Optimization of taro mucilage and fat levels in sliced breads

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Abstract Bread is one of the most commonly consumed foods, and much ongoing research is aimed at meeting the demand for higher quality bread products in terms of greater volume and softness with characteristic flavor, aroma and color. The goal of the present study was to optimize the amounts of lyophilized taro mucilage and hydrogenated vegetable fat added to sliced bread formulations to improve the physical characteristics of the bread while reducing lipid levels and maintaining good sensorial quality. For the analysis, a central composite rotatable design (CCRD) was used for the two factors, resulting in 11 total experiments. Physical, chemical, and sensory analyses were performed. Breads containing taro mucilage were soft and exhibited good sensorial quality. Optimal amounts of the two factors studied were determined using response surface methodology to produce breads with greater specific volume, higher bread-making quality, and lower fat levels than current formulations. The optimal levels of lyophilized taro mucilage and hydrogenated vegetable fat in the sliced bread formulation were $0.73 \text{ g } 100 \text{ g}^{-1}$ and $1.58 \text{ g } 100 \text{ g}^{-1}$, respectively.

Keywords *Colocasia esculenta* · Bread making · Specific volume · Central composite rotatable design · Natural additive

Introduction

Bread is one of the most commonly consumed foods and comes in a variety of shapes and types. The objective of all bread production processes is to convert wheat flour into an

aerated, palatable food, and in most cases, specific quantities of yeast, salt, and other specific ingredients are combined with flour (mainly wheat) and water to produce bread (Cauvain and Young 2009).

Among the ingredients used for bread production, fats have many important functions that contribute to increasing the softness and improving the sensory characteristics of bread. Fats also increase aeration, favor fermentation and increased volumes, and lubricate the gluten strands, thus giving the product structure as well as delaying its staling, improving its water retention and prolonging its shelf life (O'Brien 2009).

Hydrocolloids are capable of solubilizing or swelling in aqueous systems, providing viscosity characteristics similar to the characteristics provided by fats (Glicksman 1991). Hence, hydrocolloids have demonstrated good properties as fat substitutes in many products (Lucca and Tepper 1994; Albert and Mittal 2002). Given that the excessive intake of oils and fats has been frequently associated with obesity, hypercholesterolemia, cardiovascular diseases and some types of cancer (Grossklau 1996), it is very important to perform studies with the purpose of reducing the lipid content in food products without negatively affecting their technological and sensory characteristics.

Taro (*Colocasia esculenta*) mucilage is one example of a hydrocolloid that can be used for bread making (Contado et al. 2009). Taro is a tropical tuber crop with underground rhizomes containing 70–80 % starch, and it is used in a wide variety of foods because the small size of its starch granules makes it highly digestible (Kaushal et al. 2013). Mucilage, or gum, is generally present in tropical roots and tubers and is particularly abundant in taro. Mucilage has unique rheological properties and holds much potential for use as a food thickener and stabilizer (Njintang et al. 2011; Kaushal et al. 2013). This natural plant gum also produces gelling effects and increases viscosity (Fedeniuk and Biliaderis 1994).

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Physically, mucilage can be characterized as a hydrogel, i.e., a liquid, lyophilic colloidal system. Chemically, mucilage consists of water, pectins, sugars, and organic acids (Misaki et al. 1972). In a study investigating mucilage from six different taro varieties, Njintang et al. (2011) reported that the carbohydrate content of the mucilage ranged from 46 to 69 %; thus, carbohydrates were found to represent the major component of taro mucilage, and galactose, mannose and arabinose were identified as the major monosaccharides. Between 30 and 50 % of the mucilage content was protein, and aspartic acid, glutamic acid, glutamine, glycine, leucine, serine, and alanine were the most common amino acids.

A number of recent studies have investigated the effects of adding taro mucilage to baked goods. Contado et al. (2009) found that sliced breads supplemented with lyophilized taro mucilage had good consumer acceptance. Tavares et al. (2011) emphasized how the use of taro mucilage in the food industry reflects its properties as a thickener and stabilizer and demonstrated that taro mucilage can be used in sliced breads. In terms of achieving high-quality bread with reduced fat levels, however, the optimal amounts of taro mucilage and fat to add to standard formulations still need to be identified.

Consumers demand high-quality products with extended shelf life. Research efforts aimed at meeting these requirements include the development of additives and processing aids that alter the rheological properties of dough and improve bread quality (Gomez et al. 2004).

With the goal of producing bread with improved physical characteristics, reduced lipid levels and good sensorial quality, a central composite rotatable design was used in the present study to optimize the amounts of lyophilized taro mucilage and hydrogenated vegetable fat added to the formulation for sliced bread.

Materials and methods

Lyophilized taro mucilage extraction

Taro (*C. esculenta*) rhizomes were purchased from a retail market. The rhizomes were washed under running water, sanitized in a sodium hypochlorite solution (1 g L^{-1}), peeled and ground in an industrial blender (Lucre, Catanduva, Brazil). Mucilage was extracted from the ground taro by filtration through a polyester mesh, and the filtrate was lyophilized to obtain lyophilized taro mucilage.

Characterization of lyophilized taro mucilage

The analysis of the chemical composition of lyophilized taro mucilage used in the present study was performed by Andrade (2013), a member of our research group. The following values were determined: water content 8.47 %, ether extract 0.48 %, crude protein 3.18 %, crude fiber 0.35 %, ash 4.05 % and glycidic fraction 91.94 %, all on a dry basis.

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To complement the study, the pH and titratable acidity (Cecchi 2003), sugars (Somogy, adapted by Nelson 1944) and minerals (Malavolta et al. 1997) were also analyzed.

Experimental design

A central composite rotatable design (CCRD) was used to optimize the levels of lyophilized taro mucilage (X_1) and hydrogenated vegetable fat (X_2) added to sliced breads. A total of 11 experiments was performed, corresponding to four factorial points, four axial points and three central points. The replication of the central point allowed calculation of the experimental error (Rodrigues and Iemma 2009). Table 1 lists the coded and actual values used for the two analyzed factors. The levels were selected based on pre-tests.

Bread making

The sliced bread formulation used in the present study was based on the formulation described by Contado et al. (2009), and varying quantities of lyophilized taro mucilage and hydrogenated vegetable fat were added to the mixture. The bread recipe consisted of 2000 g of flour, 50 g of fresh yeast, 80 g of powdered whole milk, 120 g of sugar, 40 g of salt, and 1100 g of potable water. The amounts of taro mucilage and fat added are listed in Table 1.

The bread ingredients were combined in an AE25 spiral mixer (G Paniz, Caxias do Sul, Brazil) at high speed until the complete development of the gluten network. The dough was rested for 10 min then divided into 580 g portions, which were shaped using an MPS 350 bread moulder (G Paniz, Caxias do Sul, Brazil) and placed into rectangular pans. The dough was allowed to rise for 180 min in a CFCK-20 proofer (Klimaquip, Pouso Alegre, Brazil) at 27 °C and 85 % relative humidity, then baked for 18 min at 180 °C in an E1125 electric oven (Prática Technicook, Pouso Alegre, Brazil).

Sliced bread analysis

For the determination of moisture content, the bread was pre-dried in a drying oven at 65 °C then dried in a forced-air

Table 1 Coded and actual values of the CCRD factors used in this study

Code	Factors	Actual levels of variance				
		$-\alpha^a$	-1	0	+1	$+\alpha^a$
X_1	Taro mucilage ($\text{g } 100 \text{ g}^{-1}$) ^b	0.00	0.73	2.50	4.27	5.00
X_2	Vegetable fat ($\text{g } 100 \text{ g}^{-1}$) ^b	1.00	1.58	3.00	4.42	5.00

^a $\alpha = \pm 1.41$. ^b Proportion per 100 g of wheat flour

drying oven at 105 °C until a constant weight was obtained, as described by AOAC (2000) protocol no. 925.09.

Water activity was measured using an Aqualab device (Decagon, Pullman, USA). Samples approximately 5 g in weight were placed in a plastic container, and the readings were performed at a controlled temperature of 25 °C ±0.3 °C.

As described in AOAC (2000) protocol no. 925.38, ether extract content was measured by continuous extraction using a Soxhlet apparatus and ethyl ether as the extractor.

The specific volume of the bread was measured using the millet seed displacement method, protocol no. 55–50 (AACC 2000a). The firmness of the bread crumbs was determined using the standard method, protocol no. 74–09 (AACC 2000b), and a TAXTplus texture analyzer (Stable Micro Systems, Surrey, UK) with a P/36R cylindrical probe.

Crust and crumb colors were analyzed using the CIELab system and a CM-5 spectrophotometer (Konica Minolta, Osaka, Japan) with D65 illuminant and 45/0 geometry. The values for L* (lightness), a* (red-green component), b* (yellow-blue component), chromatic tone (hue angle - h*) and chroma (C*), or saturation, were directly measured by the device (Lawless and Heymann 1998).

The bread's sensory qualities were analyzed by a group of 15 trained testers. The components analyzed were external characteristics (volume - the volume grade was obtained by multiplying the specific volume by 3.33 - crust color, break, symmetry, and crust character - 40 points total), internal characteristics (crust characteristics, crumb color, crumb cell structure, and texture - 35 total points), aroma (10 points), and taste (15 points). Points were assigned for each of the characteristics according to (El-Dash et al. 1982). The bread samples were analyzed by the naked eye and tasted for product quality classification, i.e., assignment of an overall score with a maximum of 100 points. As described by Camargo and Camargo (1987), 90 points or more indicate very good quality, 80–90 points indicate good quality, 70–80 points indicate normal quality, and 70 points or fewer indicate low quality.

All the analyses were performed on the day after bread production.

Statistical analysis

Results from the sliced bread analysis were evaluated using the response surface methodology and Statistica version 8.0 (StaSoft. Inc. 2008). Equation 1 describes the polynomial used to fit the model:

$$y = \beta_0 + \beta_1 x_1 + \beta_{11} x_1^2 + \beta_2 x_2 + \beta_{22} x_2^2 + \beta_{12} x_1 x_2 + \varepsilon \quad (1)$$

where β_0 , β_1 , β_{11} , β_2 , β_{22} , and β_{12} are the regression coefficients; x_1 is the amount of lyophilized taro mucilage; x_2 is the amount of hydrogenated vegetable fat; and ε is the

experimental error. The criteria used to analyze the adequacy of fit of the model were the coefficient of determination ($R^2 > 80\%$) and analysis of variance (F-test for regression).

Results and discussion

Characterization of lyophilized taro mucilage

The results found for pH, titratable acidity, and total, reducing and non-reducing sugars are listed in Table 2.

The mean pH value found in the lyophilized taro mucilage (6.32) was similar to the pH observed by Tavares et al. (2011) of 6.30. However, in regards to the titratable acidity, the mean value (4.74) was lower than the value of 7.48 mEq NaOH 100 g⁻¹ obtained in the previously cited study. This result is likely explained by the difference in organic acids present in the sample as well as by the possible difference in the physiological stage of the rhizome.

The total, reducing and non-reducing sugar contents in the lyophilized taro mucilage (Table 2) were similar to the values of the study by Tavares et al. (2011): 3.65 g 100 g⁻¹, 1.40 g 100 g⁻¹ and 2.13 g 100 g⁻¹, respectively. The low values found for the reducing and non-reducing sugars in the sample indicate that the carbohydrates in the solution are mainly present in the form of polysaccharides.

Table 2 Mean values for pH, titratable acidity and sugars and values of macro- and microminerals present in lyophilized taro mucilage

Analytes	Values
pH*	6.32±0.01
Titratable acidity*	4.74±0.05
Total sugars*	3.54±0.03
Reducing sugars*	1.65±0.00
Non-reducing sugars*	1.89±0.03
Macrominerals**	Lyophilized taro mucilage g 100 g ⁻¹
P	0.10
K	1.83
Ca	0.00
Mg	0.11
S	0.08
Microminerals**	Lyophilized taro mucilage g 100 g ⁻¹
Cu	7.00
Mn	31.60
Zn	55.70
Fe	42.60

* The results reported are the means of triplicate samples±SD

** Fresh matter basis

The values found for the analysis of the minerals are presented in Table 2. The main minerals in lyophilized taro mucilage were K for the macrominerals and Zn, Fe and Mn for the microminerals. When comparing the values of this analysis with the values from the study by Tavares et al. (2011), the greatest differences were observed for the contents of Ca ($0.13 \text{ g } 100 \text{ g}^{-1}$), Cu (16.45 mg kg^{-1}) and Zn (14.45 mg kg^{-1}). According to Anderson and Wang (1991), the composition and mineral contents of plant products are substantially affected by the soil where the plants are cultivated, which would explain the discrepancy between the studies.

Optimization of the lyophilized taro mucilage and fat contents in sliced breads

Table 3 shows the CCRD matrix and lists the values for moisture content, water activity, ether extract content, specific volume, firmness, sensory analysis, and crust and crumb color analysis from the 11 experiments.

Within the analyzed ranges for the amounts of added mucilage and fat, neither the moisture content nor water activity (A_w) of the sliced breads was significantly affected ($p>0.05$) by mucilage content, fat content or the interaction between them. Table 4 lists the regression coefficients, determination coefficients (R^2) and p-values for these parameters. Guarda et al. (2004) analyzed the effects of several hydrocolloids on bread quality and found that the addition of hydrocolloids increased water absorption; specifically, they

observed a moisture level of $35.84 \text{ g } 100 \text{ g}^{-1}$ for the control and moisture levels of up to $37.81 \text{ g } 100 \text{ g}^{-1}$ for breads containing xanthan gum. In the present study, bread moisture content ranged from $37.68 \text{ g } 100 \text{ g}^{-1}$ to $39.50 \text{ g } 100 \text{ g}^{-1}$, and lyophilized taro mucilage was not found to significantly affect moisture content. In other words, water absorption by the bread was not affected by the addition of taro mucilage. The mean water activity was 0.949, with only small differences among treatments. In a study investigating the effects of hydrocolloids on bread quality, Rosell et al. (2001) observed a slight increase in water activity in the crumb. This result was expected because hydrocolloids are known to improve the water retention capacity. However, the lyophilized taro mucilage concentration (x_1) was not found to have a statistically significant effect on water activity in this study.

Because it is difficult to objectively measure many characteristics of bread, measurements of the technological quality of bread are based to a significant degree on the subjective analysis of experts (Cauvain and Young 2009). The sliced breads in the present study were analyzed by a trained panel to obtain overall quality scores. No significant effects ($p>0.05$) were observed for the parameters analyzed (Table 4). However, all of the breads had high overall scores (the sum of the scores for the external and internal characteristics, aroma and taste), which ranged from 79.1 to 87.3. As indicated above, scores of 80–90 points indicate good quality. Nabeshima et al. (2005) analyzed the technological and sensory characteristics of fortified sliced breads and reported a

Table 3 Matrix of the central composite rotatable design (CCRD) analyzing the effects of taro mucilage and vegetable fat content on the moisture content, water activity, ether extract content, firmness, sensory qualities and color of sliced bread crust and crumb

Experiments	Factors		Response											
	x_1	x_2	Moisture ($\text{g } 100 \text{ g}^{-1}$)	A_w	E.E. ($\text{g } 100 \text{ g}^{-1}$)	S.V. ($\text{cm}^3 \text{ g}^{-1}$)	Firmness (g)	Sensory analysis ^a	Crust			Crumb		
									L*	C*	h*	L*	C*	h*
1	−1	−1	38.33	0.949	1.35	4.97	238.18	79.10	52.59	35.63	63.58	76.93	19.05	86.32
2	+1	−1	37.68	0.951	1.21	4.16	328.21	83.10	47.89	35.42	61.90	77.50	19.20	85.30
3	−1	+1	38.96	0.943	3.47	4.91	175.23	81.20	45.22	31.13	58.92	77.09	18.25	87.17
4	+1	+1	38.28	0.948	3.25	4.52	244.56	86.40	44.91	31.24	57.12	76.19	19.01	85.60
5	−1.41	0	38.00	0.948	2.67	4.83	166.61	83.80	47.45	31.31	60.11	76.98	18.08	87.57
6	+1.41	0	38.16	0.947	2.39	3.97	280.06	82.90	51.06	33.43	62.35	75.40	19.94	84.84
7	0	−1.41	39.17	0.950	1.10	4.85	162.55	84.70	45.86	33.57	60.54	75.35	18.06	87.06
8	0	+1.41	39.12	0.951	4.31	5.01	185.63	87.10	45.20	34.85	58.86	75.39	18.75	86.60
9 (CP)	0	0	39.37	0.947	2.32	4.94	162.16	82.90	47.01	35.36	60.06	75.38	18.29	86.97
10 (CP)	0	0	38.26	0.951	2.34	4.88	178.04	87.30	46.33	34.53	59.75	76.87	18.27	86.64
11 (CP)	0	0	39.50	0.954	2.23	4.95	198.54	83.30	49.42	36.09	61.41	76.62	18.59	86.42

x_1 : lyophilized taro mucilage; x_2 : hydrogenated vegetable fat; E.E.: ether extract content; S.V.: specific volume; L*: lightness; C*: chroma; h*: hue angle; CP: central point

^a Mean scores assigned to each bread sample by 15 trained testers (the total points correspond to the sum of the scores for external and internal characteristics, aroma and taste)

Table 4 Regression coefficients for the moisture content, water activity, sensory analysis, ether extract content, firmness and specific volume parameters as a function of the lyophilized taro mucilage and hydrogenated vegetable fat content

Moisture			A_w		Sensory Analysis		Ether Extract		Firmness		Specific Volume	
Coefficient	p-value		Coefficient	p-value	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
β_0	39.043	0.000	0.950	0.000	84.509	0.000	2.300	0.000	179.391	0.001	4.924	0.000
β_1	-0.139	0.522	0.001	0.612	0.994	0.340	-0.095	0.240	40.036	0.046 ^a	-0.303	0.000 ^a
β_{11}	-0.559	0.068	-0.002	0.226	-1.130	0.361	0.041	0.652	34.104	0.119	-0.269	0.000 ^a
β_2	0.146	0.502	-0.001	0.456	1.101	0.295	1.088	0.000 ^a	-14.301	0.390	0.066	0.001 ^a
β_{22}	-0.024	0.925	0.000	0.802	0.153	0.897	0.129	0.192	9.333	0.629	-0.004	0.783
β_{12}	-0.007	0.980	0.001	0.659	0.300	0.831	-0.023	0.829	-5.173	0.819	0.104	0.001 ^a
R^2	57.38 %		38.24 %		42.79 %		97.92 %		69.57 %		99.65 %	

β_0 : constant; β_1 : taro mucilage (linear); β_{11} : taro mucilage (quadratic); β_2 : hydrogenated vegetable fat (linear); β_{22} : hydrogenated vegetable fat (quadratic); β_{12} : interaction between lyophilized taro mucilage and hydrogenated vegetable fat; R^2 : coefficient of determination

^a Significant at 5 % probability

score of 71.7 for the standard formulation. Thus, the amounts of lyophilized taro mucilage and hydrogenated vegetable fat used in the present study yielded sliced bread with good technological quality in terms of sensory analysis.

Table 3 shows the crust and crumb analysis results for the 11 sliced bread experiments. L^* values range from 0 to 100, with 0 and 100 indicating black (or dark color) and white (or light color), respectively. For h^* , 0 represents pure red, 90 represents pure yellow, 180 represents pure green, and 170 represents pure blue. For chroma, higher C^* values indicate more vibrant color (Lawless and Heymann 1998). In the present study, the bread crusts had a mean L^* value of 47.54, which is similar to the score of 48.14 reported by Esteller and Lannes (2005) for commercial sliced bread crusts. The chroma scores, which indicate color saturation, ranged from 31.13 to 36.09, and the mean chromatic tone, which indicates the typical crust color, was 60.42.

Table 5 lists the regression coefficients, determination coefficients (R^2) and p-values for the objective color analysis of sliced bread crust and crumb.

Neither lyophilized taro mucilage nor hydrogenated vegetable fat significantly affected ($p > 0.05$) the lightness, chroma (saturation), or hue angle (chromatic tone) of the bread crust. Forming a satisfactory crust is one of the most important aspects of baking because the crust contributes significantly to both the firmness and the flavor of the finished bread. The crust color results primarily from Maillard reactions, which occur at temperatures above 115 °C (Cauvain and Young 2009). The fat content in bread does not affect this type of reaction, which explains the non-significant effect observed. Although it does contain sugars, the taro mucilage did not significantly affect crust color at the quantities tested.

In terms of the L^* value of the crumb, neither of the factors analyzed exhibited a significant effect. The mean crumb L^* value was 76.33, indicating a lighter crumb than the

commercial and traditional sliced breads analyzed by Esteller and Lannes (2005), which had a mean L^* value of 62.37.

Mucilage level (linear) was the only factor that had a significant positive effect ($p < 0.05$) on chroma, with chroma values increasing as the amount of mucilage increased, but the coefficient of determination for this effect was relatively low (71.23 %). Furthermore, the calculated F value was lower than the tabulated F value in the analysis of variance of the regression (Table 6), indicating a poor fit of the model. Mucilage level (linear) had a significant negative effect on chromatic tone (hue angle), with increasing amounts of mucilage resulting in decreased h^* values and subtle changes in crumb color.

Table 4 lists the regression coefficients, determination coefficients (R^2) and p-values for the ether extract content and the firmness and specific volume of the sliced breads as a function of lyophilized taro mucilage and hydrogenated vegetable fat content.

The amount of added fat was the only factor that significantly affected the ether extract content. Taro rhizomes are poor in fat, proteins and vitamins but are a good source of carbohydrates and minerals, particularly potassium, magnesium and calcium (Nip 1997; Kaur et al. 2011). Accordingly, the negligible amount of lipids in taro mucilage was not found to interfere with the changes in ether extract content. The model had a good fit, with an R^2 value of 97.92 % and a regression p-value of 0.000331. Analysis of variance for the regression analysis of this parameter is shown in Table 6.

Texture corresponds to the tactile sensory response to physical stimuli resulting from contact between a part of the body and food (Bourne 2002). Food texture can be assessed by sensory evaluation or measured by instrumental evaluation. According to Callejo et al. (1999), bread texture is correlated with crumb moisture and softness and thus with consumer product quality. Texture therefore represents an

Table 5 Regression coefficients for the luminosity, chroma and hue angle parameters of sliced bread crust and crumb as a function of the lyophilized taro mucilage and hydrogenated vegetable fat content

	L* Crust		C* Crust		h* Crust		L* Crumb		C* Crumb		h* Crumb	
	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
β_0	47.584	0.000	35.323	0.000	60.404	0.000	76.282	0.000	18.381	0.000	86.677	0.000
β_1	0.011	0.991	0.363	0.593	−0.039	0.949	−0.320	0.387	0.443	0.036 ^a	−0.808	0.005 ^a
β_{11}	0.904	0.417	−1.467	0.111	0.394	0.593	0.241	0.575	0.357	0.112	−0.343	0.147
β_2	−1.414	0.160	−0.862	0.234	−1.481	0.050	−0.137	0.701	−0.003	0.985	0.063	0.720
β_{22}	−0.969	0.387	−0.540	0.509	−0.377	0.608	−0.172	0.686	0.053	0.786	−0.029	0.892
β_{12}	1.096	0.406	0.080	0.933	−0.029	0.973	−0.368	0.475	0.153	0.519	−0.136	0.589
R ²	54.19 %		54.20 %		59.88 %		32.58 %		71.23 %		84.30 %	

β_0 : constant; β_1 : taro mucilage (linear); β_{11} : taro mucilage (quadratic); β_2 : hydrogenated vegetable fat (linear); β_{22} : hydrogenated vegetable fat (quadratic); β_{12} : interaction between lyophilized taro mucilage and hydrogenated vegetable fat; R²: coefficient of determination; L*: lightness; C*: chroma; h*: hue angle

^a Significant at 5 % probability

essential factor for product acceptability in the market (Gandra et al. 2008).

The only factor significantly affecting sliced bread firmness was lyophilized taro mucilage (linear) (Table 4). However, because the R² value was relatively low (69.57 %) and the calculated F value from the analysis of variance was lower than the tabulated value (Table 6), the model did not have a good fit. Despite the lack of a well-fitted model, it is important to emphasize that the values in the present study indicate an excellent texture (i.e., soft bread). These values ranged from 162.16 g to 328.21 g, and the mean value was 210.88 g (2.06 N). Moayedallaie et al. (2010) reported higher firmness

values in white wheat bread. Specifically, these researchers compared three generations of lipase enzymes along with the emulsifier diacetyl tartaric acid ester of monoglycerides (DATEM) and found a firmness of 5.0 N for the control and values ranging from 3.6 N to 4.0 N for the other treatments. Nabeshima et al. (2005) analyzed the technological and sensory characteristics of sliced breads fortified with three different iron sources and found a firmness of 312.77 g for the control bread. Thus, lyophilized taro mucilage contributed to the softness of the breads in the present study, as the lowest firmness values (162.55 g, experiment 7) were observed when the mean mucilage amount (the central point) was combined

Table 6 Analysis of variance of the regression parameters ether extract content, specific volume, firmness and hue angle of sliced bread as a function of the lyophilized taro mucilage and hydrogenated vegetable fat content

		SS	Df	MS	F calc.	F tab.	p-value
E.E.	Regression	9.608382	5	1.921676	47.08818	5.05	0.000331 ^a
	Error	0.204051	5	0.04081			
	Total	9.812433	10				
S.V.	Regression	1.250037	5	0.250007	287.5483	5.05	0.000003 ^a
	Error	0.004347	5	0.000869			
	Total	1.254384	10				
Firmness	Regression	21040.81	5	4208.162	2.286781	5.05	0.192554
	Error	9201.06	5	1840.21			
	Total	30241.87	10				
h* Crumb	Regression	6.003022	5	1.200604	5.371609	5.05	0.044376 ^a
	Error	1.117546	5	0.223509			
	Total	7.120568	10				
C* Crumb	Regression	2.391735	5	0.478347	2.476249	5.05	0.171136
	Error	0.965870	5	0.193174			
	Total	3.357605	10				

SS sum of squares, Df degrees of freedom, MS mean squared, E.E. ether extract, S.V. specific volume, h* hue angle, F calc. calculated F, F tab. tabulated F

^a Significant at 5 % probability

Fig. 1 Response surface for specific volume as a function of lyophilized taro mucilage and hydrogenated vegetable fat content

with the lowest amount of hydrogenated vegetable fat. This finding further suggests that calories and vegetable fat levels can be reduced in bread formulations.

The specific volume shows the relationship between the solids content and the fraction of air in the baked dough. Breads with low specific volumes are known to be unappealing to consumers and are also associated with high moisture levels, mixing and cooking failures, poor aeration, difficulty chewing, inadequate flavor, and short shelf life (Esteller and Lannes 2005). Specific volume is one of the most important bread qualities, and it was used to optimize the taro mucilage and fat levels in this study.

Table 4 shows that the quadratic effect of hydrogenated vegetable fat (β_{22}) was the only factor that did not significantly ($p > 0.05$) affect the specific volume of the analyzed bread. All of the other factors and their interactions significantly affected this response. The model had a good fit with an R^2 value of 99.65 %, which was significant at a 5 % probability

level, and the F value calculated (287.5483) for the regression was higher than the tabulated F value (5.05) (Table 6).

The specific volumes of the bread loaves found in this study ($4 \text{ cm}^3 \text{ g}^{-1}$ to $5 \text{ cm}^3 \text{ g}^{-1}$) are considered good and are higher than previously reported specific volumes, such as those reported by Nabeshima et al. (2005), with values between $3.03 \text{ cm}^3 \text{ g}^{-1}$ and $3.54 \text{ cm}^3 \text{ g}^{-1}$.

The fitted response surface (Fig. 1) shows that lyophilized taro mucilage amounts between $0.73 \text{ g } 100 \text{ g}^{-1}$ and $2.5 \text{ g } 100 \text{ g}^{-1}$ led to an increase in the specific volume of the breads. Mucilage had a greater effect on specific volume than fat, which could be used at any of the amounts analyzed as long as the amount of mucilage was within the optimal range. These findings indicate that any amount of lyophilized taro mucilage and hydrogenated vegetable fat within the optimal range shown in Fig. 1 will produce bread with a greater specific volume. Thus, the initial goal of optimizing the taro mucilage and fat levels was achieved in terms of maximizing specific volume, and further experiments were performed to validate the fitted surface.

To validate the model, three points within the optimal range were chosen for each factor, and the lowest fat levels were represented among the selected points. The three resulting experiments are summarized in Table 7, which lists the predicted values, the experimental values and the relative error of the experiments for validating the optimized taro mucilage and fat levels as a function of specific volume. The validation was satisfactory, as evidenced by the similarity of the values predicted by the model to the experimental values. Furthermore, the low relative error values supported the good fit of the model. As previously stated, any value within the optimal range can be used for the amount of the analyzed factors in bread. All three validation experiments represented points within the optimal range, and experiment 1 in particular had good results for specific volume despite having reduced fat levels. Compared with the original formulation using 4 % fat/wheat flour (Contado et al. 2009), the fat levels used in experiment 1 represented an approximately 60 % decrease in added fat levels, an excellent result in terms of both nutrition and reduced raw material costs.

Table 7 Coded and actual values used to validate the optimized lyophilized taro mucilage and hydrogenated vegetable fat levels in bread, including the predicted values, experimental values and relative errors for specific volumes

	Experiment	Mucilage	Fat	Specific Volume ($\text{cm}^3 \text{ g}^{-1}$)		
				PV	EV ^b	RE (%)
Coded values	1	−1.00	−1.00	—	—	—
	2	−0.75	−0.50	—	—	—
	3	−0.50	0.00	—	—	—
Actual values ^a ($\text{g } 100 \text{ g}^{-1}$)	1	0.73	1.58	4.99	4.93	−1.26
	2	1.17	2.29	5.00	4.97	−0.70
	3	1.61	3.00	5.01	4.95	−1.16

^a Proportion per 100 g of wheat flour. ^b Mean of three replicates. PV: predicted value; EV: experimental value. Relative error = (experimental value − predicted value) * 100 / experimental value

Conclusions

The optimal levels of lyophilized taro mucilage and hydrogenated vegetable fat in the sliced bread formulation were 0.73 g 100 g⁻¹ and 1.58 g 100 g⁻¹, respectively. The resulting bread was found to have good sensory, physical and nutritional qualities; excellent values for specific volume and texture; and reduced vegetable fat and caloric content. Thus, adding an optimal concentration of lyophilized taro mucilage to sliced bread formulations is not only technically viable but also improves the characteristics of the bread.

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Highlights

Good sensory, physical and nutritional quality bread made with hydrocolloid.
Optimal values of specific volume for breads with natural additive.