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Possibility of Replacing Sugar with Apple Puree in Muffins

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Abstract: Muffins are a popular pastry product around the world, but due to their high sucrose content, they are high in calories. To meet customer demand for muffins with less sugar content, in this research, sugar was replaced with apple puree in different percentages (0–100%). For replacement levels between 0 and 50%, the physical, textural, and rheological properties did not show significant changes compared to the control sample. Higher levels of replacement (50–100%) led to changes in some quality attributes: specific gravity and loss on ripening increased significantly, height and volume decreased significantly (from 49.66 ± 0.02 to 43.36 ± 0.12, respectively, and from 60.00 ± 0.04 to 51.00 ± 0.05), springiness decreased (from 0.689 ± 0.01 to 0.504 ± 0.00), and cohesiveness did not show significant differences. The results obtained suggest that successful reduction in sucrose in muffins is possible by using apple puree at replacement levels of up to 50%, thus maintaining a similar textural quality to muffins with sugar.

Keywords: sugar; apple puree; muffins; physical properties; texture; specific gravity; dynamic viscoelastic properties

1. Introduction

As health and nutrition concerns grow, more and more consumers are looking for alternatives to refined sugar, known for its negative health impact. Sugar contributes to weight gain, obesity, type 2 diabetes, cardiovascular disease, and dental problems. Excessive sugar consumption can lead to chronic inflammation, which is linked to numerous conditions, including cardiovascular disease and type 2 diabetes. Sugar stimulates the secretion of pro-inflammatory cytokines and can affect the balance of the gut microbiome, contributing to systemic inflammation [1–8].

Excessive sugar consumption can contribute to high blood pressure, inflammation, and other risk factors for cardiovascular disease. Thus, finding suitable substitutes to maintain the taste and texture of baked goods is essential to meet market demands and promote a healthy lifestyle [5,9,10].

Sugar substitutes must not only provide sweetness but also contribute to the desired structure and texture of pastry products. It is important that these substitutes are versatile and easy to integrate into various recipes. An effective sugar substitute must maintain, or even enhance, the flavor profile of baked goods, ensuring taste satisfaction for consumers [11].

Sugar substitutes include apple puree, apple fiber, apple pomace, date powder and syrup, grape syrup, inulin, oligofructose, stevia, agave syrup or nectar, *Nypa futicans* syrup, yellow berry's pulp, jaggery, honey, Monk fruit, masaikai seeds, coconut sugar, sorghum syrup, molasses, and maple syrup [6,12–29].

Rich in fiber and vitamins, apple puree adds moisture and a subtle fruit flavor to baked goods, being ideal for cakes, muffins, and biscuits [26,30]. Apple fiber adds volume and texture to products, contributing to satiety and improving the nutritional profile through its high dietary fiber content [31].

Date powder, a natural and antioxidant-rich alternative, adds sweetness and a distinct flavor to baked goods. Date syrup, similar to date powder, is rich in antioxidants and adds

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sweetness and a rich flavor. This is ideal for cakes and biscuits [24,32–34]. Grape syrup provides a natural sweetness and is rich in antioxidants and vitamins. This is ideal for adding a distinct and rich flavor to pastry products [35–37].

A natural prebiotic extracted from chicory root, inulin, is a soluble fiber that contributes to improving intestinal health. It has a slightly sweet taste and can be used in various patisserie products [38–40].

Another prebiotic, oligofructose, contributes to digestive health and has a naturally sweet taste. It is used to replace sugar and to improve the texture of patisserie products [13,41–43].

With a low glycemic index, agave syrup provides natural sweetness and is easy to use in recipes, replacing sugar 1:1 in many preparations [44].

A natural calorie-free sweetener, glicozide steviol, is many times sweeter than sugar and should be used in smaller amounts. It is suitable for a wide range of pastry products [14,45–47].

Honey is a natural sweetener that adds a distinct flavor and antioxidant benefits. It can be used instead of sugar, but it is sweeter and denser, requiring adjustments in recipes [48].

Maple syrup is another natural alternative, rich in antioxidants and minerals, with a distinct flavor that can enrich the taste of patisserie products [49].

Apple puree is rich in fiber, vitamins (especially vitamin C), and antioxidants. Replacing refined sugar with apple puree not only reduces your intake of simple sugars but also introduces essential dietary fiber that aids digestion and maintains steady energy levels. It is also a source of natural moisture, which contributes to maintaining the moist texture of pastry products [12,50].

In pastry products, sugar does not only serve as a sweetener. It contributes to the structure, texture, and final appearance of products [51–53]. Apple puree can replace sugar in many recipes, but it is important to note that changes must be adjusted to maintain the correct balance of ingredients. For example, due to the high water content of apple puree, it may be necessary to adjust the amount of liquids in the recipe to avoid a too wet or gummy texture [12].

Apple puree adds a subtle fruit flavor to baked goods that can complement or enrich the overall taste. Depending on the recipe, this flavor can be an advantage, contributing to the complexity of the final taste. It should be taken into consideration that choosing the type of apples used for puree can further influence the flavor profile, as different apple varieties have varying levels of sweetness and acidity [30,53–55].

Apple puree can be used in a variety of baked goods, from cakes and muffins to cookies and cakes. It can be used as a full or partial sugar substitute, depending on the recipe and personal preference. It is also a great option for people following a vegan diet or looking to cut down on processed sugars [12,25,26,50].

This paper presents a study of the effects of replacing sugar in muffins with different percentages of apple puree on the modulus of elasticity and viscosity of the dough, depending on the frequency and temperature, texture, physical characteristics, and color of the muffins.

2. Materials and Methods

2.1. Materials

Eleven muffin doughs were prepared containing 0% (PC—control sample), 10% (P10), 20% (P20), 30% (P30), 40% (P40), 50% (P50), 60% (P60), 70% (P70), 80% (P80), 90% (P90), and 100% (P100), where P is the percentage of boiled apple puree as a substitute for sucrose (Table 1). Wheat flour, white sugar, baking powder, iodized table salt, milk, sunflower oil, and fresh eggs were purchased from a local supermarket. The boiled apple puree (Champion apple cultivars) used as a sugar substitute in muffins was obtained according to the method described by Huțu and Amariei (2024). To obtain the apple puree, the apples were washed, peeled, and then mixed for 5 min at maximum speed; then, the water was evaporated until half of the mass of the puree remained [50].

Table 1. Formulation of control muffin (PC) and muffin prepared with different levels of sugar replacement by apple puree.

Formulation	PC	P10	P20	P30	P40	P50	P60	P70	P80	P90	P100
Ingredients						**Mass (g)**					
Eggs	75	75	75	75	75	75	75	75	75	75	75
Sugar	100	90	80	70	60	50	40	30	20	10	-
Milk	35	35	35	35	35	35	35	35	35	35	35
Oil	100	100	100	100	100	100	100	100	100	100	100
Wheat flour	125	125	125	125	125	125	125	125	125	125	125
Baking powder	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Salt	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Apple puree	-	10	20	30	40	50	60	70	80	90	100

2.2. Muffin Batter Preparation

The eggs and sugar/apple puree were stirred for 240 s at maximum speed in a KitchenAid Professional Mixer. Milk and oil were added over the mixture, and this was stirred for 60 s at minimum speed. The solid ingredients were added, and the mixture was stirred for 60 s at minimum speed. The mixture was stored at refrigeration temperature for 1 h.

2.3. Muffins Preparation

Fifty grams of dough was weighed into each muffin paper tin. The muffins were baked for 14 min at 180 °C. All formulations were prepared in triplicate.

2.4. Specific Gravity

The specific gravity was determined using a container of known volume as follows: the mass of the container with water and the mass of the same container with raw dough were determined. The specific gravity was obtained from the ratio: raw dough mass/water mass [56–60].

2.5. Rheological Behavior of Batter Muffins

According to the method described by [61] the temperature was increased by 2 °C/min, varying between 20 and 90 °C, to evaluate the viscoelastic properties of the muffin dough. The analysis was carried out according to the frequency between 0.1 and 10 Hz, using a rotor with glossy plates of 40 mm diameter, at a distance of 1 mm between the plates. Temperature control was provided by a Peltier system and a circulating water bath (Huber, Karlsruhe, Germany) using a Haake Mars 40 dynamic rheometer (Karlsruhe, Germany) [61,62].

2.6. Baking Loss

Cooking loss (*WL*) was determined according to the method described by Simona Grasso et al. (2020), and the calculation formula used was [56,63–65]:

$$WL(100\%) = (Wb - Wm)/Wb \times 100 \tag{1}$$

where *Wb*—the mass of the dough before baking, g; and *Wm*—the mass of the muffin after baking, g.

2.7. Muffin Height

To determine the height of the muffins, a digital caliper was used to measure the distance between the highest point and the bottom of the muffin [56,66].

2.8. Volume

The volume of the muffins was determined by the rapeseed displacement method described by Zahide (2019) [57,66–70].

2.9. Texture

Using a TVT-6700 texture analyzer (Perten Instruments, Hägersten, Sweden), the evaluation of the textural profile was performed [71]. The tension was applied on 50% of the sample height, with a test speed of 1 mm/s. Two compressions were performed with an interval of 5 s between the two compression cycles. A trigger force equivalent to a mass of 5 g was selected using an aluminum plate with a diameter of 75 mm (P/75). The cubes were compressed twice. The texture parameters obtained were springiness and cohesiveness [71].

2.10. Color Analysis

The analysis of the color of the muffins involved the determination of the parameters L*, a*, and b* for both crust muffins and crumb muffins. Determinations were made using a Konica Minolta CR-400-colorimeter (Tokyo, Japan) (Science, 2020) [72,73].

2.11. Statistical Analysis

Statistical analysis (means and standard deviations) was performed using SPSS 25.0 (trial version) software (IBM, New York, NY, USA). Differences between data were assessed by an analysis of variance (ANOVA) followed by Tukey's HSD test. In addition, Origin Pro 2019b software (student version) was also used for data analysis. Values marked with different letters indicate statistically significant differences at the 95% confidence level.

3. Results

3.1. Specific Gravity

The specific gravity of the dough reflects its air retention capacity. The lower the specific gravity, the better the aeration of the dough, indicating a greater ability of the dough to incorporate air bubbles during kneading and retain them during baking [74]. The specific gravity increased with increasing water content and ranged from 0.93 (PC) to 1.03 (P100); this increase may be due to the high water content of apple puree compared to sugar (Figure 1). Similar results were obtained by Martínez-Cervera et al. in 2012 by replacing sucrose in muffins with erythritol [56]. Following the substitution of sucrose in the muffin dough, it was observed that its reduction significantly increased the specific gravity values, which implies a lower capacity of the dough to retain air. This suggests that sucrose plays a crucial role in aerating the dough and maintaining the fluffy structure of the muffins.

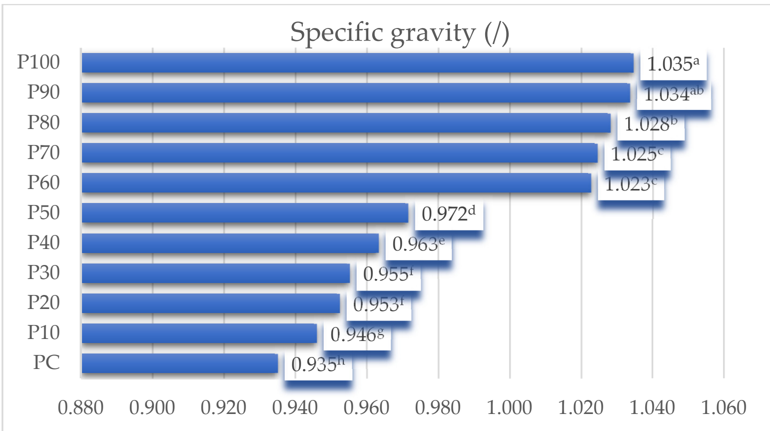

Figure 1. Muffin dough specific gravity. Values followed by different superscript letters (a, b, c, d, e, f, g, h) are statistically different at 95% confidence level.

3.2. The Effect of Replacing Sucrose in Muffins with Apple Puree on the Viscoelastic Properties of Dough

Figure 2 shows the effect of replacing sucrose in different percentages with apple puree on the flow curves of muffin doughs.

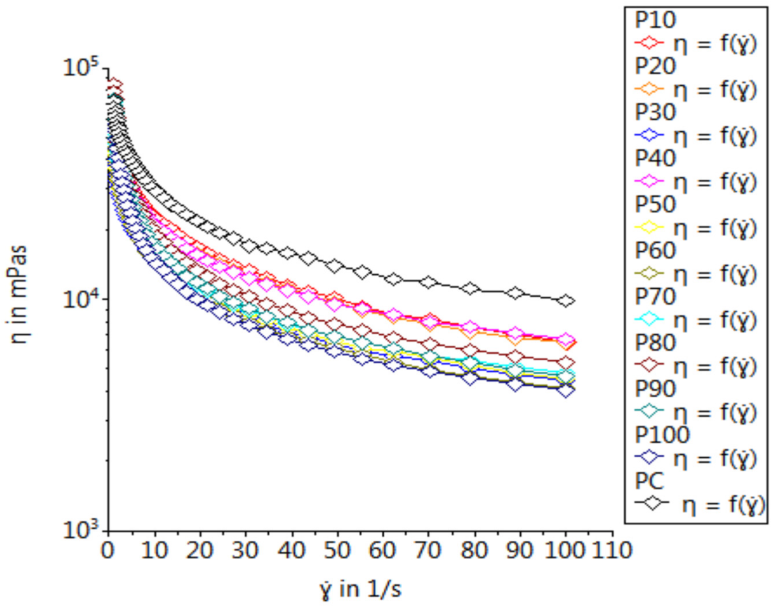

Figure 2. The impact of sucrose replacement by apple puree on the flow curves of the muffin dough.

A typical shear-thinning behavior was observed in all doughs (Figure 2), with the doughs being less viscous when sucrose was substituted with apple puree. This behavior is very likely related to the moisture content of the apple puree, which would have led to a decrease in the viscosities of the doughs in which sucrose was partially substituted for total sugar. Apparent viscosity decreased significantly ($p < 0.05$) with increasing percentage of sucrose substituted with apple puree. Other authors also obtained a decrease in viscosity by substituting sucrose in muffin batter with agave syrup [44] by replacing sucrose with grape, mulberry, or apricot molasses [75].

The results showed that the values for the elastic modulus G′ were higher than those for the viscous modulus G″ in the temperature range of 20–90 °C (Figures 3 and 4).

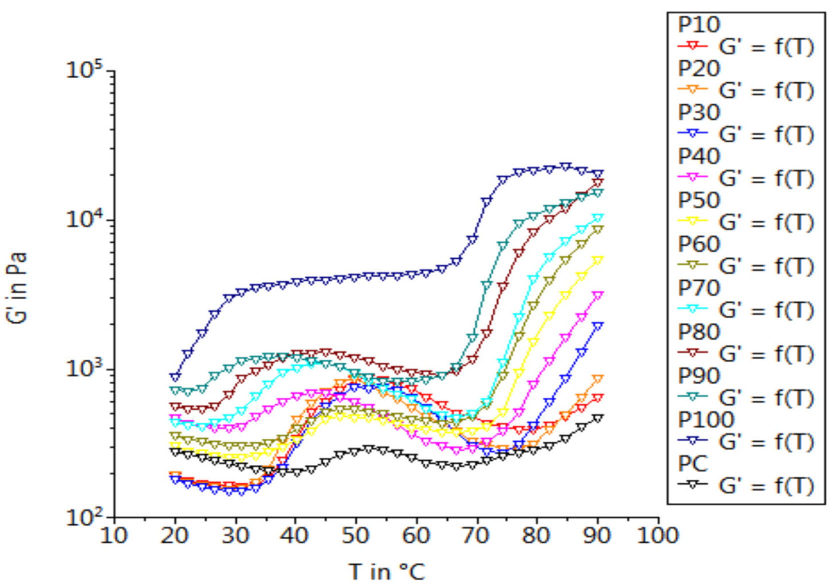

Figure 3. Effect of sucrose substitution in muffin dough on storage modulus (G′) with temperature.

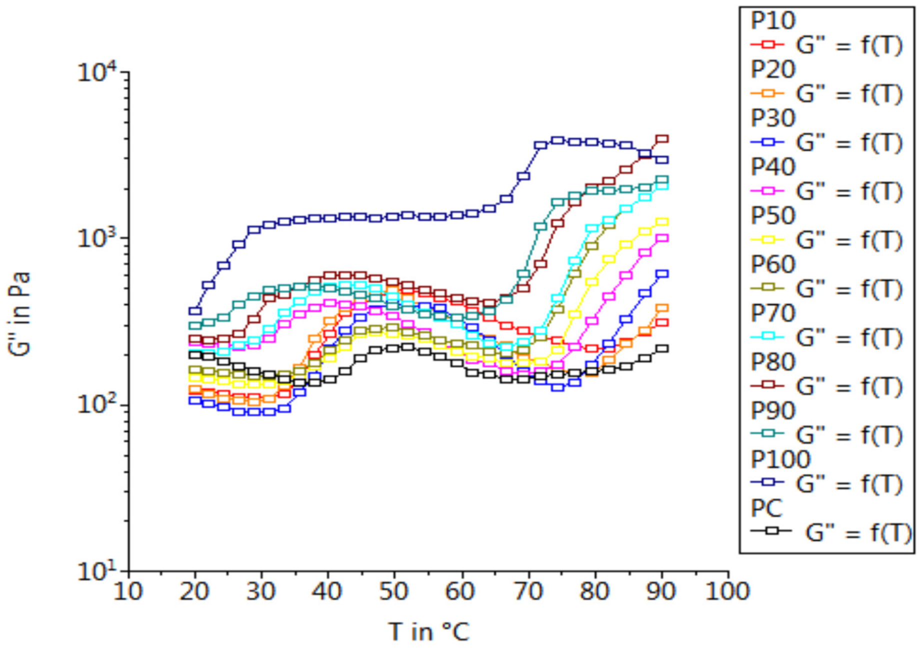

Figure 4. Effect of sucrose substitution in muffin dough on loss modulus (G″) with temperature.

The viscoelastic properties were evaluated in accordance with the temperature, from 20 °C to 90 °C, to observe the structural changes in the muffin doughs by simulating the behavior of the dough in the oven. The final structure and texture of the muffins are directly influenced by the structural changes that occur in the dough during baking. Sucrose increases the gelatinization temperature of starch, its role being crucial during dough heating. This allows for the correct formation of water vapor and CO_2 and sufficient expansion of the air bubbles before the dough sets. Thus, sucrose contributes to the development of the fluffy structure of the muffins, ensuring an airy and uniform texture [74]. The effects of temperature on the storage modulus (G′) and loss modulus (G″) during dough heating are shown in Figures 3 and 4.

The results showed that, in the temperature range of 20–90 °C, the values for the storage modulus G′ were higher than those for the loss modulus G″.

The values for G′ and G″ decreased with increasing temperature, probably due to the denaturation of the proteins, which lose their ability to retain water in the dough system. Subsequently, as the temperature continues to rise, the released water begins to be absorbed by the starch granules, which hydrate and subsequently gelatinize, leading to increased G′ and G″ values. Regarding the behavior of the doughs, samples P10-P60 showed values close to those of the control sample for G′ and G″. Therefore, the behavior was similar, unlike the other samples that showed significantly higher values than the control sample. Similar results were obtained by Ozuna et al. (2020) by substituting sucrose in muffin dough with agave syrup [44].

Also, viscoelastic properties were studied as a function of frequency, which varied between 0.1 and 10 Hz at a constant temperature. Figures 5 and 6 show the frequency dependence of the different doughs on the storage modulus (G′) and the loss modulus (G″). Doughs with 40%, 70%, 80%, 90%, and 100% apple puree showed higher values for the modulus of elasticity compared to the control sample, compared to doughs with 10%, 20%, 30%, and 50% apple puree that presented lower values for the storage modulus compared to the control sample (Figures 5 and 6). The sample with 60% apple puree showed the same values for the storage modulus versus frequency as the control sample.

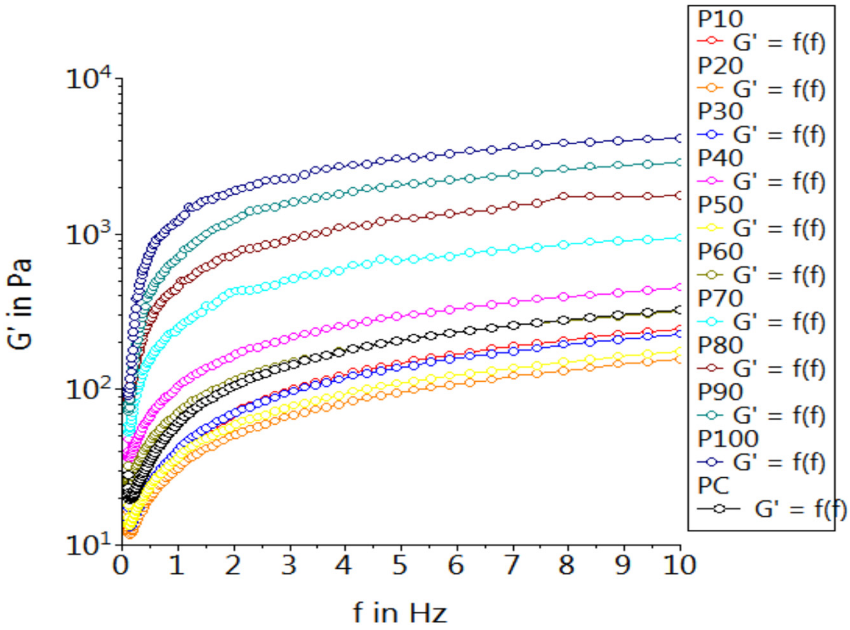

Figure 5. The effect of replacing sucrose in muffin dough with apple puree on the storage modulus (A) with frequency.

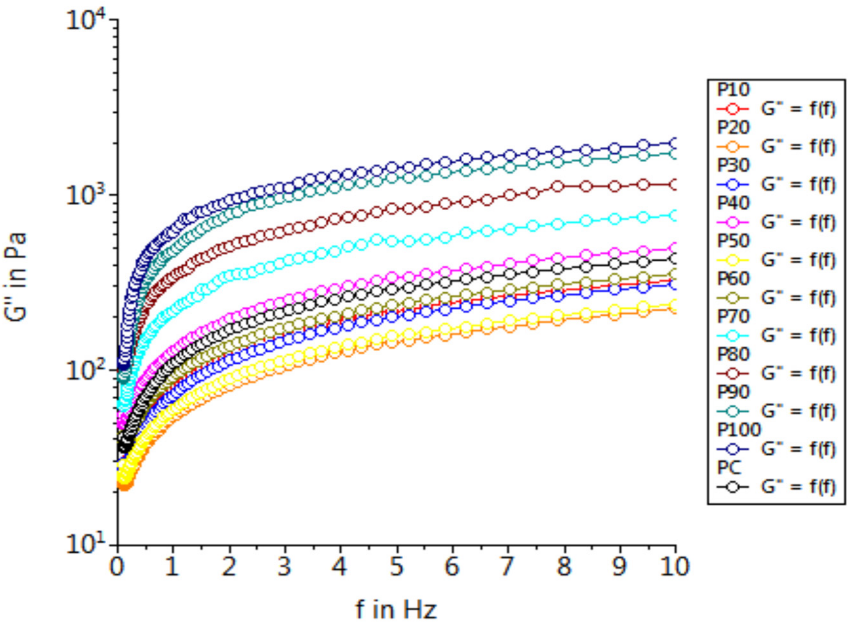

Figure 6. The effect of replacing sucrose in muffin dough with apple puree on the loss modulus (G″) with frequency.

The dough samples with 10%, 20%, 30%, and 50% sugar substituted with apple puree showed values of the loss modulus (G″) with lower frequency compared to the control sample, and the samples with 70%, 80%, 90%, and 100% substituted sugar obtained higher values than those of the control sample. The samples with 40% and 60% substituted sugar presented values for the loss modulus (G″) with a frequency close to those of the control sample. Similar results were obtained by Ozuna et al. (2020) by substituting sucrose in muffin dough with agave syrup [44].

3.3. Muffin Height

In general, muffins with a high value of height are more acceptable, being considered to have a more porous and softer texture [66]. The final height and volume of the muffins depend on both the amount of air initially incorporated into the dough and its ability to retain this air during baking. These parameters are positively influenced by air incorporated into the dough during mixing, CO_2 released by baking powder, water vapor generated during baking, thermal structural changes due to gelatinization of starch, and heating rate [66]. Sucrose has an important role in delaying starch gelatinization during baking, thus facilitating adequate expansion of air bubbles before the muffin hardens [66].

The height of the muffins showed a decrease in values with an increase in the percentage of sugar substituted with apple puree (Figure 7). The height of the muffins varied between 43.36 mm (100% sugar substituted sample) and 49.66 (control sample). Similar results were obtained by Rodríguez-García et al. (2014) by replacing sucrose in cookies with inulin and Martínez-Cervera (2012) by replacing sucrose in muffins with erythritol [13,56]. In addition, Majzoobi et al. (2018) and Nieto-Mazzocco et al. (2022) obtained decreases in the height of muffins and cakes by substituting sucrose with rebaudioside A, respectively, and with agavin-type fructans [66,76].

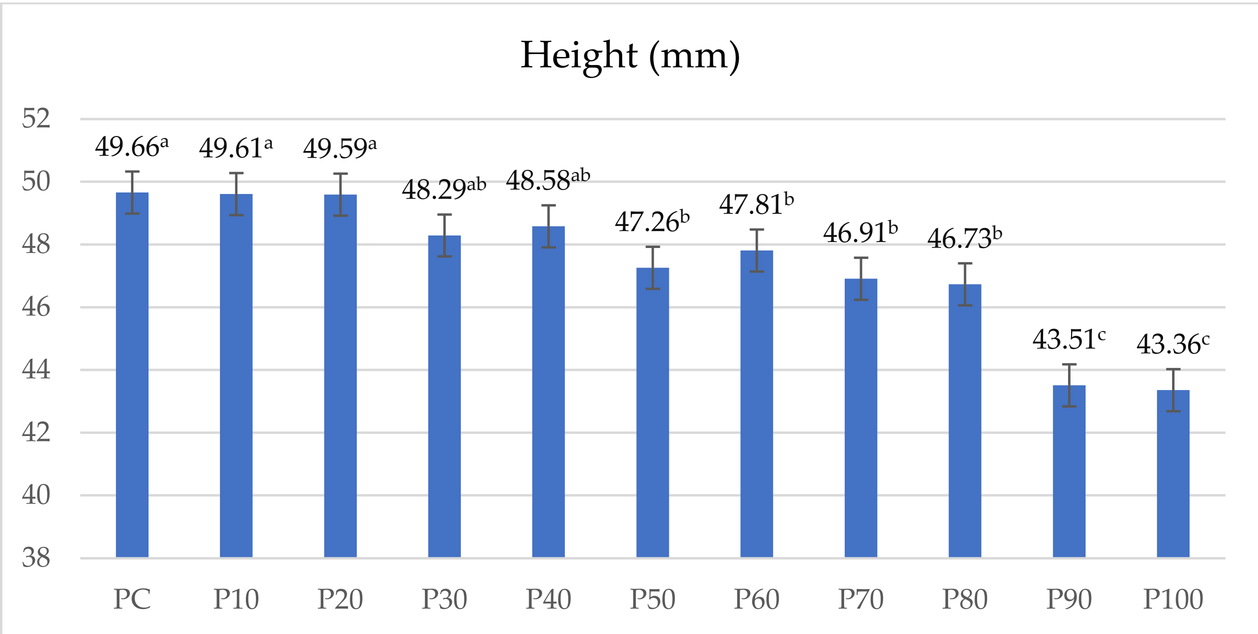

Figure 7. Graphic representation of muffin height. Values followed by different superscript letters (a, b, c) are statistically different at 95% confidence level.

3.4. Volume of Muffins

As in the case of height, the volume of the final product depends on the amount of air incorporated in the dough and the ability of the dough to retain that air during baking [66], with sucrose favoring this process. As to the volume of muffins obtained by replacing sucrose with apple puree, it decreased with the increase in the percentage of substituted sugar. The volume of muffins prepared with different levels of apple puree as a substitute for sucrose together with that of the control muffin is shown in Figure 8. Samples in which sugar was substituted in a percentage higher than 50% showed significantly lower volume values ($p < 0.05$) versus the control sample. The incorporation of fewer air bubbles, and the reduced capacity of the dough to retain air during baking lead to decreased expansion of sugar-free muffins [77]. Decreases in muffin volume by replacing sucrose with stevia, erythritol, or a combination of fiber (apple fiber/wheat fiber/pea fiber), water, and steviol glycosides were also obtained by Gao et al. (2019), Martínez-Cervera et al. (2012), and Struck et al. (2016), respectively [56,77,78].

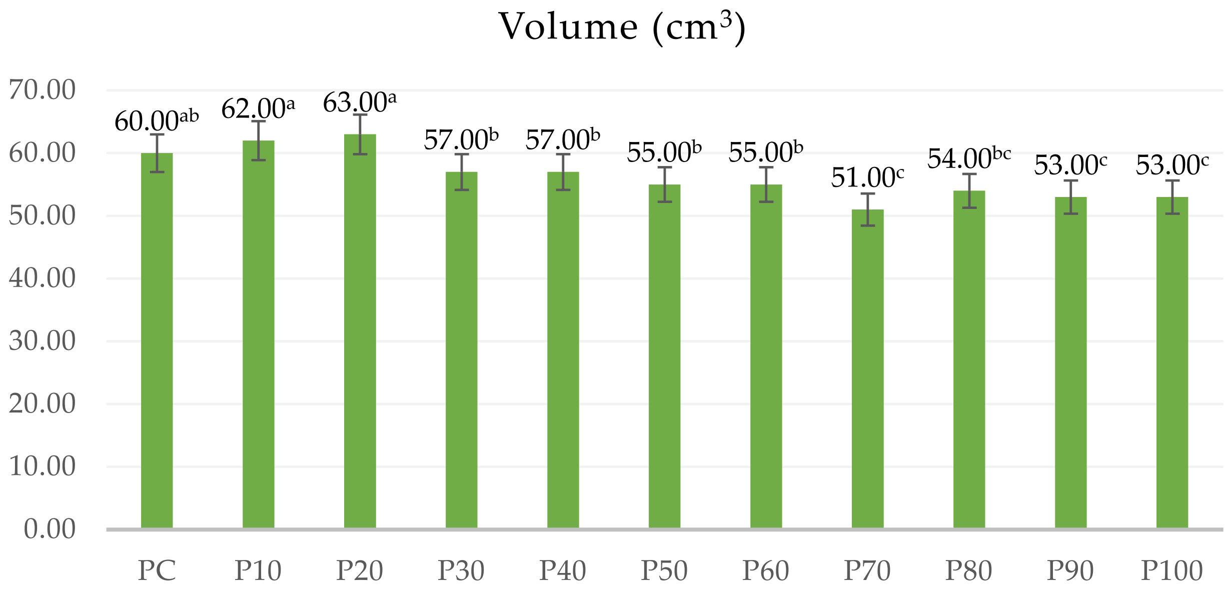

Figure 8. Graphic representation of muffin volume. Values followed by different superscript letters (a, b, c) are statistically different at 95% confidence level.

3.5. Weight Loss during Baking

Weight loss during baking is due to the evaporation of water during this process. In dough, sucrose significantly influences water retention during the baking process, as it can bind to water molecules, preventing their evaporation. Sucrose also delays starch gelatinization, which results in greater water retention by the starch. Baking weight loss of muffins increased with an increasing percentage of sugar substituted with apple puree. This suggests that apple puree has a lower water binding capacity compared to sucrose, resulting in greater water evaporation during baking (Figure 9).

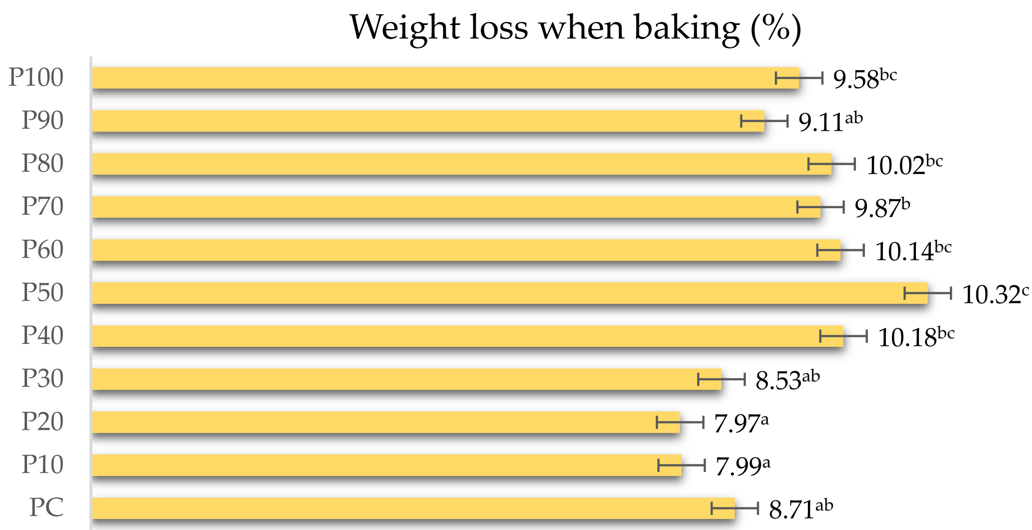

Figure 9. Graphical representation of muffin baking weight loss. Values followed by different superscript letters (a, b, c) are statistically different at 95% confidence level.

3.6. Texture

For muffins, texture is very important to consider. Well-aerated and springy muffins are of high quality and are fresh [72]. An important texture parameter is cohesiveness, which refers to the degree of adhesion of the particles in the product, indicating how well the structural components of the muffin are linked.

The textural characteristics of the muffins were investigated by textural profile analysis, focusing on springiness and cohesiveness. The obtained results of these parameters are presented in Figure 10.

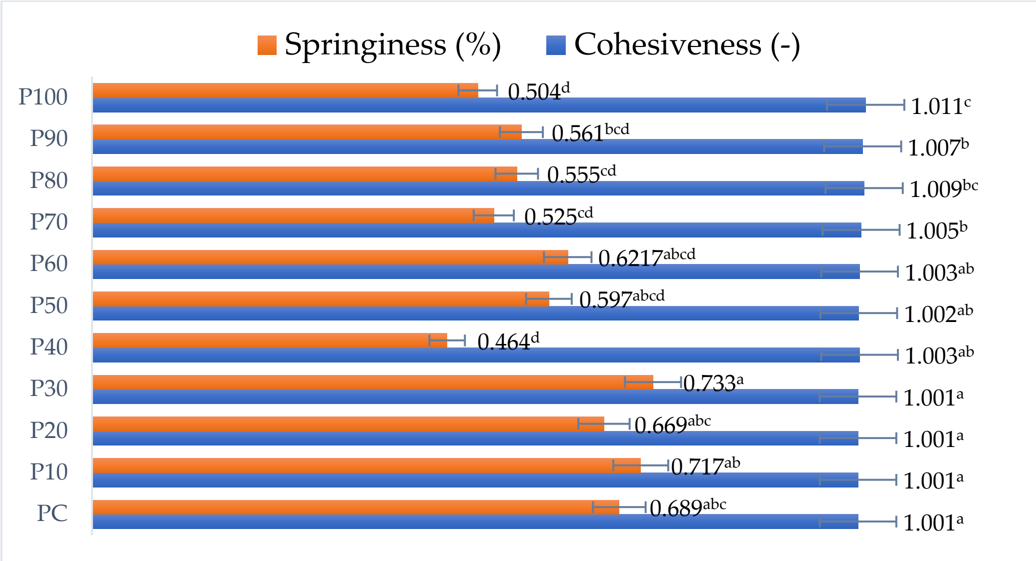

Figure 10. Graphic representation of the cohesiveness and springiness. Values followed by different superscript letters (a, b, c, d) are statistically different at 95% confidence level.

Springiness and cohesiveness are important properties that influence product texture and consumer acceptability.

Springiness refers to the ability of the muffin to recover its original shape after deformation, indicating the airy and fluffy texture desired by consumers. Springiness varied between 0.464 (P40) and 0.733 (P10), and the sample with the cohesiveness value closest to the control sample was the one in which the sugar was substituted with apple puree at a percentage of 20% (P20). By replacing sucrose in muffins with stevia, Gao (2019) also obtained a decrease in the springiness of the finished product; Rodríguez-García (2014) replaced sucrose in cakes and obtained a reduction in their springiness values [13,77].

Cohesiveness is the extent to which a muffin maintains its structural integrity under compressive force. This is an indication of the binding of the muffin ingredients and can be gauged by how much the muffin disintegrates under pressure [79].

The cohesiveness of the muffins did not show significantly higher values ($p < 0.05$) compared to the control sample, and similar results were obtained by Majzoobi et al. (2018) by replacing the sucrose in muffins with rebaudioside A [66]. The cohesiveness of the samples varied between 1.001 and 1.011, and samples P10, P20, and P30 showed the same value as the control sample.

3.7. The Color

The color of the muffins is an important characteristic that can affect the acceptability of the product. The color of the muffins varied according to the percentage of sugar substituted. The effects of sucrose replacement on muffin crust and crumb color are shown in Table 2.

In this study, it was observed that with the increase in the percentage of substituted sugar, muffins with a darker crust (L*) were obtained compared to the control muffin, with the crust color of the reformulated muffins being affected by the absence of sugar. Sugar contributes to caramelization, favoring the formation of the brown-gold color of the crust [80]. Color variations may be due to the darker color of apple puree compared to that of white sugar, and similar results were obtained by Stavale (2019) by replacing the sugar in cookies with apple puree [12]. Also, Milner et al. (2020) obtained low values for L* in the case of crusts where sucrose was substituted with apple pomace [81].

Table 2. Color parameters of the crust and crumb of the muffins.

Sample	Crust			Crumb		
	L*	a*	b*	L*	a*	b*
PC	47.18 ± 0.02 [a]	15.08 ± 0.06 [a]	38.02 ± 0.06 [a]	68.94 ± 0.05 [c]	−6.24 ± 0.03 [g]	24.51 ± 0.06 [fg]
P10	43.52 ± 0.03 [c]	15.86 ± 0.04 [a]	33.36 ± 0.05 [c]	68.04 ± 0.12 [d]	−5.48 ± 0.32 [ef]	24.50 ± 0.14 [h]
P20	42.85 ± 0.04 [d]	15.53 ± 0.03 [b]	31.37 ± 0.12 [d]	69.12 ± 0.07 [c]	−5.09 ± 0.09 [ef]	24.98 ± 0.51 [gh]
P30	46.85 ± 0.02 [b]	15.34 ± 0.02 [c]	34.17 ± 0.07 [b]	69.54 ± 0.06 [b]	−4.93 ± 0.04 [de]	24.96 ± 0.49 [gh]
P40	38.91 ± 0.02 [e]	14.57 ± 0.07 [d]	25.13 ± 0.06 [e]	67.04 ± 0.07 [e]	−4.47 ± 0.04 [cd]	26.21 ± 0.50 [f]
P50	35.89 ± 0.01 [g]	13.63 ± 0.04 [e]	21.17 ± 0.08 [g]	65.04 ± 0.06 [g]	−4.13 ± 0.07 [c]	28.94 ± 0.04 [d]
P60	34.81 ± 0.05 [i]	11.58 ± 0.02 [f]	19.82 ± 0.06 [h]	65.91 ± 0.04 [f]	−3.94 ± 0.04 [bc]	30.73 ± 0.03 [c]
P70	38.64 ± 0.02 [h]	12.71 ± 0.02 [h]	18.22 ± 0.06 [i]	65.66 ± 0.03 [f]	−2.71 ± 0.03 [a]	27.98 ± 0.01 [e]
P80	38.64 ± 0.08 [f]	12.71 ± 0.03 [g]	17.12 ± 0.04 [f]	70.66 ± 0.02 [a]	−3.45 ± 0.04 [b]	34.81 ± 0.01 [a]
P90	31.86 ± 0.07 [j]	10.92 ± 0.04 [i]	15.19 ± 0.06 [j]	68.28 ± 0.04 [d]	−5.11 ± 0.01 [ef]	32.27 ± 0.03 [b]
P100	35.85 ± 0.05 [g]	13.74 ± 0.04 [e]	20.93 ± 0.10 [g]	62.83 ± 0.17 [h]	−624 ± 0.02 [f]	25.95 ± 0.02 [f]

L* (brightness)—ranging 0 (black)—100 (white); a*—color variation green (−)—red (+); b*—color variation blue (−)—yellow (+). Values followed by different superscript letters (a, b, c, d, e, f, g, h, i, j) are statistically different at 95% confidence level.

Crust subtones are represented by the a* (red hue) and b* (yellow) values, and crumb subtones are represented by the a* (green hue) and b* (yellow) values.

4. Conclusions

The present study demonstrated that using apple puree as a sugar substitute in muffins can be an effective alternative for reducing sugar content by up to 50%.

In the samples with sugar substituted up to 50% with apple puree, the height and volume of the muffins, the specific gravity of the dough, and the baking loss did not show significant differences compared to the control sample. In addition, the modulus of elasticity and viscosity as a function of frequency and temperature showed values similar to those of the control sample.

In samples where more than 50% of the sugar was substituted with apple puree, a significant decrease in the height and volume of the products was observed, which may affect the final appearance and texture. An increase in the loss on baking and specific gravity was also found under the same conditions, and the values for the modulus of elasticity and viscosity as a function of frequency and temperature were significantly influenced.

Regarding the texture of the muffins, the cohesiveness was not significantly influenced.

In conclusion, replacing sugar with apple puree is a promising solution for the development of healthier pastry products without significantly influencing the physical and textural properties of the finished products.

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