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Influence of almond and coconut flours on Ketogenic, Gluten-Free cupcakes

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ABSTRACT

Ketogenic, gluten-free cupcakes containing varying amounts of almond and coconut flours were evaluated for textural and sensory attributes. Coconut-flour particle-size influenced cupcake volume and crumb structure, with smaller flour-particle size resulting in increased volume and decreased crumb density. Although almond-flour particle size itself did not directly influence cupcake properties, volume increases were observed in cupcakes with higher percentages of almond flour. Addition of coconut flour increased cell size and decreased cell density. Mechanical testing showed almond flour resulted in a cupcake that was more tender. Adhesion and cohesion values showed no statistical difference after 24 h and minimal change at subsequent evaluation periods. Quantitative descriptive analysis and consumer acceptance evaluation indicated that cupcakes containing almond flour were more moist and tender, and were preferred over cupcakes made with only coconut flour. Almond and coconut flours may be used in gluten-free, ketogenic cupcakes, with almond flour performing better in evaluated parameters.

Introduction

Popularity of cupcakes as a dessert continues to grow. Cupcakes provide a portable, portion-controlled alternative to the traditional cake and, due to its reduced portion size, is sometimes perceived as a healthier option by consumers (Mintel Group Ltd, 2012). Once considered more of a novelty, cupcakes have become mainstream and represent an affordable luxury in a market that continues to grow (Adleman, 2012).

Gluten-free and ketogenic lifestyles are also becoming more prevalent as a means of weight loss, a treatment for diabetes, and a way to minimize the effects of neurological disorders (Castro et al., 2015; Churuangsuk, Kherouf, Combet, & Lean, 2018; Davis, Fournakis, & Ellison, 2020; Li, Liu, Liu, & Li, 2020; Merrill et al., 2020; Yancy, Mitchell, & Westman, 2019). Food markets catering to these alternative food choices are increasing exponentially: the global ketogenic diet was market valued at 9.57 billion USD in 2019; and it is expected to expand at a compound annual growth rate of 5.5% through 2027 (GVR, 2020). Although investigations of gluten-free products are common, products that are both gluten-free and ketogenic have not been researched extensively.

Gluten is composed of the proteins glutenin and gliadin, which interact to give unique viscoelastic properties that are difficult to replicate in the structure of leavened products. Gluten is present in wheat, barley, and rye, and these gluten-containing grains are commonly used in numerous products. As celiac diagnoses have increased, an increase in the generation of GF products has followed. This has caused a heightened interest in GF products for those who do not have celiac disease; and a growing number of individuals follow a gluten-free lifestyle for personal reasons (Makovicky et al., 2020).

A diet of low-carbohydrate intake, now known as the *ketogenic diet* (K_D), earned its name from its goal to place the body in a state of ketosis. Traditionally, the K_D is defined by a 4:1 or 3:1 ratio of fat to nonfat grams of food, although there are many modifications of the diet (Mahan & Raymond, 2017). Although the long-term consequences of a K_D are not yet fully understood, identified side effects include constipation, headaches, bad breath, and increases in blood uric-acid concentrations. Additionally, when used for weight loss, short-term K_D subscription results in greater water weight loss than body fat loss (Freeman, Kossoff, & Hartman, 2007). Recent reviews associated with gluten-free and ketogenic diets are available for additional insights (Churuangsuk et al., 2018; Lerner, O'Bryan, & Matthias, 2019; Li & Heber, 2020; Makovicky et al., 2020; Newberry, McKnight, Sarav, & Pickett-Blakely, 2017; O'Neill & Raggi, 2020).

Many nut and seed flours provide higher contents of fat and protein while providing limited available carbohydrates, making them viable alternatives for gluten-free and ketogenic products. Coconut flour is the byproduct of coconut milk production. After coconut-milk extraction,

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the coconut meat is dried at a low temperature and ground to produce a soft, fine powder. It is a soft, gluten-free, protein-rich, high-fat and fiber alternative to traditional grain-based flours, with approximately 75% of total carbohydrates being from fiber. It contains 14 to 18 g protein and 11 to 14 g fat per 100 g of flour, and has become increasingly popular for individuals following carbohydrate- and gluten-free diets. Likewise, with approximately 60% of total carbohydrates coming in the form of fiber, and with 21 g of protein and 53 g fat per 100 g flour, almond flour is also suitable for GF and ketogenic products.

To date, coconut flour and almond flour have been studied as supplemental ingredients in regular and gluten-free bakery products; however, they have not been compared side by side. The objective of this study was to evaluate the sensory attributes and mechanical properties of almond and coconut flours, alone and in combination, for gluten-free, ketogenic cupcakes.

2. Materials and methods

2.1. Cupcake formulation and materials

Cupcake formulations and mixing procedures were optimized on the basis of extensive preliminary mechanical and sensory evaluations. During formula development, 25% almond flour (wt/wt) was determined as the ideal amount for a cupcake with the most accepted texture and taste. When this ratio was used for a coconut flour cupcake, the cupcake was dry and did not show any signs of leavening. Levels of coconut flour were progressively reduced until the most acceptable all-coconut flour products was obtained. Pictures, cupcake volume and crumb structure of these inferior products are presented in Appendix 1. Approximately 11% coconut flour (wt/wt) was optimal for cupcakes containing only coconut flour. Higher percentages of coconut flour resulted in a cupcake that was too dry; and lower percentages produced a cupcake with poor leavening that was excessively moist. Differences between almond and coconut flour requirements may be attributed to the high water-absorbing and retention capacity of coconut fiber that is reported in the range of 4.48–8.3 g of water to one gram of coconut flour (Singthong, Yaowapan, & Teankaew, 2011). Other studies observed similar results when wheat flour was replaced with varying levels of coconut flour which demonstrated significant water retention capacities and drier products (Dat & Phuong, 2017; Dhankhar & Tech, 2013). Correlating ratios of almond to coconut flour were applied to the four variations tested. The almond flour cupcake (AF) used 45 g of almond flour; the almond/coconut hybrid (AC) was composed of 30 g almond flour and 5 g of coconut flour; the coconut/almond hybrid (CA) was composed of 10 g coconut flour and 15 g of almond flour; and the coconut flour cupcake (CF) contained 15 g of coconut flour. Ratios of almond flour (Costco Wholesale, Seattle, Washington), coconut flour (Arrowhead Mills, Hereford, Texas) or blends defined above were combined with 3 g baking powder (Clabber Girl Corp, Terre Haute, Indiana), 0.5 g salt (NaCl), 2.0 g psyllium husk (Now Foods, Bloomindale, Illinois), and 0.2 g xanthan gum (Grindsted Easy, Danisco, Copenhagen, DK); it was then set aside until ready to be combined with wet ingredients. Fifteen grams of hot water were combined with 27 g erythritol (Whole Earth Sweetener Co. LLC, Chicago, IL), 5 g soybean oil (ConAgra Foods, Omaha NE), 4.5 g vanilla, and 1.6 g monk fruit concentrate (Guilin GFS Monk Fruit Corp., Guangxi, China); all was mixed well with one egg (56 g) at room temperature and 15 g of softened cream cheese with the whisk attachment in an electric mixer (Model KSM180 QHSD, KitchenAid, St. Joseph, MI) until homogeneous. Dry ingredients were slowly added to the wet mixture and beaten until smooth and fully incorporated. Each cup of the standard cupcake tins was greased with canola oil spray and filled with 50 g batter. Due to increased batter viscosity, cupcake tops were smoothed with a moist spatula prior to baking. All cupcakes were baked for 18 min at 176 °C in a rotary oven (Model 12/24-SS, National Manufacturing, Lincoln NE), cooled at room temperature, and stored in re-sealable plastic bags at room temperature for subsequent testing. Although total flour percentages between the optimal almond flour cupcake and optimal coconut flour cupcake are different (45 g to 15 g respectively), the comparisons were made based on the most acceptable single flour products and hybrids were adapted based upon equal percent modifications.

2.2. Flour particle size and cupcake volume

Median particle size of coconut and almond flours was determined using laser light diffraction (Malvern Mastersizer IP, PS65 for dry samples). Particle size distribution for each sample was determined in triplicate using approximate 20 g of dry sample. Mean diameter and particle-size distribution of coconut and almond flours were determined by placing 100 g of flour in the top of a nest of sieves of decreasing apertures (U.S. series 20, 30, 40, 50, 60, 70, 100, 120, 180 and 220). The nest was then shaken for 15 min in a sieve shaker (Ro-Tap model RX-29, W.S. Tyler, Mentor, Ohio), after which the mass of sample retained on each sieve was recorded. Cupcake volume was conducted using the Rapeseed Displacement Method 10–05.01 (AACC, 2000).

2.3. Crumb analysis

Crumb quality was evaluated by analyzing cell size (mm^2) and density (cells/cm^2). Three cupcakes from two batches of each treatment were cut in half and analyzed using Digital Image Analysis (DIA) with the ImageJ program (National Institute of Health, Bethesda, MD, USA). Samples were photographed with an iPhone 11 (Apple Inc., Cupertino, CA, USA) with a dual lens 12 MP camera (26 mm f/1.8; 13 mm f/2.4) and analyzed according to the procedure described by Rosales-Juarez et al. (Rosales-Juárez et al., 2008). Briefly, photos were converted to 8-bit images, measurement scales calibrated, and cell crumb density measured through Threshold analysis. Measured cells were grouped into one of four categories: 1) cells <1 mm^2, 2) cells between 1 and 4 mm^2, 3) cells between 4 and 7 mm^2, and 4) cells greater than 7 mm^2 for comparison and statistical analysis.

2.4. Moisture and mechanical analysis

Moisture content was conducted by the two-stage bread-moisture Method 44–15.02 (AACC, 2000). Crumb tenderness (measured as a function of firmness), cohesion, adhesion, springiness and chewiness were measured with the TA-XT2 texture analyzer (Texture Technologies Corp., Scarsdale, NY) similar to AACC method 74–09, modified with a 10 N load cell and a probe speed of 1.7 mm/*sec*, set 10 mm from the surface with a TA-4 acrylic cylinder (35-mm diameter, 35-mm tall) probe. Applications software (Texture Exponent 32, V6.1.13.0, Stable Micro Systems Ltd., Godalming, Surrey, UK), and system macros were applied without modification. Texture measurement (12 values) were performed using cupcakes with the tops removed to give a 25-mm sample for compression to 50% deformation. After initial deformation, samples rested for two seconds, followed by a second compression cycle. Tenderness was measured as the maximum force of the initial compression and expressed in newtons (N). Cohesiveness is a measure of the positive area of work of the second compression divided by the positive work area of the first compression (no units). Springiness was defined as the ratio of the distance of the detected height during the second compression divided by the original compression contact point, with a value of 1 indicating the material returned to its original height after the first compression. Adhesiveness was a measure of the negative area after the first compression. Chewiness is expressed as tenderness (firmness) multiplied by cohesiveness and springiness. Samples were tested 24, 72 and 120 h after baking.

2.6. Sensory evaluation

Quantitative Descriptive Analysis (QDA): Twelve trained panelists, all regular consumers of bakery products, met weekly for a twelve-week period to establish descriptor attributes and terminology related to cake attributes. Reference standards and performance evaluations were conducted as described by Ahlborn (Ahlborn, Pike, Hendrix, Hess, & Huber, 2005). Attributes for analysis were developed and refined through consensus and ballot methods, facilitated through group discussion. Final attributes selected for evaluation at 24 h post-baking were moistness, adhesion, cohesion, tenderness, vanilla aroma, vanilla flavor, richness, and chewiness. Attribute definitions are identical, as described by Setser (Setser, 1993).

Consumer preference of cupcakes was conducted at the Brigham Young University Sensory Laboratory. Recruited participants (112 people, 49% female and 51% male) were divided into two groups; and one group (55 panelists) were informed that they were evaluating a ketogenic, gluten-free cupcake. The second group (57 panelists) were informed that they would be evaluating cupcakes without details around the cupcake composition. Following their evaluation, participants of the second group were informed that the cupcakes were ketogenic and gluten-free, and then asked to re-evaluate their impression of the products. Every panelist received samples through a pass-through compartment following a monadic sequential order. Sample were served on separate foam plates labeled with 3-digit blinding codes with distilled water and crackers for pallet cleansing between samples. Attributes selected for evaluation were appearance, aroma, flavor, texture, aftertaste, moistness, chewiness, color, vanilla aroma, vanilla flavor, and eggy flavor. Questions were presented to panelists via computer screen using Compusense Cloud® (Compusense, Inc., Guelph, ON, Canada), which instructed panelists to evaluate samples one at a time. Sensory evaluation was approved through the Brigham Young University Institutional Review Board; and panelists provided informed consent prior to testing.

2.7. Statistical analysis

Data were analyzed using JMP® Pro 15.0 (SAS, Institute Inc., Cary, NC). Treatment effects were compared through Least Square Means with Tukey-Kramer grouping to differentiate treatment effect and significant differences determined at $p \leq 0.05$. Consumer acceptance data were analyzed using analysis of variance with Tukey's HSD, except for ranking data, which were analyzed using Friedman Analysis of Ranking.

3. Results and discussion

3.1. Flour particle size and cupcake volume

Significant differences in cupcake volume and crumb from various lots of coconut flour were observed during early evaluations of coconut flour variations. As such, an analysis of particles size distribution from coconut flours and their impact on several cupcake properties was included in the experimental design. Four different lots of coconut flour were obtained from the same vendor and analyzed. Table 1 shows the distribution of sieved flours in different lots of coconut flours and their impact on cupcake volume. Flours from Lots 2 and 3 were composed of higher percentages of material from the number 40 and 50 sieves, which resulted in smaller, denser cupcakes. In contrast, Lots 1 and 4 had smaller particles sizes, as evidenced by greater percentages of flour collected from the 60- and 70-sieves, and resulted in larger, less dense cupcakes. Only cupcakes made from the 70-seived flour were significantly more voluminous than the un-sieved flour. Insufficient amounts of flour were collected in the 20, 30, 100, and 120 sieves to make cupcakes from those fractions, to prevent further analysis. Although a detailed analysis of particle- size distribution and impact on cupcake volume was conducted for almond flour, no statistical differences were observed between lots or fractions of almond flour. In comparison of the two flours, higher almond flour percentages correlated with increased cupcake volume. Cupcake volume of AF was greater than that of AC and CA, which were both greater than CF (Fig. 1).

3.2. Crumb analysis

Manual identification and Threshold Calculations were applied to the ImageJ analysis protocol. No significant difference was observed between either method of cell structure classification and enumeration. The percentage of cells <1 mm^2 were more predominate in AF and AC, while CA and CF consisted of more cells in the 4–7 mm^2 range, as well as cells greater than 7 mm^2 (Table 2). The average density of cells per cm^2 was highest in AF and AC compared to CA and CF. Increased cell density correlated with increases in cupcake volume, as described above, and is visibly noticeable in the bottom of Fig. 1. Heterogeneous cellular structures developed during the processing of baked goods can contribute to the mechanical properties and behavior of the crumb (Zghal, Scanlon, & Sapirstein, 2002). Several other studies have evaluated the relationships and mechanical properties of cellular solids or food sponges, including those containing gluten and starches (Ashby, 1983; Attenburrow, Goodband, Taylor, & Lillford, 1989; Keetels, Vliet, & Walstra, 1996; Scanlon, Sapirstein, & Fahloul, 2000).

3.3. Moisture and mechanical analysis

Table 3 provides moisture and mechanical endpoints as measured 24, 72 and 120 h after baking. AF and AC were significantly lower in moisture than CA and CF. Over time, all variations decreased in water

Table 1
Particle-size distribution of almond flour and coconut flour lots, and corresponding cupcake volume. Values with common letters are not significantly different ($p < 0.05$). nd = not determined; na = not applicable.

			Coconut Flour					Almond Flour	
			Distribution (%)				Cupcake volume (cm^3/g)	Distribution (%)	Cupcake volume (cm^3/g)
Sieve number	Theoretical particle size(mm)	Measured particle size (mm)	Lot 1	Lot 2	Lot 3	Lot 4		Average of all Lots	
20	<840	n/a	< 0.1	< 0.1	< 0.1	< 0.1	nd	< 0.1	nd
30	<595	558.1 ± 19.45	1.1	1.5	0.9	1.9	nd	1.4 ± 0.44	nd
40	<420	408.3 ± 27.64	27.2	31.8	32.1	17.9	2.9 ± 0.12^{a}	27.3 ± 6.62	3.31 ± 0.03^{A}
50	<300	270.7 ± 11.59	42.0	54.9	52.8	37.6	3.2 ± 0.10^{b}	46.8 ± 8.35	3.32 ± 0.05^{A}
60	<250	195.7 ± 2.31	20.4	8.3	10.4	27.8	3.4 ± 0.11^{bc}	16.7 ± 9.08	3.35 ± 0.07^{A}
70	<210	144.7 ± 12.10	5.2	2.6	2.5	8.2	3.7 ± 0.07^{d}	4.6 ± 2.69	3.34 ± 0.06^{A}
100	<150	106.3 ± 7.57	2.7	0.6	1.0	5.3	nd	2.4 ± 2.14	nd
120	< 125	nd	1.4	0.3	0.3	1.3	nd	0.8 ± 0.61	nd
unsieved	na	384 ± 28.4	na	na	na	na	3.1 ± 0.12^{ab}		3.34 ± 0.05^{A}
Volume (cm^3/g)			3.20 ± 0.05^{A}	2.74 ± 0.08^{B}	2.83 ± 0.05^{B}	3.28 ± 0.03^{AC}		3.34 ± 0.05^{C}	

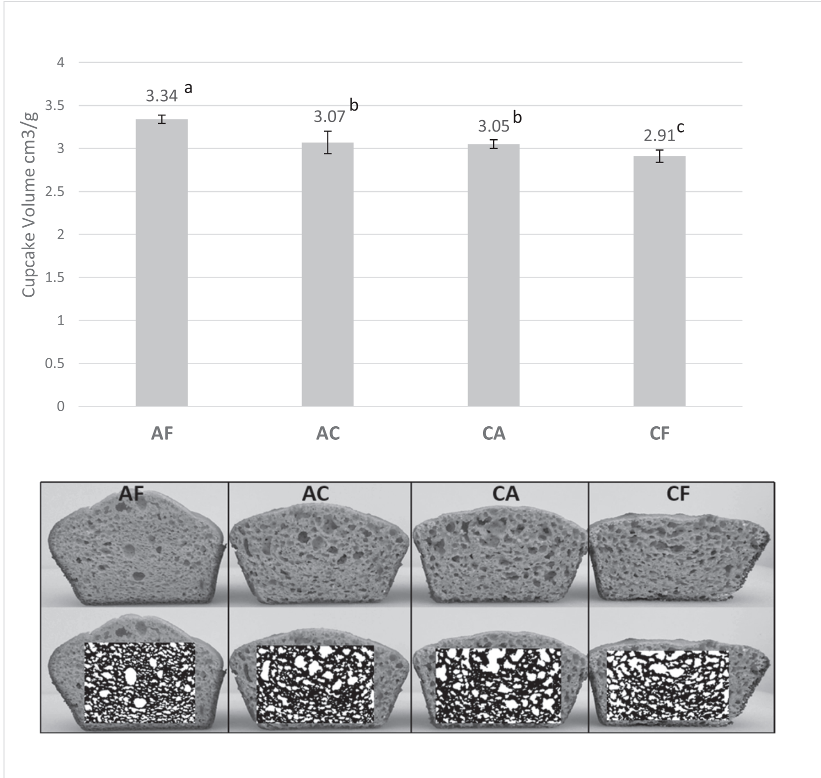

Fig. 1. Volumes and structural crumb comparison of gluten-free, ketogenic cupcakes made with almond and coconut flour formulations 2 h after baking with processed digital images. Values with common letters are not significantly different ($p < 0.05$).

Table 2
Crumb-cell size and density for ketogenic, gluten-free cupcakes. Values in the same row with common letters are not significantly different ($p < 0.05$).

	Almond Flour	Almond/ Coconut	Coconut/ Almond	Coconut Flour
Cell size range	%			
<1 mm^2	50.0 ± 3.90^{a}	48.5 ± 6.61^{a}	29.9 ± 1.71^{b}	24.6 ± 2.18^{b}
1–4 mm^2	41.9 ± 2.36^{a}	35.9 ± 6.86^{a}	40.7 ± 2.15^{a}	41.7 ± 1.79^{a}
4–7 mm^2	5.6 ± 1.05^{a}	10.3 ± 1.28^{b}	14.3 ± 2.02^{c}	18.3 ± 1.25^{d}
>7 mm ^{2}	2.5 ± 0.67^{a}	5.3 ± 0.82^{a}	15.1 ± 2.31^{b}	15.4 ± 1.08^{b}
	cells/cm^2			
Cell Density	26.4 ± 1.82^{a}	21.5 ± 1.20^{b}	15.2 ± 1.96^{c}	13.5 ± 1.22^{c}

Table 3
Moisture and mechanical attributes for ketogenic, gluten-free cupcakes. Upper case letters represent differences between cupcake variations; lower case letters represent differences for each variation at different times. Values with common letters are not significantly different ($p < 0.05$).

Time (hrs)	Attribute	AF	AC	CA	CF
24	Moisture (%)	33.2 ^{Aa}	34.2 ^{Aa}	41.9 ^{Ba}	42.0 ^{Ba}
72		30.9 ^{Ab}	32.1 ^{Aa}	38.9 ^{Ba}	39.7 ^{Bb}
120		29.1 ^{Ab}	30.3 ^{Bb}	36.5 ^{Cb}	37.6 ^{Dc}
24	Adhesion (g/sec)	(-) 10.21^{Aa}	(-)8.81^{Aa}	(-) 11.90^{Aa}	(-) 9.57^{Aa}
72		(-) 16.00^{Ab}	(-) 14.38^{Ab}	(-)8.75^{Ba}	(-) 8.91^{Ba}
120		(-) 13.71^{Ab}	(-) 12.55^{Ab}	(-) 10.57^{Aa}	(-) 9.16^{Aa}
24	Cohesion	0.64 ^{Aa}	0.62 ^{Aab}	0.61 ^{Aa}	0.62 ^{Aab}
72		0.60^{Ab}	0.60^{Aa}	0.62 ^{Ba}	0.61 ^{ABa}
120		0.63 ^{Aa}	0.64 ^{Ab}	0.64 ^{Aa}	0.64 ^{Ab}
24	Tenderness (N)	5.2 ^{Aa}	8.1 ^{Ba}	9.7 ^{Ca}	12.3 ^{Da}
72		8.6 ^{Ab}	9.4 ^{Ab}	9.3 ^{Aa}	12.1 ^{Ba}
120		10.2 ^{Ac}	10.0 ^{Ab}	11.3 ^{Bb}	14.2 ^{Cb}
24	Springiness (recovery)	0.99 ^{Aa}	0.98 ^{Aa}	0.99 ^{Aa}	0.98 ^{Aa}
72		0.99 ^{Aa}	0.98 ^{Aa}	0.98 ^{Aa}	0.97 ^{Aa}
120		0.98 ^{Aa}	0.97 ^{Aa}	0.97 ^{Aa}	0.97 ^{Aa}
24	Chewiness (N)	3.3^{Aa}	4.9^{Ba}	5.9^{Ca}	7.4 ^{Da}
72		5.1^{Ab}	5.5^{Aab}	5.7^{Aa}	7.1^{Ba}
120		6.2^{Ac}	6.2^{Ab}	6.9^{Bb}	8.6^{Cb}

content. These results were anticipated as AF and AC had higher amounts of flour on a weight/weight basis. Based on formulations and % water to dry matter, AF and AC were ~ 41.2% and 43.5% water, while CA and CF were ~ 46.5 and 49.7%.

Increased tenderness (with lower values indicating a tenderer product) was correlated with higher amounts of almond flour, with AF being the most tender. With the addition of higher levels of coconut flour, cupcakes were significantly less tender, despite having higher moisture values. These decreases in tenderness are similar to observations by Dat & Phuong (2017) in replacing wheat flour with coconut flour. Because all variations were absent of starch, staling was not anticipated to be a major factor over time. However, most variations exhibited decreases in tenderness over time, with CF showing the most pronounced changes after 120 h. These observations could be attributed to the natural loss of water over time. At 24 h, the cohesion and adhesion values of the cupcakes were not statistically different among variations. Yet, after 72 h, the adhesions of CA and CF decreased, while the cohesion slightly increased. After 120 h, there were no longer any statistical differences in adhesion and cohesion among variations.

There was no difference in springiness between variations at any time points, as all cupcakes maintained a very high level of structural resilience. This may be attributed to the high levels of fat and protein, and similar observations were made by Gillespie and Ahlborn (2021) in their evaluation of ketogenic, gluten-free breads. At 24 h, CF was the chewiest, whereas AF was the least chewy. After 72 h, CF was the chewiest, and no difference were observed between the other variations. After 120 h, AF and AC were the least chewy, followed by CA, and CF as the chewiest. All variations exhibited increases in chewiness from the 24-hour evaluation compared to the 120-hour evaluation period which can also be attributed to the natural loss of moisture over time.

Although coconut and almond flours have never been compared side-by-side, both have been evaluated in conjunction with other flours, including white rice flour, soybean flour, and wheat products. Our observations correlate with those seen in other studies. Martínez, Marín, Gili, Penci, and Ribotta (2017) observed that 40% addition of partially defatted almond flour decreased hardness and chewiness compared to a wheat control. Jia, Kim, Huang, and Huang (2008) replaced varying levels of wheat flour with almond flour in Chinese moon cakes and reported that almond flour increased the chewiness, and decreased the hardness (indicative of increases in tenderness) through sensory and mechanical evaluation. Mechanical evaluation of moon cakes showed significant increases in cohesiveness with higher amounts of almond flour as well. It was also demonstrated it was possible to replace wheat flour in traditional bread and wheat noodles with up to 20% coconut flour and still maintain acceptable sensory attributes (Gunathilake & Yalegama, 2009; Gunathilake & Abeyrathne, 2008). Similarly, the addition of coconut flour to wheat muffins improved overall acceptability (Ramya & Anitha, 2020). With a primary focus on nutritional quality and consumer acceptance, Abimbola (2017) supplemented wheat biscuits with almond/coconut blends. Although 100% wheat biscuits were preferred, an 80% wheat, 10% coconut and 10% almond flour biscuit was acceptable to consumers.

3.4. Sensory evaluation

Summaries of QDA data can be found in Table 4. Contrasting the measured moisture values above, AF and AC were perceived as significantly moister than CA and CF, with CF being the least moist. Although less coconut flour was used in proportion to almond flour, water binding properties of coconut flour resulted in a product that was perceived as drier by panelists, despite containing more water than the higher almond flour counterparts after the baking process.

Tenderness values were highest in AF and AC, while cupcakes decreased in tenderness as coconut flour percentages increased. These findings mirror the mechanical testing, as lower tenderness scores through texture analysis correlate with increased sensory scores. Sensory values for chewiness also followed mechanical testing and was most pronounced in CF, with AF being the least chewy. No differences were observed between AC and CA variations. CF was the only sample that showed significant increase in adhesiveness, while higher percentages of almond flour correlated to higher cohesive values. An inverse relation was observed in comparison of mechanical cohesive values to QDA values. This difference was also observed in a comparison of ketogenic, gluten-free bread (Gillespie & Ahlborn, 2021) and supports other findings which indicate that mechanical cohesiveness endpoints are not predictive of sensory evaluations for cohesiveness (Di Monaco, Cavella, & Masi, 2008; Wee, Goh, Stieger, & Forde, 2018). Richness was scored highest in the CF cupcake, with no significant difference between cupcakes containing almond flours. Although levels of vanilla were identical in all variations, CF exhibited the highest vanilla aroma scores, and vanilla flavor was not statistically different among formulations.

Consumer Acceptance testing showed that AF was the most preferred, closely followed by AC, regardless of panelists being informed or uninformed. CF was least preferred, and based on purchase likelihood, panelists preferred higher percentages of almond flour over coconut flour. Higher levels of almond flour also affected appearance

Table 4
QDA analysis of gluten-free, ketogenic cupcakes. Values in the same row with common letters are not significantly different ($p < 0.05$).

Sensory Attributes	Almond Flour	Almond/ Coconut Flour Hybrid	Coconut/ Almond Flour Hybrid	Coconut Flour
Moistness	6.2 ^{a}	5.9 ^{a}	4.9^{b}	4.3^{c}
Adhesion	2.1 ^{a}	2.0 ^{a}	2.1 ^{a}	2.9^{b}
Cohesion	2.8 ^{a}	2.8 ^{a}	2.3^{b}	2.1^{b}
Tenderness	6.7 ^{a}	6.8 ^{a}	4.9^{b}	4.0^{b}
Vanilla Aroma	5.1 ^{a}	5.8^{b}	5.8^{b}	6.5^{c}
Vanilla Flavor	4.2 ^{ab}	3.7^{b}	4.8 ^{a}	4.1 ^{ab}
Richness	5.3 ^{a}	5.6 ^{a}	5.6 ^{a}	6.6^{b}
Chewiness	2.1 ^{a}	2.9^{b}	3.2^{b}	4.7^{c}

scores, which decreased in acceptability as coconut flour increased. Flour percentages did not influence consumer perceptions on flavor or aroma, and the texture and tenderness of AF were more frequently accepted compared to CF and correlates with QDA and mechanical testing parameters. Whereas trained panelist identified differences in moistness and richness values, general consumers did not identify significant discrepancies (Appendix 1).

4. Conclusions

Low-carbohydrate cupcakes suitable for a ketogenic diet made from almond flour, coconut flour, and combinations of both were compared through mechanical and sensory means. Based solely on the solid foam structure and cell density, it would be anticipated that AF would be least tender. However, our observations demonstrated otherwise. While crumb structure can play a significant role in the textural properties in the crumb of baked goods, it appears that the physical and chemical properties of the crumb-cell wall materials are more influential on crumb strain in gluten-free, ketogenic cupcakes. Additional work is required to validate this point. Additional work is also required when comparing attributes such as adhesiveness and cohesiveness through mechanical and sensory endpoints. Cupcakes made with higher amounts of almond flour were moister, more tender, and more preferred over the coconut-flour products, despite having significantly lower moisture. However, the fact that all variations were acceptable and conform to a low-carbohydrate or ketogenic lifestyle provides viable options for individuals who subscribed to those particular lifestyles.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.fochx.2021.100182.

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