mineral premix) in a beef feeding trial that evaluated feed additives (data not yet published). The pH range of the semimembranosus muscle for all beef in this study ranged from 5.50 to 5.70. In study 1, one master batch of extra lean ground beef (15 kg; targeted to 97% lean and 3% fat; actual composition: 74.3% moisture, 22.0% protein, 2.8% fat) from a single animal was used for all replications of the study. In study 2, one master batch of lean ground beef (39 kg; targeted to 90% lean and 10% fat; actual composition: 70.5% moisture, 21.2% protein, and 6.8% fat) was used for all replications of the study. Beef was ground and packaged according to the standard operating procedures of the University of Guelph Meat Science Laboratory for ground beef manufacture.

Comminuted beef (lean beef, salt, and water) prepared with breadfruit flour, soy flour, corn flour, wheat flour, tapioca flour, and no added flour (negative control) were evaluated for cooking loss, texture analysis, and color using 2 separate studies. In study 1, comminuted beef with inclusion levels of 0, 1, 2, 3, 4, and 5% flour were prepared as finely minced comminuted beef batters and evaluated for cooking loss and texture. Comminuted meat batters present an appropriate model to test product texture and water retention (Yousseff and Barbut, 2009; Vasquez Mejia et al., 2018, 2019). In study 2, comminuted beef with inclusion levels of 0, 2.5, and 5% flour were formed into patties and evaluated for color over a simulated retail display. Comminuted meat formed into patties present an appropriate model to test product color stability (Bess et al., 2013; Cooper et al., 2016; Fruet et al., 2019). Different inclusion levels of flour were included for each study so that all treatments for each replication could be performed on the same day, although a maximum inclusion level of 5% was used for both studies.

Nutrient composition analysis of flour

In both studies the same flour sources were used. Flour sources included breadfruit, soy, corn, wheat, and tapioca (Table 1). The breadfruit flour was provided by Natural Foods International, Apia, Western Samoa. The flour was prepared from fresh fruit, harvested at the mature but not fully ripe stage, peeled,

Table 1. Nutrient composition and pH of flour types used in both study 1 and study 2

Item	Unit	Breadfruit	Soy	Corn	Wheat	Tapioca
Energy	KJ/100 g	1430	1880	1500	1484	1491
Calories	kcal/100 g	342	449	358	355	356
Protein	g/100 g	3.42	42.84	0.21	12.74	ND
Fat	g/100 g	0.85	19.3	0.57	1.51	0.33
Moisture	g/100 g	12.6	6.6	11.1	12.2	11.2
Ash	g/100 g	3.0	5.2	ND	1.1	0.1
Carbohydrates	g/100 g	80.1	26.1	88.1	72.5	88.3
Starch	g/100 g	67.1	0.4	85.0	60.4	84.9
Total fiber	g/100 g	4.77	25.95	1.44	6.12	1.34
Insoluble fiber	g/100 g	3.21	25.16	0.34	4.77	0.18
Soluble fiber	g/100 g	1.56	0.79	1.10	1.35	1.16
pH		6.09	6.67	5.44	5.84	6.07

cored, and sliced into thin wedges (~0.25 cm thick). The slices were dehydrated and ground into flour at a certified food safe facility. The flour was not modified in any way other than drying and nothing was added to the flour. The other sources of flour were obtained commercially from a local ingredient supplier in Ontario, Canada (Bulk Barn Foods, Aurora, ON, Canada). All the flour sources obtained from the local ingredient supplier were labeled as unmodified with nothing added to the flour. The chemical composition of the 5 types of flour used in this study were conducted by a third-party commercial laboratory and included energy, calories, protein, fat, moisture, ash, carbohydrates, and starch. The determination of moisture was performed according to AOAC methodology. Protein, ash, and starch content were determined according to the AOAC methods 992.15, 923.03, 996.11, respectively (AOAC, 2006). A conversion calculation of N × 6.25 was used for determination of protein. The determination of fat was performed using acid hydrolysis according to AOAC 922.06 and 933.05 (AOAC, 2006). Calorie and energy content was calculated with the following formula (Buchholz and Schoeller, 2004):

$$\text{Calories (kcal/100 g)} = 4 \times [\text{protein content (g/100 g)} + \text{carbohydrate content (g/100 g)}] + 9 \times \text{fat content (g/100 g)};$$

$$\text{Energy (KJ/100 g)} = 0.239 \times \text{Calories (kcal)}.$$

Carbohydrate content was calculated with the formula according to the Food and Agriculture Organization of the United Nations (FAO, 2003), with minor modification:

$$\text{Carbohydrate (g/100 g)} = 100 - \text{protein content (g/100 g)} - \text{fat content (g/100 g)} - \text{moisture content (g/100 g)} - \text{ash content (g/100 g)}.$$

Fiber content was determined using AOAC method 991.43 and AACC method 32–07.01 in accordance with the total dietary fiber assay kit instructions (Megazyme International Ltd.; Wicklow, Ireland). The pH of the flour samples was determined (in triplicate) after 10 g of each sample was homogenized in 50 mL of distilled water. A benchtop pH meter (Sartorius pHBasic; Göttingen, Germany) was used following calibration with buffer solutions of pH 4.0 and pH 7.0.

Study 1: Determination of cooking loss and texture analysis

Manufacturing process of finely minced comminuted meat. A total of 15 kg of extra lean beef (targeted to 97% lean and 3% fat; i.e., no added fat) was coarse ground (8 mm) from the round primal (NAMI# 158; North American Meat Institute, 2014) of a single beef animal using an industrial meat grinder/mixer (Master 90 Y12, Sirman, Marsango, Italy). Beef was collected from the same primal of an individual animal to control variation of raw material among replication and treatments. The experiment was conducted in 3 independent replicates for each treatment and all treatments were represented equally in each replicate. Ground samples were partitioned into 500 g vacuum sealed packages and stored in a freezer (–20°C) until further analysis. Each individual package (500 g of beef) was thawed overnight at 4°C and mixed with 200 g of water in a food processor (Cuisinart Elemental 11-cup [2.6 L] Food Processor, Conair Corporation, Stamford, CT) for 15 s. This procedure (mixing in a food processor for 15 s) was repeated 3 times. Then

17.5 g of salt (NaCl) was added into the mixture of beef and water and was mixed in the food processor for 10 s. This procedure (mixing in a food processor for 10 s) was repeated twice. Comminuted beef samples (beef, water, and salt) were weighed and mixed into different ratios of flour inclusion level (according to the treatments shown in Table 2) consisting of 100 g comminuted beef and 0 g flour (0%), 99 g comminuted beef and 1 g flour (1%), 98 g comminuted beef and 2 g flour (2%), 97 g comminuted beef and 3 g flour (3%), 96 g comminuted beef and 4 g flour (4%), and 95 g comminuted beef and 5 g flour (5%). Throughout the mincing process, the temperature of the beef mixture was below 10°C, as ensured by proper storage of the meat before use and the short mixing times used.

Determination of cooking loss. Cooking loss was determined with similar methodology described previously by Álvarez and Barbut (2013). A 40-g batter (0, 1, 2, 3, 4, and 5% flour treatments separately) was stuffed into centrifuge tubes and heated in a water bath incubator (Model W26, Haake, Berlin, Germany) until the internal temperature of the product reached 72°C. The water in the water bath was at room temperature (approximately 22°C) until the samples were placed in the water bath, and then the temperature of the water bath was increased to 80°C until the samples reached an internal temperature of 72°C. The cooking process took roughly 1.5 h in its entirety. A thermocouple (Model #52 K / J, Fluke Co. Inc., Everett, WA) was placed in the center of the samples to monitor and control the internal temperature throughout the cooking process. The cooked beef samples were cooled immediately in an ice bath until the internal temperature of the product dropped to 40°C. Cooking loss was determined with the following calculation:

Cooking loss (%) = [weight of liquid loss of cooked meat batter (g)/weight of raw meat batter (g)] × 100.

After the weight of cooking loss was measured, the cooked beef samples were stored overnight in refrigeration at 4°C until texture profile analysis was conducted the following day.

Texture profile analysis. Texture profile analysis (TPA) was determined with a Texture Analyzer (Model TA.XT2, Stable Micro Systems, Texture Technologies Corp., Scarsdale, NY) equipped with a 30 kg load cell. The cooked beef samples were removed from the refrigerator and tempered to room temperature. Each beef sample was cut into at least 3 cylindrical cores (15 mm in diameter and 10 mm length) and were compressed twice to 75% of their original height using a 101.6 mm diameter × 10 mm tall cylindrical acrylic probe (TA-40A; Texture Technologies Corporation) at a test speed of 1.5 mm/s and post-test speed of 1.5 mm/s. Data were collected and the following TPA parameters were analyzed: hardness (N), adhesiveness(g · s), springiness (mm), cohesiveness (no units), gumminess (N), chewiness (N · mm), and resilience (%). The average of the 4 cores was calculated and reported for each parameter.

Table 2. Formulations used in study 1 (finely minced comminuted beef batters)[1]

Inclusion level	Lean beef, %	Water, %	Salt (NaCl), %	Flour[2], %	Total, %
0	69.69	27.87	2.44	0	100
1	68.99	27.60	2.41	1	100
2	68.29	27.32	2.39	2	100
3	67.60	27.04	2.36	3	100
4	66.90	26.76	2.34	4	100
5	66.20	26.48	2.32	5	100

[1] Comminuted beef was prepared as 500 g beef, 200 g water, and 17.5 g of salt.

[2] Flour sources were breadfruit flour, soy flour, corn flour, wheat flour, and tapioca flour.

Study 2: Determination of color stability

Manufacturing processes of comminuted beef patties. One 39 kg master batch of lean beef (targeted to 90% lean and 10% fat) was ground to achieve a coarse particle size (8 mm in diameter) using an industrial meat grinder/mixer (Master 90 Y12, Sirman, Marsango, Italy). The same master batch of beef was used to control variation of raw material among replication and treatments. The ground beef was allotted and packaged in 3 vacuum package bags (13 kg per bag) for each of the 3 replicates and kept in frozen storage (–20°C) until day of manufacture of the treatments tested in this study.

The packaged ground beef was thawed in refrigeration (4°C) for a period of 48 h before it was allotted into the independent batches used to formulate and manufacture the test products. This experiment had eleven treatment groups: control (no flour added) and 5 flour varieties (breadfruit, soy, corn, wheat, and tapioca at 2 inclusion levels: 2.5 and 5%). Ice was added to the ground beef at a 10 g/100 g inclusion. High purity commercial salt was added to the ground beef at a 1.5 g/100 g inclusion. Breadfruit flour, soy flour, wheat flour, corn flour, and tapioca flour were added at a 2.5 g/100 g and 5.0 g/100 g inclusions (according

Table 3. Formulations used in study 2 (comminuted beef formed into patties)

				Flour type					
Treatment[1]	Lean beef, %	Water, %	Salt (NaCl), %	Breadfruit, %	Soy, %	Corn, %	Wheat, %	Tapioca, %	Total, %
Control	88.5	10.0	1.5	–	–	–	–	–	100
2.5% breadfruit flour	86.0	10.0	1.5	2.5	–	–	–	–	100
5.0% breadfruit flour	83.5	10.0	1.5	5.0	–	–	–	–	100
2.5% soy flour	86.0	10.0	1.5	–	2.5	–	–	–	100
5.0% soy flour	83.5	10.0	1.5	–	5.0	–	–	–	100
2.5% corn flour	86.0	10.0	1.5	–	–	2.5	–	–	100
5.0% corn flour	83.5	10.0	1.5	–	–	5.0	–	–	100
2.5% wheat flour	86.0	10.0	1.5	–	–	–	2.5	–	100
5.0% wheat flour	83.5	10.0	1.5	–	–	–	5.0	–	100
2.5% tapioca flour	86.0	10.0	1.5	–	–	–	–	2.5	100
5.0% tapioca flour	83.5	10.0	1.5	–	–	–	–	5.0	100

[1] Treatment was defined as Flour source × Inclusion level.

to the treatments shown in Table 3). The lean beef and all the ingredients were mixed using a bowl chopper equipped with 2 mm blades (SSM40, Alexanderwerk Schneidmeister, Germany) for 1 min on high-speed and 1 min on low speed. Throughout the mincing process, the temperature of the beef mixture was below 10°C, as ensured by proper storage of the meat before use, the use of water in the form of ice, the short mixing times used, and the environmental conditions (refrigerated meat laboratory).

Patties (115 g) were manufactured with a handheld hamburger press (Starfrit, Atlantic Promotions Inc., Longueuil, QC, Canada). Four patty samples for each treatment were used for color measurement during a simulated retail display period. The patties were grouped as pairs and immediately placed on Styrofoam meat trays (Genpak 1005, Genpak, Mississauga, ON, Canada) with a soaker pad placed between the Styrofoam meat tray and the patties (Tite-dri Industries, Boynton Beach, FL). Patties were crust frozen (placed into the –20°C freezer for 1 h) before being packaged with polyvinylchloride (PVC) overwrap film (60-gauge meat wrapping film, Western Plastics, Calhoun GA) using a film wrapping machine (Avantco WM-18 single roll film wrapping machine, Avantco Equipment, Lancaster, PA). Samples were then stored at refrigerated temperatures (4°C) in simulated retail display for 7 d. Two LED light fixtures (121.92 cm long, 52-W, light output = 1850 lumens, color temperature = 4000 K [cool white]) were suspended 40 cm above each shelf. Throughout the study, LUX was measured with the LightMeter (LUX Light Meter Free, Nipakul Buttua) mobile phone application on an iPhone 8 Plus (Apple Inc., Cupertino, CA) to ensure a range of 1612.5 to 2152 lux was maintained at the surface of the meat packages. The location of the packaged patties was randomly rotated daily within the shelf to minimize any potential shelf location effects.

Chemical composition analysis. Moisture and fat content of patties was determined with methods previously described by Sivendiran et al. (2018). Duplicate 5-g patty samples were weighed into an aluminum weighing dish and covered with 2 pieces of filter paper (#1 Whatman filter paper, GE Healthcare Life Science, Kent, UK). The sample was dried in an oven at 100°C for 24 h to determine moisture content. The dried sample was washed multiple times over 5 h with warm petroleum ether using a modified procedure of the Soxhlet method (AOAC, 2006; method 991.36) to determine lipid content. Nitrogen content was determined by Dumas nitrogen analyzer (model TruMac, LECO Corp., St. Joseph, MN), and protein content was calculated according to the nitrogen content (AOAC, 2006; method 990.03), using EDTA as a standard. The factor for the conversion of nitrogen content to protein content was 6.25.

Color analysis. Objective CIE L* (lightness), a* (redness), and b* (yellowness) scores were collected with a Minolta CR-400 Chroma meter (Konica Minolta Sensing, Inc., Osaka, Japan) utilizing a D65 light source and a 0° observer with an aperture size of 8 mm on each day of the simulated retail display. The Chroma meter was calibrated each day through the PVC film that was used for packaging, which allowed for measurement to be taken through the film. Measurements were collected at 2 locations from each patty (2 patties for each tray; 2 trays for each treatment) every 24 h, with the aperture placed directly on the film surrounding the surface of the patty, and the mean of the 8 measurements was recorded as the objective color score for L*, a*, and b*.

Experimental Design and Statistical analysis

Both studies were conducted in 3 independent replications for each treatment. All statistical analyses were performed with SAS (SAS 9.4; SAS Inst. Inc., Cary, NC). Statistical analyses for parameters evaluated in study 1 (cooking loss, hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness, and resilience) were conducted using the MIXED procedure of SAS with fixed effects of flour source, inclusion level, and their interaction. Least square means were separated using the PDIFF option with a Tukey-Kramer adjustment. Least squares means were further separated using an orthogonal set of estimate statements to analyze linear and quadratic effects for inclusion level of each flour source. Statistical analyses for parameters evaluated in study 2 (L*, a*, and b*) were conducted using the MIXED procedure of SAS as repeated measures over time (day) with fixed effects of flour source × inclusion level, day, and their interaction. A repeated least square means were separated using the PDIFF option with a Tukey-Kramer adjustment. Differences were considered statistically different at $P < 0.05$.

Results and Discussion

Hypothesis

It was hypothesized that breadfruit flour would have the proper technological properties to perform as a binder ingredient, and elicit similar texture and water holding properties when compared with other sources of flour/starch used in the meat industry. Initial laboratory testing provided insight of the color enhancing properties that breadfruit flour may elicit when added to comminuted beef, thus it was further hypothesized that breadfruit flour could improve initial color and potentially prolonged color during storage (color stability) of comminuted beef.

Nutrient composition of flours

The energy content and calories of breadfruit, tapioca, corn, and wheat flours were similar (1430 to 1500 KJ/100 g and 342 to 358 kcal/100 g), while those of soy flour were greater (1880 KJ/100 g and 449 kcal/100 g). The protein (3.42 g/100 g) and fat (0.85 g/100 g) content of breadfruit flour were intermediate when compared with other flours, while soy flour had the greatest protein and fat content and tapioca flour had the least protein and fat content. The main composition of soy flour was protein (42.84 g/100 g) while the breadfruit flour, tapioca flour, and corn flour had very high carbohydrate content (80.1 g/100 g to 88.3 g/100 g), with most of the carbohydrates of those flours being starches (67.1 g/100 g to 85 g/100 g). Relatively speaking, breadfruit flour contained a high amount of carbohydrates (80.1 g/100 g) and starch (67.1 g/100 g), which were similar to the levels reported in other studies (Wootton and Tumaalii, 1984; Oshodi et al., 1999; Turi et al., 2015). Breadfruit flour contained an intermediate amount of total fiber (4.77 g/100 g), which was similar to wheat flour (6.12 g/100g), greater than corn flour (1.44 g/100g) and tapioca flour (1.34 g/100g), and much less than soy flour (25.95 g/100g). Soy flour contained a much greater amount of insoluble fiber compared with all other flour sources. Breadfruit flour contained the greatest amount of soluble fiber (1.56 g/100g) but was similar to the other flour sources which ranged from 0.79 g/100g to 1.35 g/100g. pH of the flours ranged in value from 5.44 to 6.67, with corn flour being the lowest and soy flour being the greatest.

Study 1

Cooking loss. Flours usually have the ability to bind and retain moisture (Shewry and Tatham, 2000) and generally increase processing and cooking yields and decrease shrink in processed meat products (Brewer, 2012). In this study, flour source, flour inclusion level, and their interaction affected cooking loss ($P < 0.05$; Table 4). Cooking loss of beef batters prepared with breadfruit flour and the 4 other flour sources observed in this study had a linear relationship with inclusion level and decreased at differing rates as the inclusion level increased (Linear $P < 0.01$). The cooking loss of beef batters prepared with different flours at different inclusion levels was all less than 15% (Fig. 1). As shown in Fig. 1, beef batters prepared with tapioca flour (high level of starch) had the lowest cooking loss from 2 to 5% flour inclusion levels evaluated, and soy flour (high level of protein) had the lowest cooking loss among flour sources at 1% flour inclusion level. This may be related to the ability of these polymers (starch and protein) to restrict water mobility and prevent the release of water during the cooking process. On the other hand, some starches require higher gelatinization temperature, such as corn starch of which the peak gelatinization temperature is around 70°C (Zhang et al., 2018). Therefore, corn flour was less able to achieve a complete gelatinization process in the comminuted meat sample and consequently retained less water. This was further evidenced by the previously reported gelatinization temperatures of other

Table 4. *P*-values for cooking loss and texture attributes of comminuted beef formulation used in study 1 (finely minced comminuted beef batters)

P-value	Cooking loss	Hardness	Adhesiveness	Springiness	Cohesiveness	Gumminess	Chewiness	Resilience
Flour source	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Inclusion level	< 0.0001	0.10	0.23	0.01	< 0.01	0.01	< 0.01	< 0.0001
Flour × Inclusion level	0.01	0.05	0.22	0.77	< 0.01	0.01	< 0.01	< 0.0001
			Linear effect of inclusion level					
Breadfruit flour	< 0.0001	< 0.01	0.27	0.15	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Soy flour	< 0.0001	< 0.01	0.15	0.47	0.01	< 0.01	< 0.01	< 0.01
Corn flour	< 0.01	0.13	0.34	0.44	0.16	0.13	0.15	0.21
Wheat flour	< 0.01	0.74	0.14	0.47	0.03	0.42	0.45	0.03
Tapioca flour	< 0.0001	0.03	< 0.0001	0.18	0.14	0.03	0.03	0.02

native starches used in this study. Zhou et al. (2008) reported the peak gelatinization temperature for native wheat starch was 57.9°C Ren, and Wang (2019) reported the peak gelatinization temperature for native tapioca starch was 65.6°C. The previously reported peak gelatinization temperature for breadfruit flour was approximately 75°C (Wang et al., 2010). The soy flour used in this study had very low starch content (0.4 g/100 g), so it was clear that starch gelatinization temperature only explained some of the water binding ability of a meat batter. An additional component of the flours that may be affecting the ability of the meat batters to bind and retain moisture was pH. Unfortunately, pH of the meat batters was not measured in this study, the differences observed in the pH content of the flours may be influencing the overall pH of the meat batters and the inherent water holding characteristics of the meat batters especially at high inclusion levels.

Greater research is warranted from a fundamental standpoint on the interaction of different macrocomponents of flour ingredients and meat batter water retention properties. Overall in regard to cooking loss, results in this study followed what was hypothesized and breadfruit flour performed similarly to other flour sources, most notably tapioca and wheat flour.

Texture profile analysis. Flour source and its interaction with inclusion level affected hardness ($P < 0.05$), while flour inclusion level did not affect hardness ($P = 0.10$; Fig. 2). Hardness for meat batters prepared with breadfruit, soy, and tapioca flour had a linear relationship (Linear $P < 0.05$) with inclusion level (0 to 5%); while hardness for meat batters prepared with corn (Linear $P = 0.13$) and wheat flour (Linear $P = 0.74$) did not have a linear relationship with inclusion level (0 to 5%). Hardness was at lesser values compared to control and decreased (Linear $P < 0.01$) as inclusion level in-

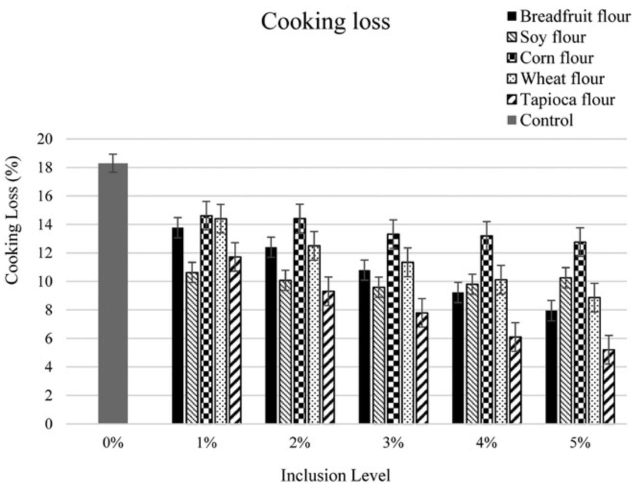

Figure 1. Effects of flour source and inclusion level on cooking loss of comminuted beef formulation used in study 1 (finely minced comminuted beef batters). *P*-values for data in these figures can be found in Table 4.

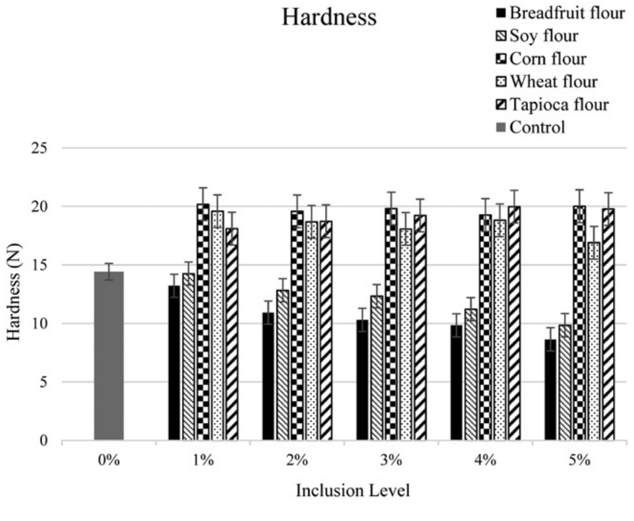

Figure 2. Effects of flour source and inclusion level on hardness of comminuted beef formulation used in study 1 (finely minced comminuted beef batters). *P*-values for data in these figures can be found in Table 4.

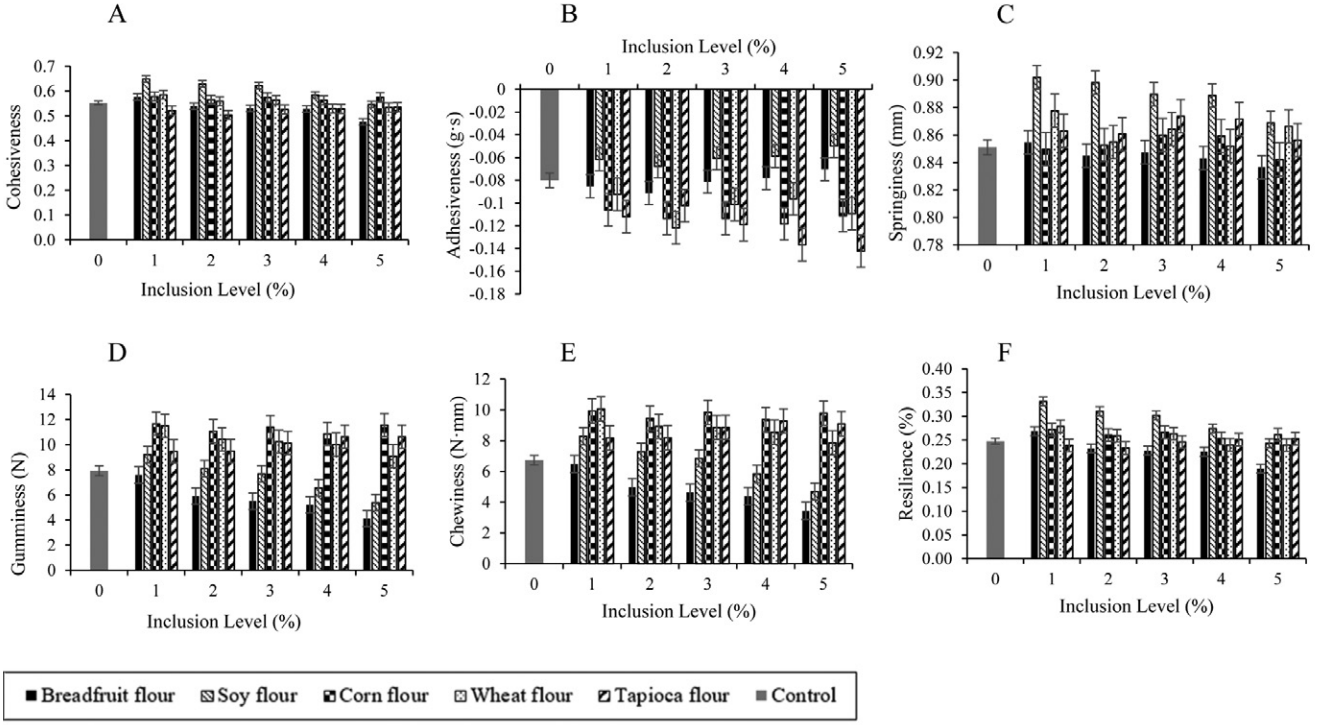

Figure 3. Effects of flour source and inclusion level on cohesiveness (A), adhesiveness (B), springiness (C), gumminess (D), chewiness (E), and resilience (F) of comminuted beef formulation used in study 1 (finely minced comminuted beef batters). *P*-values for data in these figures can be found in Table 4.

creased (0 to 5%) for meat batters prepared with breadfruit and soy flour, while hardness was at greater values and remained constant as inclusion level increased (0 to 5%) for meat batters prepared with corn and wheat flour. For meat batters prepared with tapioca flour, hardness was at greater values compared to control samples and was sustained at similar levels as inclusion level increased from 0 to 5%. Hardness is very related to the amount of water retained by the batters during the cooking process and subsequent cooling. When the samples lost more water (greater cooking loss) as in the case of batters prepared with corn and wheat flour, the structure became more rigid and harder. On the other hand, when a lot of water is retained by the hydrocolloids, the structure also becomes rigid because the water is not free in the batter. Therefore, there must be a balance between the water immobilized by the hydrocolloids in a meat batter, the water retained that influences the tenderness (succulence) of the sample, and the water that remains free and would eventually be lost during cooking.

Flour source, flour inclusion level, and their interaction affected cohesiveness ($P < 0.01$). Cohesiveness for meat batters prepared with breadfruit, soy, and wheat flour had a linear relationship (Linear $P < 0.05$) with inclusion level (0 to 5%), while cohesiveness for meat batters prepared with corn (Linear $P = 0.16$) and tapioca flour (Linear $P = 0.14$) did not have a linear relationship with inclusion level (0 to 5%). Cohesiveness decreased in value as inclusion level increased (0 to 5%) for breadfruit and soy flour; while cohesiveness remained constant or increased as inclusion level increased (0 to 5%) for meat batters prepared with corn, wheat, and tapioca flour (Fig. 3A).

Flour source affected adhesiveness ($P < 0.05$), while flour inclusion level ($P = 0.23$) and its interaction with flour source ($P = 0.22$) did not affect adhesiveness. Adhesiveness for meat batters prepared with breadfruit (Linear $P = 0.27$), soy (Linear $P = 0.15$), corn (Linear $P = 0.34$), and wheat flour (Linear $P = 0.14$) did not have a linear relationship with inclusion level (0 to 5%). For meat batters prepared with breadfruit and soy flour, adhesiveness was at lesser values compared to 3 other flours and was the greatest in samples with 2% inclusion level. Adhesiveness remained constant as inclusion level increased (0 to 5%) for meat batters prepared with corn flour. Adhesiveness was the greatest at 2% inclusion level for meat batters prepared with wheat flour. For meat batters prepared with tapioca flour, adhesiveness was the least at 2% inclusion level while it increased as inclusion level increased from 2 to 5% (Linear $P < 0.0001$; Fig. 3B).

Flour source and inclusion level affected springiness ($P < 0.05$), while their interaction did not affect springiness ($P = 0.77$). Springiness remained constant as inclusion level increased (0 to 5%) for be meat batters prepared with corn and tapioca flour (Fig. 3C). Springiness for meat batters prepared with breadfruit (Linear $P = 0.15$), soy (Linear $P = 0.47$), corn (Linear $P = 0.44$), wheat flour (Linear $P = 0.47$), and tapioca flours (Linear $P = 0.18$) did not have a linear relationship with inclusion level (0 to 5%). Springiness was the greatest at 1% inclusion level for meat batters prepared with breadfruit, soy, and wheat flour. Meat batters prepared with soy flour has the greatest springiness compared to 4 other flours at all inclusion levels. Springiness has been previously reported as greater when protein content was increased in meat batter systems (Youssef and Barbut, 2010), thus it was unsurprising that soy flour elicited greater springiness compared with other treatments in this study.

Flour source, flour inclusion level, and their interaction affected gumminess ($P < 0.05$). Gumminess for meat batters prepared with breadfruit, soy, and tapioca flour had a linear relationship with inclusion level (0 to 5%); while gumminess for meat batters prepared with corn (Linear $P = 0.13$) and wheat flour (Linear $P = 0.42$) did not have a linear relationship with inclusion level (0 to 5%). For meat batters prepared with breadfruit and soy flour, gumminess was at lesser values compared to 3 other flours and decreased (Linear $P < 0.01$) as inclusion level increased (0 to 5%); while gumminess was at greater values and remained constant as inclusion level increased (0 to 5%) for meat batters prepared with corn and wheat flour. For meat batters prepared with tapioca flour, gumminess increased (Linear $P < 0.05$) as inclusion level increased (0 to 5%; Fig. 3D).

Flour source, flour inclusion level, and their interaction affected chewiness ($P < 0.01$). Chewiness for meat batters prepared with breadfruit, soy, and tapioca flour had a linear relationship (Linear $P < 0.05$) with inclusion level (0 to 5%); while chewiness for meat batters prepared with corn (Linear $P = 0.15$) and wheat flour (Linear $P = 0.45$) did not have a linear relationship with inclusion level (0 to 5%). For meat batters prepared with breadfruit and soy flour, chewiness was at lesser values compared to 3 other flours and decreased (Linear $P < 0.01$) as inclusion level increased (0 to 5%); while chewiness was at greater values and remained constant as inclusion level increased (0 to 5%) for meat batters prepared with corn and wheat flour. For meat batters prepared with tapioca flour, chewiness increased as inclusion level increased from 0 to 4% with a slight decrease at 5% (Fig. 3E).

Based on the combination of texture profile analysis, it was concluded that breadfruit flour behaved most similar to soy flour, and less similar to other flours. This was highlighted by the results of hardness, adhesiveness, and gumminess. It is acknowledged that there were certainly inconsistencies among the breadfruit flour and soy flour treatments for cohesiveness, springiness, chewiness, and resilience. For an explanation as to why these differences were observed, all components of the flours should be considered; however, there is the most supporting documentation for the carbohydrate components (starch and fiber). Hardness is generally thought to be affected by high viscosity of carbohydrate ingredients, and greater hardness is not necessarily more desirable—it depends on the application or product being manufactured. With that said, it was interesting that breadfruit flour and soy flour were so similar in their hardness properties as their starch and fiber compositions were very different. In a previous study, hardness values were reported as lower in meat batters prepared with β-glucan (an ingredient high in soluble dietary fiber) compared with starch and micro-crystalline cellulose (Vasquez Mejia et al., 2019).

Study 2

Chemical composition. Addition of different flour sources at both inclusion levels decreased ($P < 0.05$) the moisture content of beef patties compared with the control samples, with exceptions for 2.5% inclusion levels of breadfruit flour and wheat flour (Table 5). To the contrary, Khalil (2000) reported that beef patties prepared with modified corn starch and water had greater moisture content than those formulated with water alone. Nisar et al. (2009) also reported that moisture content was significantly greater in low fat (<10% total fat) buffalo meat patties prepared with tapioca starch compared with the control samples. No difference ($P > 0.50$) was found in moisture content among the beef patties prepared with different flour sources at each inclusion level. Protein content in the treatment of 2.5% and 5% soy flour was greater ($P < 0.05$) than that of breadfruit, corn, wheat, and tapioca flour sources confirming the high protein content of soy flour. Angor and Al-Abdullah (2010) reported that beef burger prepared with texturized soy increased protein content compared with the control sample. No difference ($P > 0.53$) was found among treatments for fat content. Overall, the patties used in this study were all very low in their fat content (as expected), which would increase myoglobin content of the meat.

Color determination. There was not a storage day × treatment effect ($P = 0.99$) for L* during the 7-d simu-

Table 5. Proximate composition of comminuted beef used in study 2 (comminuted beef formed into patties) after preparation with different sources of flours at 2.5% and 5.0% inclusion levels[1]

	Treatment[2]												
	Control	Breadfruit flour		Soy flour		Corn flour		Wheat flour		Tapioca flour			
	0	2.5	5.0	2.5	5.0	2.5	5.0	2.5	5.0	2.5	5.0	SEM	*P*-value
Moisture	71.87^{a}	70.42^{ab}	69.30^{bc}	69.96^{bc}	68.56^{c}	70.02^{bc}	68.99^{bc}	70.3^{ab}	69.05^{bc}	70.16^{bc}	69.17^{bc}	0.32	< 0.0001
Fat	4.27^{a}	3.72^{a}	3.46^{a}	3.84^{a}	4.28^{a}	3.79^{a}	3.68^{a}	3.77^{a}	3.73^{a}	3.62^{a}	3.49^{a}	0.37	0.84
Protein	20.99^{bc}	20.65^{c}	19.89^{d}	21.54^{ab}	22.12^{a}	20.69^{c}	19.89^{d}	20.79^{c}	20.69^{c}	20.67^{c}	19.98^{d}	0.12	< 0.0001

[a-d] Least square means within row with different superscripts are different ($P < 0.05$).

[1] Data presented are LS means and reported SEM is the maximum SEM among treatments.

[2] Treatment was defined as Flour Source × Inclusion level.

lated retail display period (Table 6). There was an effect of storage day ($P = 0.01$) on L*; however, this effect was small as L* changed only 0.77 units from Day 0 to Day 7 (when all treatments were averaged). There was an effect of treatment ($P < 0.0001$) on L*. The L* of beef patties prepared with 2.5% breadfruit flour were not different ($P = 0.95$) compared with control samples, while L* was less ($P < 0.05$) in these 2 treatments compared with all other treatments. Interestingly, when included at the 5% inclusion level, L* of beef patties prepared with breadfruit flour was less ($P < 0.05$) than other flour types at the 5% inclusion level. Rocha-Garza and Zayas (1995) reported that no difference in lightness between beef patties prepared with wheat germ protein flour and control samples. Generally, lower L* of uncooked beef patties was observed as a positive, although color that was too dark can be viewed as a negative (Mancini and Hunt, 2005). However, other components of the color spectrum (most notably a*) must also be considered.

There was a storage day × treatment effect ($P < 0.0001$) for a* during the 7-d simulated retail display period, as a* decreased at differing rates for each treatment throughout the display period (Table 7). Storage day affected a* value ($P < 0.0001$) with the aforementioned trends (a* value decreased as display period increased). There was a main effect of treatment ($P < 0.0001$) on a*. Beef patties prepared with 2.5 and 5% breadfruit flour were redder (greater a*; [$P < 0.05$]) compared with other treatments and control samples over the 7-d display period. To the contrary, a* values of beef patties prepared with soy flour were less than ($P < 0.05$) other treatments and the control samples on Day 0 and Day 1, and remained constant at lower values as the display period increased. Soy ingredients are usually low priced ingredients that are high in protein which has led to their use in many processed meat products, such as, cooked sausage and nonspecific meat loaves (Rakosky, 1974); however, several reports have indicated that soy ingredients caused meat products to be less red. Youssef and Barbut (2011) found that pre-emulsified oil (using soy protein isolate) resulted in a significant reduction in redness of comminuted beef product. Several other studies have since confirmed less redness in meat products prepared with soy ingredients (Gao et al., 2015; Kang et al., 2016; Lee et al., 2017). There was no difference ($P > 0.43$) between the a* values of beef patties prepared with the 3 other treatments—corn, wheat, and tapioca flour were similar to the control samples over the 7-d display period.

There was a storage day × treatment effect ($P < 0.0001$) for b* during the 7-d simulated retail display period, as b* changed at different rates for each treatment throughout the display period (Table 8). There

Table 6. Instrumental color of comminuted beef used in study 2 (comminuted beef formed into patties) after preparation with different sources of flours at 2.5% and 5.0% inclusion levels[1]

	Treatment[2]												*P*-value		
	Control	Breadfruit flour		Soy flour		Corn flour		Wheat flour		Tapioca flour					
	0	2.5	5.0	2.5	5.0	2.5	5.0	2.5	5.0	2.5	5.0	SEM	Storage day	Treatment	Storage day × treatment
L*	41.65^{f}	42.03^{f}	43.83^{de}	44.84^{bcd}	46.96^{a}	43.72^{de}	46.07^{ab}	43.50^{e}	45.18^{bc}	44.42^{cde}	46.49^{a}	0.27	0.01	< 0.0001	0.99
a*	9.08^{e}	10.32^{b}	11.21^{a}	8.22^{f}	8.57^{f}	8.57^{f}	9.34^{de}	9.00^{e}	9.73^{cd}	9.14^{e}	9.87^{c}	0.09	< 0.0001	< 0.0001	< 0.0001
b*	7.07^{f}	8.18^{de}	9.40^{bc}	8.29^{d}	9.29^{c}	8.30^{d}	9.79^{a}	7.84^{e}	9.37^{bc}	8.39^{d}	9.70^{ab}	0.07	< 0.0001	< 0.0001	< 0.0001

[a-f] Least square means within row with different superscripts are different ($P < 0.05$).

[1] Data presented are LS means and reported SEM is the maximum SEM among treatments.

[2] Treatment was defined as Flour Source × Inclusion level.

Table 7. Instrumental a* (redness) of comminuted beef used in study 2 (comminuted beef formed into patties) after preparation with different sources of flours at 2.5% and 5.0% inclusion levels over a 7-d display period[1]

	Treatment[2]												
	Control	Breadfruit flour		Soy flour		Corn flour		Wheat flour		Tapioca flour			
Day	0	2.5	5.0	2.5	5.0	2.5	5.0	2.5	5.0	2.5	5.0	SEM	*P*-value[3]
0	11.59^{a}	12.57^{a}	12.54^{a}	9.59^{b}	9.94^{b}	11.87^{a}	12.50^{a}	11.82^{a}	12.00^{a}	12.36^{a}	12.98^{a}	0.36	< 0.0001
1	11.51^{ab}	12.06^{ab}	12.67^{a}	9.43^{d}	9.91^{cd}	10.89^{bc}	11.65^{ab}	11.33^{abc}	11.80^{ab}	11.61^{ab}	12.31^{ab}	0.36	< 0.0001
2	10.53^{abc}	11.47^{a}	11.86^{a}	9.38^{c}	10.25^{bc}	9.97^{bc}	10.72^{abc}	10.65^{abc}	11.54^{a}	10.68^{abc}	11.35^{ab}	0.36	< 0.0001
3	9.27^{bc}	10.56^{ab}	11.38^{a}	9.27^{bc}	9.73^{bc}	8.94^{c}	9.50^{bc}	9.69^{bc}	10.77^{ab}	9.58^{bc}	10.03^{abc}	0.36	< 0.0001
4	8.09^{cd}	9.76^{ab}	10.90^{a}	8.36^{bcd}	8.54^{bcd}	7.73^{d}	8.41^{bcd}	8.26^{bcd}	9.31^{bc}	8.36^{bcd}	8.89^{bcd}	0.36	< 0.0001
5	7.51^{bcd}	9.05^{ab}	10.36^{a}	7.14^{cd}	7.14^{cd}	6.60^{d}	7.62^{bcd}	7.14^{cd}	8.05^{bcd}	7.31^{cd}	8.22^{bc}	0.36	< 0.0001
6	7.15^{c}	8.77^{ab}	10.15^{a}	6.42^{c}	6.65^{c}	6.29^{c}	7.25^{bc}	6.65^{c}	7.43^{bc}	6.76^{c}	7.75^{bc}	0.36	< 0.0001
7	6.96^{c}	8.36^{bc}	9.78^{a}	6.20^{c}	6.43^{c}	6.25^{c}	7.05^{bc}	6.45^{c}	6.96^{bc}	6.43^{c}	7.42^{bc}	0.36	< 0.0001

[a-d] Least square means within row with different superscripts are different ($P < 0.05$).

[1] Data presented are LS means and reported SEM is the maximum SEM among treatments.

[2] Treatment was defined as Flour Source × Inclusion level.

[3] *P*-value is the test of the effect of slice for each individual storage day.

was an effect of storage day ($P < 0.0001$) on b*, with the general effect being quadratic in nature (the greatest 2 b* values were at Day 0 and Day 7, and the lowest b* value was on Day 5). There was an effect of treatment ($P < 0.0001$) on b*. The b* values were lower for the control samples during the display period compared with the 5 flour treatments. At 5% of inclusion, yellowness (b* value) was greater in the patties prepared with tapioca, wheat, and corn flours.

Conclusion

Based on the cooking loss and textural profile analysis of finely comminuted meat batters (raw beef used was 97% lean and 3% fat) prepared with different flours, the inclusion of breadfruit flour showed promise as a binder ingredient. Based on color determination of comminuted beef (raw beef used was 90% lean and 10% fat) formed into patties using a simulated retail display for 7 d, breadfruit flour improved the redness of comminuted beef products immediately and prevented discoloration of beef for a longer period of time. Therefore, it is reasonable to conclude that breadfruit flour can be effectively used as a binder ingredient in processed beef products that may elicit positive effects on color stability. More research is warranted to further investigate the mechanism of action of breadfruit flour in governing the quality of comminuted beef products and sensory attributes of beef products prepared with breadfruit flour.

Table 8. Instrumental b* (yellowness) of comminuted beef used in study 2 (comminuted beef formed into patties) after preparation with different sources of flours at 2.5% and 5.0% inclusion levels over a 7-d display period[1]

	Treatment[2]												
	Control	Breadfruit flour		Soy flour		Corn flour		Wheat flour		Tapioca flour			
Day	0	2.5	5.0	2.5	5.0	2.5	5.0	2.5	5.0	2.5	5.0	SEM	*P*-value[3]
0	7.39^{f}	9.17^{abc}	9.95^{ab}	8.62^{cdef}	9.06^{abcde}	8.53^{cdef}	9.40^{abcd}	8.06^{ef}	9.80^{abc}	8.88^{abc}	10.03^{a}	0.30	< 0.0001
1	7.48^{f}	8.66^{bcdef}	10.15^{a}	8.13^{def}	9.01^{abcde}	8.08^{ef}	9.41^{abcd}	7.88^{ef}	9.70^{ab}	8.24^{def}	9.58^{abc}	0.30	< 0.0001
2	7.06^{d}	8.25^{bcd}	9.36^{ab}	7.90^{cd}	9.14^{abc}	8.00^{cd}	9.66^{a}	7.73^{d}	9.59^{a}	8.16^{bcd}	9.62^{a}	0.30	< 0.0001
3	6.80^{c}	7.99^{bc}	9.10^{ab}	8.06^{bc}	9.06^{ab}	8.13^{b}	9.66^{a}	7.89^{bc}	9.54^{a}	7.90^{bc}	9.47^{a}	0.30	< 0.0001
4	6.66^{ef}	7.86^{cdef}	9.14^{abc}	7.99^{cdef}	9.12^{abcd}	8.10^{bcde}	9.53^{a}	7.80^{ef}	9.31^{ab}	8.14^{bcde}	9.34^{ab}	0.30	< 0.0001
5	6.78^{d}	7.65^{cd}	9.06^{ab}	8.14^{bcd}	9.32^{ab}	8.10^{bcd}	9.72^{a}	7.39^{cd}	8.91^{abc}	8.18^{bcd}	9.53^{a}	0.30	< 0.0001
6	6.93^{f}	7.93^{cdef}	9.21^{abc}	8.45^{bcde}	9.66^{ab}	8.52^{bcde}	10.29^{a}	7.79^{def}	9.00^{abcd}	8.57^{bcde}	9.86^{a}	0.30	< 0.0001
7	7.45^{e}	7.89^{de}	9.21^{bc}	9.05^{bcd}	9.91^{ab}	8.96^{bcd}	10.65^{a}	8.22^{cde}	9.13^{bcd}	9.06^{bcd}	10.19^{ab}	0.30	< 0.0001

[a-f] Least square means within row with different superscripts are different ($P < 0.05$).

[1] Data presented are LS means and reported SEM is the maximum SEM among treatments.

[2] Treatment was defined as Flour Source × Inclusion level.

[3] *P*-value is the test of the effect of slice for each individual storage day.

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