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A Comprehensive Study on Physical Properties of Two Gluten-Free Flour Fortified Muffins

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Abstract

Background: Muffin a Cereal based snacks, has been considered as the most popular breakfast cereals by average Americans now-a-days, because of their unique pleasant taste and easily consumable characteristics. Flour is the main ingredient to prepare muffins and Gluten is the major protein constituent of Wheat flour, which is considered to be responsible for Celiac disease. Life-long Gluten-free diet has been considered as the only effective treatment for Celiac disease.

Aim: The project was aimed to produce gluten free healthy cereal based snacks muffins prepared from two gluten free flours, Rice and Quinoa flour and to conduct a comprehensive study on their physical properties. 100% Wheat flour was used as control. 100% Rice flour was replaced by 25%, 50%, 75% and 100% Quinoa flour to prepare muffin. Physical property measurements including percentage increase/decrease of crest height, moisture and specific gravity, color by Hunter colorimeter and Texture Profile Analysis (TPA) by TAXT. Plus Texture analyzer was done for the final product. The Sensory attributes, appearance, flavor, sweetness, texture and general acceptability, were evaluated by a group of un-trained panelists, using a 9-point Hedonic scale. Sensory and instrumental data were analyzed statistically.

Results: 100% Rice flour and a replacement of Quinoa flour up to 75% to Rice flour was considered as overall consumer acceptable range for gluten free muffins.

Keywords: Rice flour; Quinoa flour; Muffins; Celiac disease; Gluten intolerance

Introduction

Celiac disease (CD) which is a gluten sensitive inflammatory disorder of the small intestine, also known as gluten intolerance, affects genetically predisposed individuals when they ingest gluten proteins from wheat, barley and rye. CD results due to an intolerance to gliadin and glutenin proteins. In 2006, the American Dietetic Association updated its recommendations for a gluten-free diet. The only effective treatment [1] for celiac disease is a life-long gluten-free diet. Gluten-free breads and cookies are principally based on flour from rice or maize with low content and poor-quality proteins. CD patients, especially children on a strict gluten-free diet, are undernourished because of the reduced intake of energy which is largely taken from wheat-based foodstuffs in a current western diet [2]. Recently, the use of two pseudo cereals (non-grass family) in particular amaranth and quinoa have been considered for the preparation of gluten-free snack foods. Amongst those Quinoa was our main consideration. Quinoa has excellent reserves of protein and high lysine content, an important amino acid for tissue growth, so the protein is more complete compared to other grains. High lysine content in quinoa raises the biological value of this protein. Nutritionally, Quinoa is a super grain and the World Health Organization has rated Quinoa as equivalent to milk as it contains high levels of potassium, riboflavin, B6, niacin and thiamin along with magnesium, zinc, copper and manganese and some folate. Therefore, Quinoa flour alone or fortified with other gluten free flour can replace Wheat flour and can represent a healthy alternative for people with CD.

Keeping in view of the above, the current study was aimed to produce a gluten free healthy muffin from gluten free flours, considering muffins are an important part of a daily breakfast. Rice flour and Quinoa flour were used as gluten free flour. Rice flour is naturally gluten-free, rich in carbohydrates and low in fat. This study examined the effects of substitution of Rice flour with Quinoa flour at 25%, 50%, 75% and 100% on the physical, textural, and sensory characteristics of gluten free muffins. 100% Whole wheat flour was used as control flour composition to prepare muffin.

Materials and Methods

Muffin formulations and preparations

Muffin recipe was a combined modifications [3,4] and contained the following ingredients : pure granulated white sugar (Domino Foods, Inc., Yonkers, NY, USA), salt (IGA brand, IGA Inc., Chicago, IL, USA), double-acting baking powder (Clabber Girl, Co., Terre Haute, IN, USA), 100% pure canola oil (Safeway brand, Safeway Inc., Pleasanton, CA, USA), natural 2% reduced fat milk (Safeway brand, Safeway Inc.), fresh large eggs as Table 1.

White Rice flour and Quinoa flour were a free gift from Bob's Red Mill and Whole wheat (General Mills, Inc., Minneapolis, MN, USA) flour was purchased from a local supermarket.

Whole wheat flour was used as control flour and was replaced with White Rice flour and Quinoa flour as gluten free flour replacement. Wheat flour in the control recipe was replaced by 25%, 50%, 75% and 100% Rice flour and Quinoa flours to prepare muffins. Therefore, there were total 6 formulations were tried in terms of flour compositions and

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Ingredients	(% w/w)
Flour	35.25
White sugar	15.42
salt	0.13
Baking powder (double-acting)	1.29
Vegetable oil	13.88
2% reduced fat milk	25.31
Fresh large eggs	8.72
Total	100

Table 1: Muffin formulations.

they will be designated as F_1 (100% Wheat flour), F_2 (100% Rice flour), F_3 (75% Rice flour+25% Quinoa flour), F_4 (50% Rice flour+50% Quinoa flour), F_5 (25% Rice flour+75% Quinoa flour) and F_6 (100% Quinoa flour) from now.

Flour, sucrose, baking powder, and salt were mixed together in a separate bowl, and then were shifted into the wet ingredients at speed 4 for 10 seconds. Muffin pans were filled with the batter (55-65 g each) and were baked for 20 minutes or until done at 204°C in a preheated oven. Following a five-minute setting period, muffins were removed from the pans and allowed to cool on wire racks for one hour after which analyses were performed.

Studies on muffins and muffin batters

Basic physical properties:

Batter specific gravity: Specific gravity of muffin batters (at 21.8 ± 2°C) was measured using a pycnometer (Fisher Scientific, Pittsburg, PA) and was calculated by dividing the weight of a standard measure of the batter by the weight of an equal volume of water.

Batter viscosity: The viscosity of muffin batter was determined [5] using Brookfield DV-II+Pro Viscometer (Middleboro, MA). Muffin batter was transferred to a 600-mL Beaker. The spindle speed was set to 5 rpm, and spindle no. 4 (S64) was used for all the experiments. The experiment was run at room temperature (at 21.8 ± 2°C).Viscosity was measured immediately.

Line spread test for muffin batters were performed using a line spread chart. All tests were performed in triplicate.

Moisture properties: A study was conducted to know the changes in moisture content and water activity due to substitution of Quinoa flour to Rice flour. Moisture was determined by moisture analyzer (OHAUS Explorer, MB 45, Pinebrook, NJ).

Water activity was determined by a water activity meter (Decagon, CX-1). All measurements were done in triplicate by taking the sample from the geometric center of the muffin.

A vernier caliper (Monostat Corp., Merenschwand, Switzerland) was used to measure height and percent increase/decrease in height was determined from initial and final heights.

Color analysis

The color of muffin crust was measured with a Hunter colorimeter (Hunter Colour-Flex, CFLX 45-2, Hunter Associates Laboratory, Inc., Reston, VA, USA) based on CIE scale in triplicate using, L*, *a**, *b** color space; L* value measuring black (0)/white (100), *a** value measuring green (-)/red (+) and *b** value measuring blue (-)/yellow (+). The Hunter colorimeter was calibrated using color standard (white and black) ceramic tiles supplied by the manufacturer. The observations were made using D-65 illuminant and 10° observer. For each replicate, crust color was measured at three random areas. The crust of the muffin was carefully removed using a serrated bread knife to expose the crumb for color measurement. Both the crust and crumb color were analyzed by this way.

Texture analysis

The textural properties of muffin were determined using a TA.XT Plus Texture Analyzer (Texture Technologies Corp., Scarsdale, NY) (Stable Micro Systems Ltd.).

Cubes of 2.5 cm were gently cut out of the center of each muffin with a serrated bread knife to expose the crumb for texture measurement. Crumb texture measurement was performed by texture profile analysis (TPA) using a TA-25 MUF1/P36R probe and a TA-90 platform, with pretest speed=5 mm/s, test speed=1 mm/s, post test speed=2 mm/s and distance=10 mm.

Texture analysis program parameters were set as follows: pretest speed=5 mm/s; test speed=1 mm/s; post-test speed=2 mm/s; test distance=5 mm; and distance=10 mm.

Textural variables from force and area measurements [6] were: hardness=peak force (g) during the first compression cycle; cohesiveness=ratio of the positive force area during the second compression to that during the first compression; springiness=height that the sample recovers during the time that elapses between the end of the first bite and the start of the second bite (cm); and chewiness=hardness X cohesiveness X springiness (g cm).

Three muffins from each formulation were used to evaluate textural parameters.

Sensory evaluation

A panel of 20 semi-trained judges of both genders aged 18-50 years evaluated the muffins on a 9-point hedonic scale (1=dislike extremely, 5=neither like nor dislike, 9=like extremely). Muffins were sliced into half and identified by a three-digit random number. The samples were offered to the judges on a white plate at room temperature in individual booths under white light. Panelists were given room temperature water to cleanse the palate before tasting the samples from each formulation. No prior training was provided to panelists. All five samples were served, one at a time, to each panelist. General, appearance, flavor, texture, sweetness and overall acceptability were evaluated using an attribute rating form.

Statistical analysis

Sensory and all other experimental data were analyzed using one-way analysis of variance (ANOVA). $P<0.05$ was considered significant.

Results and Discussions

Quality of muffin depends mainly on the quality of its batter's physical properties. Changes of pH, Specific gravity, and Viscosity and LST values for all different muffin batters are represented in the Table 2.

A slight increase of pH was observed due to incorporation of

Flour formulations	Batter pH	Batter Sp. Gravity	Batter Viscosity (cp)	LST (mm/20 min)
F_1	6.5 ± 0.3^b	1.35 ± 0.03^b	134000 ± 7.07^d	8.5 ± 0.43^c
F_2	7.0 ± 0.25^b	1.11 ± 0.01^b	31116 ± 6.52^d	38.7 ± 0.26^c
F_3	7.25 ± 0.05^a	1.12 ± 0.01^a	34313 ± 6.74^d	34.88 ± 0.13^c
F_4	7.25 ± 0.25^a	1.15 ± 0.01^a	36181 ± 5.48^d	33.17 ± 0.15^c
F_5	7.5 ± 0.3^a	1.18 ± 0.02^a	38991 ± 12.45^d	31.61 ± 0.35^c
F_6	7.5 ± 0.2^a	1.26 ± 0.02^a	48470 ± 9.05^d	24.75 ± 0.66^c

Table 2: Physical properties of Batters.

Flour formulations	Hardness (g)	Springiness (cm)	Cohesiveness	Gumminess	Chewiness (g cm)
F_1	1405.19 ± 49.29[b]	1.005 ± 0.03[b]	0.873 ± 0.02[a]	510.04 ± 29.29[b]	1412.59 ± 37.64[c]
F_2	868.27 ± 20.33[b]	0.906 ± 0.09[b]	0.784 ± 0.02[a]	229.52 ± 21.51[b]	781.20 ± 33.69[c]
F_3	949.04 ± 41.27[a]	1.003 ± 0.48[a]	0.873 ± 0.01[a]	386.69 ± 26.79[a]	949.00 ± 51.46[c]
F_4	1079.12 ± 54.56[b]	1.006 ± 0.06[a]	0.842 ± 0.03[a]	645.79 ± 43.27[a]	1079.00 ± 33.04[a]
F_5	1243.37 ± 82.82[a]	1.013 ± 0.02[a]	0.805 ± 0.06[a]	825.16 ± 16.35[b]	1253.33 ± 57.93[a]
F_6	1478.28 ± 30.46[a]	1.040 ± 0.05[a]	0.790 ± 0.04[a]	1015.45 ± 23.43[d]	1537.00 ± 24.24[a]

Table 3: Effect of different flour formulations on Textural properties.

Flour formulations	Attributes (n=20)				
	Appearance	Flavor	Texture	Sweetness	Overall acceptance
F_1	5.04 ± 1.20[c]	6.05 ± 0.22[d]	5.05 ± 0.67[d]	6.09 ± 0.89[c]	6.04 ± 0.66[d]
F_2	6.57 ± 1.21[c]	7.08 ± 0.59[d]	7.14 ± 0.48[d]	7.05 ± 0.86[c]	7.42 ± 0.81[d]
F_3	6.23 ± 1.26[b]	7.09 ± 0.31[a]	6.71 ± 0.78[d]	5.95 ± 0.74[a]	6.52 ± 0.51[b]
F_4	6.14 ± 1.23[b]	7.10 ± 0.95[a]	5.86 ± 0.48[b]	4.76 ± 1.09[c]	5.98 ± 0.67[d]
F_5	6.09 ± 1.13[b]	7.16 ± 0.62[a]	4.09 ± 0.31[d]	4.24 ± 1.13[d]	5.78 ± 0.78[b]
F_6	5.95 ± 1.24[b]	7.38 ± 0.59[d]	4.05 ± 0.38[d]	3.76 ± 1.67[d]	4.90 ± 0.53[d]

F_1 is 100% Wheat flour, F_2 is 100% Rice flour, F_3 is 75% Rice flour+25% Quinoa flour, F_4 is 50% Rice flour+50% Quinoa flour, F_5 is 25% Rice flour+75% Quinoa flour and F_6 is 100% Quinoa flour.
All data are presented by means ± SD. Means and standard deviation (SD) followed by the same letter in the same column are not significantly different ($P<0.05$).

Table 4: Muffin sensory by 9-point hedonic scales.

Flour formulations	Before baking (mm)	After baking (mm)	% increase of height
F_1	30 ± 0.25	53 ± 1	75.93 ± 7.31
F_2	28 ± 0.15	45.8 ± 0.5	65.04 ± 1.85
F_3	27.5 ± 0.5	45.5 ± 0.5	60.81 ± 6.55
F_4	27 ± 0.25	45 ± 1	60.81 ± 6.55
F_5	26.5 ± 0.18	44.85 ± 0.15	60.77 ± 4.39
F_6	25.8 ± 0.15	44 ± 1	58.28 ± 2.81

Table 5: Percentage increase of height due to baking.

Flour formulations	Moisture (%)	Water activity (aω)
F_1	27.15 ± 0.11[d]	0.862 ± 0.015[a]
F_2	24.54 ± 0.01[d]	0.835 ± 0.012[a]
F_3	24.96 ± 0.05[c]	0.833± 0.017[a]
F_4	24.08 ± 0.14[c]	0.826 ± 0.018[a]
F_5	25.58 ± 0.07[c]	0.821 ± 0.020[a]
F_6	26.61 ± 0.12[b]	0.816 ± 0.010[b]

Table 6: Physical properties of Muffins.

Quinoa flour to Rice flour. Batter viscosity is an important physical property as it is closely related to the final quality of a baked product. A good quality muffin should be a uniformly aerated baked product. Air incorporation, retention, bubble stability and the generation of convection currents during baking are closely related to initial batter viscosity. Batter viscosity is dependent on shear thinning and shear thickening behavior of different muffin flour formulations. In other words, muffin viscosity is closely related to texture and appearance of the baked product. Batter made with 100% Wheat flour had the highest viscosity and specific gravity compared to others. Lower viscosity of 100% Rice flour (F_2) muffins and 75% Rice flour+25% Quinoa flour (F_3) muffins decreases hardness, gumminess and chewiness and gives better consumer's Textural acceptance (Tables 3 and 4).

Higher water binding capacity for wheat flour imparts higher percentage increase of height due to baking (Table 5). Gluten free flour formulated muffins shows lower water activities (Table 6).

Color is an important attribute of the Baked Food products because it affects to the consumer's perception to the acceptability of the product as well as determines nutritional quality of food products. The original intrinsic colors due to the individual ingredients are affected by the interaction between the ingredients themselves during baking of the products, which is likely due to the increased Mallard browning reactions in the product. Color also depends on the concentration of a certain ingredients. The tristimulus color values L (lightness), a (redness) and b (yellowness) were recorded on CIE scales in triplicate for both crust and crumb using Hunter colorimeter in this study and represented in Table 7.

Crust lightness (L) was always lower than Crumb lightness (L) for all combinations; means crusts are darker than crumbs. Rice flour is white in color and Quinoa flour has an intrinsic golden yellow color. Lightest golden yellow crust and crumb color for 100% Rice flour muffin (F_2) and 75% Rice flour+25% Quinoa flour muffin (F_3) are consumer's best choice in terms of muffin appearance (6.57 and 6.23) as shown in Table 4. However, the appearance attributes of 50% Rice flour+50% Quinoa flour muffins (F_4) and 25% Rice flour+75% Quinoa flour muffins (F_5) were 6.14 and 6.09 and which do not differ very much from the previous two flour formulations.

Hedonic ratings for product attributes and overall likeability are presented in Table 4. If an attribute score is above 5 (neutral), it was considered to the desirable range [7-9]. Higher percentage of Quinoa flour did not affect too much to the Appearance and Flavor to muffins. Quinoa flour has a uniquely different flavor. Therefore, the Hedonic rating for flavor 7.38 was highest for 100% Quinoa flour (F_6) muffin.

But, Quinoa flour has a natural bitter taste, therefore, the attribution for sweetness was considerably lower, 4.76 for 50% Rice flour+50% Quinoa flour (F_4), 4.24 for 25% Rice flour+75% Quinoa flour (F_5) and 3.76 for 100% Quinoa flour (F_6). Which also reduces their overall acceptability and it is 7.42, highest for 100% Rice flour (F_2) and 6.52 for 75% Rice flour+25% Quinoa flour (F_3) and 4.90, the lowest for 100% Quinoa flour (F_6) muffins.

W hich means 100% Rice flour and a substitution for Quinoa flour up to 75% to Rice flour are the best overall acceptable composition for a gluten free muffin. However, Flavor is the only attribute whose desirability was not affected considerably by fortification of 100% Quinoa flour to Rice flour and which compensates the bitterness due to 50% and 75% Quinoa flour in 50% Rice flour+50% Quinoa flour (F_4)

Flour formulations	L		a		b	
	Crust	Crumb	Crust	Crumb	Crust	Crumb
F_1	20.89 ± 0.17[a]	50.35 ± 0.46[c]	13.72 ± 0.29[c]	9.03 ± 0.13[c]	24.39 ± 0.20[c]	24.81 ± 0.22[c]
F_2	22.43 ± 0.48[a]	74.68 ± 0.42[c]	17.61 ± 0.44[c]	3.06 ± 0.18[c]	35.34 ± 0.18[b]	35.88 ± 0.16[a]
F_3	21.46 ± 0.31[a]	72.45 ± 0.51[c]	15.33 ± 0.06[b]	4.04 ± 0.22[a]	35.88 ± 0.16[c]	35.34 ± 0.19[b]
F_4	20.62 ± 0.41[a]	71.52 ± 0.36[c]	15.03 ± 0.08[c]	4.66 ± 0.01[b]	36.87 ± 0.11[d]	36.87 ± 0.11[c]
F_5	18.58 ± 0.31[b]	66.74 ± 0.37[c]	14.31 ± 0.06[a]	5.08 ± 0.04[c]	34.74 ± 0.14[a]	34.74 ± 0.14[a]
F_6	15.94 ± 0.13[c]	56.59 ± 0.43[c]	14.45 ± 0.23[b]	5.23 ± 0.19[b]	33.05 ± 0.18[c]	33.05 ± 0.18[c]

Table 7: Effect of different flour formulations on CIE color.

and 25% Rice flour+75% Quinoa flour (F_5) formulations and keep the overall acceptability range to over 5, a neutral range.

Qualities of the muffins are greatly influenced by their appearance due to its Texture. A good muffin should be softer in Texture. There were significant change of textural properties (Table 3) of muffins because of the replacement of Wheat flour with gluten free flours, such as Rice and Quinoa. 100% Wheat flour muffin is very hard (1405.19 g), Hedonic Texture rating is 5.05, might be because of high gluten content. 100% Rice flour muffin is comparably softer (868.27 g) and Hedonic rating for Texture is 7.14, the highest. Hardness increases and Hedonic rating for Texture decreases with the increase of Quinoa flour fortification. 100% Quinoa flour muffins are the hardest (1478.28 g) muffins, whose Texture Hedonic rating for consumers is 4.05, the lowest. Gumminess and Chewiness also increases with the percentage increase of Quinoa flour fortification. Rice flour has the lowest value for Hardness, Gumminess and Chewiness. We do not see any big differences in the Cohesiveness and Springiness due to replacement of gluten free flour to Wheat flour in muffins.

Conclusions

This study shows that, 100% Rice flour and 25% to 75% replacement with Quinoa flour to Rice flour formulations for muffin has the better overall consumer acceptability compared to 100% Quinoa flour muffin, which has the lowest overall consumer acceptability because of the bitter taste of Quinoa flour. 100% Rice flour and 75% Rice flour+25% Quinoa flour formulated muffins are the softest muffins and most acceptable muffin formulations in terms of overall consumer acceptability.

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