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## Structural and sensory changes in short-dough biscuits: addition thaumatin and sucrose reduction effects

Alterações estruturais e sensoriais em biscoitos amanteigados: efeitos da adição de taumatina e redução de sacarose

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### ABSTRACT

The objective of this research was to study the mechanical properties of the biscuit dough and baked biscuits with sucrose reductions and the addition of thaumatin, as well as the consumers' sensory perceptions. The analyses were related to dough and baked biscuits rheology as back extrusion and texture profile analysis, moreover, structure and sensory analyses were performed. The dough cohesiveness increased proportionally with the sucrose reduction in the formulation and the viscosity index results showed the same behavior. Structure analysis revealed greater compaction of biscuits with sucrose reduction and a greater amount of free starch, not properly incorporated into the mixture. Sensorially, the texture attributes were similar, but the taste attributes were different. The sucrose reduction tests of 25% and 35% led to minimal changes in rheological characteristics and provided better physical quality.

**Keywords:** texture properties, thaumatin, short-dough, rate all that apply, back and forward extrusion.

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### RESUMO

O objetivo desta pesquisa foi estudar as propriedades mecânicas da massa de biscoito e biscoitos assados com redução de sacarose e adição de taumatina, bem como a percepção sensorial dos consumidores. As análises realizadas foram relacionadas à reologia da massa e dos biscoitos assados como extrusão traseira e análise do perfil de textura, além disso, foram realizadas análises de estrutura e sensorial. A coesividade da massa aumentou proporcionalmente com a redução da sacarose na formulação e os resultados do índice de viscosidade apresentaram o mesmo comportamento. A análise de estrutura revelou maior compactação dos biscoitos com redução de sacarose e maior quantidade de amido livre, não devidamente incorporado à mistura. Sensorialmente, os atributos de textura foram semelhantes, mas os atributos de sabor foram diferentes. Os testes de redução de sacarose de 25% e 35% levaram a alterações mínimas nas características reológicas e proporcionaram melhor qualidade física.

**Palavras-chave:** propriedades de textura, taumatina, massa curta, *rate all that apply*, extrusão traseira.



## INTRODUCTION

Sucrose, popularly known as sugar, is an essential ingredient in many kinds of food, including bakery products such as cakes and biscuits. Short dough biscuits are characterized by high-fat and sugar content and “low amount of water”, where the role of sugar and fat within the dough is well understood (Maache-Rezzoug et al., 1998). Sucrose contributes significantly to the energy content of bakery products and is responsible for providing sweetness, texture, flavor, and color. Sucrose characteristics, including type, the amount on formulation, and particle size influence the product quality, mainly on the development of the gluten network and starch gelatinization (Manley, 2011). However, in recent years, due to the high consumption of the sucrose and its association with health issues, public health agencies have already recommended the reduction of sugar in the human diet (Van der Sman et al., 2022). Currently, food industries have expressed a growing interest in sucrose substitutes as a response to the public interest in low-calorie products, in this context, searching for alternative natural sources is indispensable (Jafari et al., 2021; Mariotti and Alamprese, 2012).

The sucrose replacement by natural or artificial sweeteners in biscuit has been the focus of several studies. Thaumatin is a vegetal low-calorie protein sweetener, extracted from *Katemfe*, the fruit of the West African plant *Thaumatococcus daniellii* and considered as the sweetest substance on nature. The sweetener power of Thaumatin is 1600 – 3000 times higher compared to sucrose power, and it also presents health benefits to consumers that are related to the amino acids chain. The benefits include mask metallic and bitter tastes, ability to enhance certain flavors and aromas as peppermint and coffee, improvement of mouthfeel, stability on adverse conditions of pH and temperature. Thaumatin is an innocuous substance, classified as GRAS (*Generally Recognized As Safe*), allowing its industrial use on food and showing no consumption restriction by any populational group in different countries. In some countries, Thaumatin food use was allowed without limits (*quantum satis*) but, high usage levels contribute to licorice-like after taste (Bassoli and Merlini, 2003).

Biscuits can be described as a matrix in which air bubbles are incorporated. Rheologically, biscuit dough is

a dense solid-liquid paste, with complex flow behavior. The short-dough biscuit is brittle and for this type of dough, it is important to avoid gluten network development, ensuring the product characteristics. During the manufacturing process the dough rheological properties are changed by the loss of water, thermal denaturation, and melting of its components. Furthermore, flour type, sucrose concentration, sucrose replacers, and fat can also influence the mechanical properties of the dough (Baltasvias et al., 1997, 1999; Chevallier et al., 2002), and, consequently, the physical and sensory properties of biscuit (Biguzzi et al., 2014).

Rheological properties are responsible for allowing or limiting the dough expansion, influencing the cold extrusion process (dough molding). During the extrusion stage, the dough is fed on extrusion barrel, while a screw (single or twin) carries it to the barrel exit. The screw speed decreases, restricting the volume and increasing the dough movement resistance, which results in a full barrel and compressed spaces. The dough is modified into a semi-solid plastic dough, which is pushed through draws (restrict apertures) at the outlet of the barrel. A guillotine or rotating blade (in the outlet) allows obtaining products of desired size (Fellows, 2009). Thus, the characteristics of the final product depend on the characteristics of the dough and the conditions under which the extrusion process is carried out, such as pressure, draws size and shear strength. Furthermore, sucrose content in biscuits influences the sensory attributes, providing flavor, spreadability, gluten mobility, and coloring to the surface of the final product due to the browning reaction (Pareyt et al., 2009). Due to these functions, the sucrose replacement is rather difficult to achieve. Therefore, it is important to carry out studies that present solutions in relation to the reduction of sucrose with the maintenance of the structural characteristics of the dough and the biscuits. In this context, the aim of this work was to study the mechanical and sensory properties of the biscuit dough and baked biscuits, with reduction of the sucrose and addition of thaumatin.

## MATERIAL AND METHODS

### Biscuits Production

Short-dough biscuits were prepared by the creaming method formulated according to the information in Table 1.

**Table 1.** Dough biscuit formulations - control and sucrose reduction added thaumatin.

Ingredients	Control (g)	RED 25% (g)	RED 35% (g)	RED 50% (g)	RED 65% (g)
Wheat Flour	100.00	100.00	100.00	100.00	100.00
Butter	50.37	50.38	50.38	50.38	50.38
Sugar	40.44	30.34	26.30	20.23	14.16
Thaumatococcus	0.000	0.0033	0.0039	0.0038	0.0053
Powdery Milk	2.28	2.29	2.29	2.29	2.29
Ammonia Bicarbonate	1.14	0.99	0.92	0.92	0.92
Soy Lecithin	2.02	2.06	2.06	2.06	2.06
Sodium Acid Pyrophosphate	0.33	0.32	0.11	0.11	0.11
Salt	0.69	0.69	0.68	0.68	0.69
Sodium Bicarbonate	0.12	0.11	0.37	0.37	0.37
Water	6.86	6.87	13.74	13.74	13.74

The first step consisted of manually mixing the butter and sucrose until a homogeneous mixture was obtained. The second step consisted of adding the other ingredients: powdered milk, soy lecithin, water, thaumatin, salt, and ammonia bicarbonate in the butter/sucrose mixture. This mixture was whipped manually for 7 minutes until a homogeneous mixture was formed, being called “cream mixture.” The third and final step was the addition of enriched white wheat flour, sodium acid pyrophosphate, and sodium bicarbonate to the cream mixture. Then, it was mixed manually for 7 minutes until a homogeneous mass was obtained. In samples containing thaumatin, 2 ppm of this protein was diluted in water, forming a solution, as suggested by the manufacturer, and then added in the second formulation step, following the procedure described above. The sucrose-reducing samples were named as follows: RED 25%, RED 35%, RED 50%, and RED 65%, based on the standard formulation, totaling five formulations. The biscuit mold standardization was performed in a manual molding machine; each biscuit weighed approximately 5g. The cooking process was carried out in an industrial oven at 180°C for 20 minutes.

### Mechanical Properties of the Dough

#### Back-extrusion

The dough's firmness, consistency, cohesiveness, and viscosity index were obtained by the back-extrusion deformation test using a TA-TX plus Texture Analyzer (Stable Micro Systems, England). The sample was placed inside an acrylic cylindrical cell, and a 40mm diameter disc probe (A/BE) was used. The experimental conditions were: measure force in compression, test speed, 2 mm/s; distance, 25 mm; sample dimensions: 40g x 2cm x 5cm

(weight x height x diameter). The test was performed in triplicate.

#### Texture Profile Analysis (TPA)

The test consisted of compressing two times a baked biscuit in a reciprocating motion that imitates the jaw's action. The TPA was performed using a TA-TX plus Texture Analyzer (Stable Micro Systems, England). The baked biscuit was placed on the center of a base and compressed with a 100mm diameter metal disc probe. The experimental conditions were: test speed, 1mm/s; target mode strain, 20%; time, 3 sec; trigger force, 5g. Sample dimensions: 5cm x 3cm x 2cm (Length x Width x Height). The mechanical textural characteristics of hardness, cohesiveness, springiness (elasticity), adhesiveness, fracturability (brittleness), chewiness, and gumminess were obtained. The test was performed in decaplicate.

#### Structural Analysis - Scanning Electron Microscopy (SEM)

The biscuit samples were fractured naturally and then immediately analyzed by Scanning Electron Microscope (Hitachi TM-3000, Japan), and viewed under vacuum, at a magnification of x1000 and voltage of 15kV.

#### Sensory Analysis

The test was approved by the Human Research Ethics Committee of the Federal University of São Carlos, assessed and certified under the number CAAE 74079317.4.0000.5504. Thirty regular consumers of short-dough biscuits (twenty-four women and six men, aged 18–65) participated voluntarily in this study. Participants were recruited among undergraduates and employees from the Federal University of São Carlos, Campus Lagoa do Sino. The consumers

reported a consumption frequency of 7% consuming the product daily; 23% consuming once every 15 days; 23% consuming once a month, and 40% consuming the product rarely. Sensory analysis was performed at the participant's home. Due to the preparation time, only the Control, RED 25%, and RED 35%, samples were considered for the sensory analysis. The consumers received three samples (Control, RED 25%, and RED 35%) packaged and coded with three random numbers and a sheet with the instructions to access the online test. Consumers tasted the samples following a Latin square design to avoid bias, and then they were asked to indicate their overall liking using a 9-point hedonic scale from (1) dislike very much to (9) like very much. This study's sensory terms characterized the biscuits' taste and texture as buttery, artificial, metallic, bitter, sweet, soft, hard, crunchy, sticky, and brittle. Subsequently, Rate-all-that-apply (RATA) method was applied (Ares et al., 2014), in which the consumers were asked to check all the attributes that characterize each biscuit sample and then rate their intensity using a 5-point scale going from (1) not intense at all to (5) very intense. Finally, consumers answered a questionnaire with their sociodemographic information and their frequency of eating the biscuit. The sensory data were collected using the Compusense cloud software (Compusense Inc., Guelph, Ontario, Canada).

#### Statistical Analysis

One-way analysis of variance (ANOVA) followed by Tukey's test for pairwise comparison at  $p \leq 0.05$  was applied for instrumental results using the Minitab 18 Statistical Software. The RATA data were treated by Canonical variate analysis (CVA) to represent the sensory attributes and treatments (Merlo et al., 2019; Peltier et al., 2015) synthetically.

## RESULTS AND DISCUSSION

### Mechanical Properties of the Dough and Baked Biscuits

#### Back extrusion

Biscuit dough is considered a low-water content matrix of starch, protein, and lipid paste that embeds gas bubbles of different sizes and dimensions. The knowledge of the mechanical properties of the dough is essential, as they are directly associated with the workability and sensory characteristics. Understanding the mechanical properties of short doughs and their corresponding biscuits can guide specific phases of the production process, such as handling the biscuit on the production line, packaging, and distribution, during which the biscuit has to resist mechanical stresses (Brennan and Samyue, 2004; Cairano et al., 2021).

Table 2 presents the short dough rheological properties. For firmness, the parameter that defined as resistance to dough deformation, the highest value was found for RED 50% dough, and this value was similar to the control ( $p > 0.05$ ). The second highest value was found for sample RED 25%, followed by RED 60% and the lowest firmness in sample RED 35%.

The consistency, property related to dough density and consequently to the amounts and combinations of the formulation ingredients and development of gluten network, indicated higher value for the control sample. For this parameter, RED 50% was statistically lower than the control ( $p < 0.05$ ). Nevertheless, other sugar reduced samples showed same profile as for firmness with lowest value found for RED 35%. These results show that this property may not be only related to the sucrose content.

Cohesiveness and viscosity properties for semi-solid samples, as the short dough, are related to flowability. Cohesiveness indicates how much the dough constituents

**Table 2.** Rheological parameters of the back extrusion test.

Sample	Firmness (g)	Consistency (g/s)	Cohesiveness	Viscosity (g/s)
Control	6108 ± 267 <sup>a</sup>	17751 ± 375 <sup>a</sup>	-619 ± 259 <sup>a</sup>	-247 ± 219 <sup>a</sup>
RED 25%	5242 ± 61 <sup>b</sup>	10965 ± 1082 <sup>c</sup>	-582 ± 117 <sup>a</sup>	-209 ± 29 <sup>a</sup>
RED 35%	3632 ± 163 <sup>d</sup>	8950 ± 555 <sup>d</sup>	-1166 ± 324 <sup>ab</sup>	-480 ± 188 <sup>a</sup>
RED 50%	6225 ± 158 <sup>a</sup>	15175 ± 791 <sup>b</sup>	-1382 ± 98 <sup>b</sup>	-518 ± 47 <sup>ab</sup>
RED 65%	4248 ± 157 <sup>c</sup>	10537 ± 485 <sup>cd</sup>	-1729 ± 248 <sup>b</sup>	-838 ± 53 <sup>b</sup>

Means followed by different letters in the same column are significantly different by Tukey test ( $p < 0.05$ ).

are associated. On the other hand, the viscosity indicates the tendency to flow resistance. According to Table 2 dough cohesiveness increases (in module) according to the sucrose reduction in the formulation, and the viscosity index indicates the same behavior (in module). In this context, lower sucrose content leads to a greater interaction of the dough ingredients, which contributes to the gluten network development, resulting in a higher dough viscosity index. However, the 25% and 35% sucrose reductions did not differ significantly ( $p>0.05$ ) from the control sample, indicating that these concentrations do not change the brittle structure characteristic of the short dough biscuit.

#### Texture Profile Analysis (TPA)

Double compression test mimics the mouth's biting action and determines the texture parameters, such as cohesiveness, chewiness, adhesiveness, fracturability, resilience, springiness and hardness. Table 3 presents the results of TPA and show the influence of sucrose content on texture properties of the biscuits.

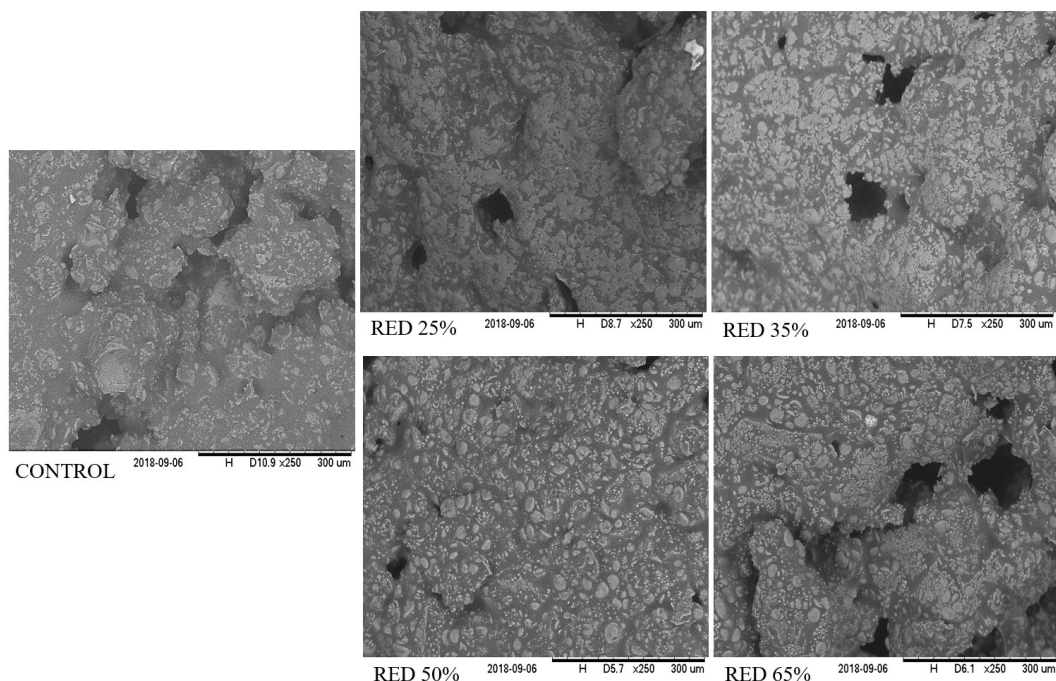
Hardness represents the maximum force needed to compress the sample. Springiness corresponds to the capacity of the sample recovery after the application of the deformation force. Resilience is defined as the recovery energy necessary to return to its original form.

Cohesiveness is the measure of sample deformation before the rupture. Chewiness is the force required to chew a solid sample until the deglutination process (Chen and Opara, 2013). According to the results, hardness was not significantly different among all the samples ( $p>0.05$ ), showing that sucrose content did not influence on it. Same profile was found for parameters such as adhesiveness, springiness and chewiness were not significantly different among samples.

Fracturability, in general, is a characteristic of products with high levels of hardness and low cohesiveness. The results show lower values for the control sample and the sample with 65% sucrose reduction. The cohesiveness results confirm this behavior.

#### Structural Analysis

The scanning electron microscopy (SEM) (Figure 1) revealed a higher compaction of the biscuits with sucrose reduction. These samples also showed a greater amount of free starch (white halos), which was not properly incorporated into the mixture. The sucrose content can also influence this behavior, shifting the starch gelatinization point to a higher temperature, therefore samples with sucrose reduction have more apparent white halos (Manley, 2011). This possibly influenced the texture of the dough and the baked biscuits. On the other hand, porosity was

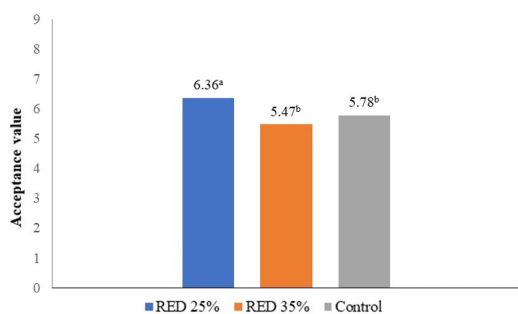


**Figure 1.** SEM micrographs of the baked biscuits.

**Table 3.** Texture Profile Analysis (TPA) double-compression of baked biscuits.

Sample	Hardness (gf)	Fracturability (gf)	Resilience	Cohesiveness	Adhesiveness (gf/s)	Springiness	Chewiness (gf/mm)
Control	19.51 ± 10.60 <sup>a</sup>	4.67 ± 3.14 <sup>b</sup>	0.15 ± 0.06 <sup>a</sup>	0.21 ± 0.08 <sup>a</sup>	-2.03±0.37 <sup>a</sup>	0.44±0.17 <sup>a</sup>	2.35±1.85 <sup>a</sup>
RED 25%	14.00 ± 7.36 <sup>a</sup>	28.29 ± 19.70 <sup>a</sup>	0.04 ± 0.00 <sup>b</sup>	0.06 ± 0.01 <sup>b</sup>	-0.48±0.84 <sup>a</sup>	0.47±0.25 <sup>a</sup>	1.04±0.62 <sup>a</sup>
RED 35%	6.76 ± 0.59 <sup>a</sup>	5.86 ± 0.42 <sup>ab</sup>	0.05 ± 0.02 <sup>b</sup>	0.07 ± 0.04 <sup>b</sup>	-1.31±0.12 <sup>a</sup>	0.24±0.00 <sup>a</sup>	0.12±0.08 <sup>a</sup>
RED 50%	6.66 ± 0.33 <sup>a</sup>	6.00 ± 0.29 <sup>ab</sup>	0.04 ± 0.00 <sup>b</sup>	0.07 ± 0.00 <sup>b</sup>	-1.10±0.29 <sup>a</sup>	0.23±0.01 <sup>a</sup>	0.11±0.02 <sup>a</sup>
RED 65%	5.19 ± 1.88 <sup>a</sup>	3.72 ± 1.79 <sup>b</sup>	0.06 ± 0.00 <sup>ab</sup>	0.11 ± 0.00 <sup>ab</sup>	-1.55±0.93 <sup>a</sup>	0.26±0.03 <sup>a</sup>	0.15±0.05 <sup>a</sup>

Means followed by different letters in the same column are significantly different ( $p < 0.05$ ).



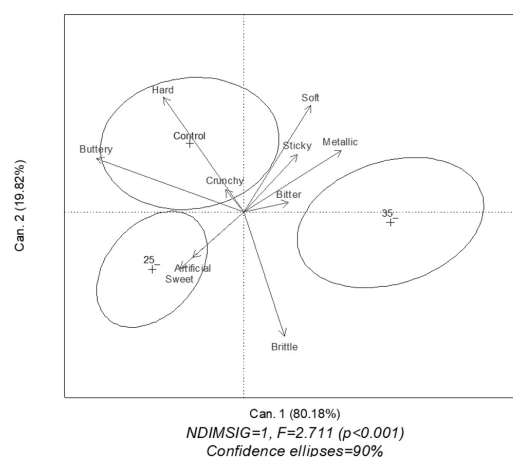
**Figure 2.** Acceptance analysis of formulations by 9-point hedonic scale.

observed in control formulation, which may be associated to a higher sucrose content, and greater incorporation of the components of the formulation into the dough, leading to a higher rupture force. Irregular fragments in shape and size were observed in all samples, possibly due to the differentiated incorporation of the various ingredients in the formulation.

### Sensory Analysis – Rate All That Apply (RATA)

Based on sensory analysis results, RED 25% had the highest overall acceptance value (Figure 2). According to the attributes analysis, this sample is crunchy, with a buttery flavor and sweet taste. For tasters, the RED 25% sample generally has better sensory characteristics than the others.

Figure 3 shows the three samples and the sensory attributes that characterize them. In the first canonical variable, it is observed that the control sample and the sample with 25% reduction of sucrose were very similar, while the sample with 35% reduction was at the other end of this canonical variable showing itself completely different. The control sample was perceived as “hard”, “buttery”, and “crunchy”, while the sample with 25% reduction was perceived as “sweet” and “artificial”. Finally, the sample with 35% reduction of sucrose was described as “metallic”, “bitter”, “soft”, and “sticky”.



**Figure 3.** Representation of samples and attributes using Canonical Variate Analysis.

The attributes artificial, metallic, and bitter indicate that the addition of thaumatin influenced the intensity of these attributes in the samples with reduction of sucrose, despite this, these samples presented satisfactory intensity as the texture attributes.

## CONCLUSION

The results of the study indicated that the sucrose content in the biscuit formulation plays an important role in the rheological characteristics of the dough and the products. The extent of the effects is correlated with the level of sucrose reduction since, in the formulations tested, the 25% and 35% sucrose reductions produced minor changes in the rheological characteristics. This provided better physical quality of the biscuit dough, such as firmness, consistency, and hardness. These attributes positively influenced the sensory quality, as greater crunchiness and mouthfeel. The results obtained in this study show that it was possible to maintain the technological and sensory quality of the biscuits, from formulations containing less sucrose in combination with thaumatin.

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