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Article

Characterization and Quality Analysis of Puff Pastry Made with Corn-Based Dough

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Abstract. This study aimed to analyze the dough characteristics and quality of puff pastry with corn flour as a partial substitute for wheat flour. The use of local ingredients such as corn is important for supporting food diversification and developing healthier bakery products. An experimental method compared a control puff pastry made with 100% wheat flour and a formulation containing corn flour substitution. Samples were evaluated through microscopic observation, Scanning Electron Microscopy (SEM), and nutritional analysis. The results showed that corn flour substitution affected the properties of puff pastry. Microscopic observations indicated that the substituted product had higher porosity and less distinct layer formation than the control, especially on the first day after baking. During storage, the corn-based puff pastry exhibited an increase in hollow structures, indicating changes in internal morphology. SEM analysis confirmed differences in microstructure, with the control sample displaying smoother, clearly defined layers, whereas the substituted sample showed a more porous and irregular structure. Nutritional analysis revealed that corn substitution increased moisture, ash, and protein contents while decreasing fat and carbohydrate levels compared with the control. Overall, corn flour substitution influenced puff pastry texture and composition while demonstrating potential for developing nutritious bakery products from locally available ingredients

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1. Introduction

Corn is one of the abundant food ingredients in Indonesia, but its use in premium processed products such as puff pastry is still limited. With increasing public awareness of the importance of food diversification and the use of healthier and more sustainable local ingredients, this study is very relevant [1-2].

The use of substitute ingredients in food products has long been recognized to affect various physical and organoleptic properties of the final product. In this case, the theory of ingredient substitution states that changes in basic ingredients will have an impact on the structure and texture of the product, which affects the quality and consumer acceptance. Partial substitution of the main ingredients such as wheat flour with other ingredients such as corn in bakery and pastry products can result in significant changes in the aspects of friability, softness, and layer-forming ability [3-4].

The use of corn as a substitute for wheat flour can be a solution to reduce dependence on imported ingredients while increasing the added value of corn as a local commodity [5]. Corn has advantages in terms of higher fiber content, vitamins, and a lower glycemic index compared to wheat flour, so it can provide health benefits for consumers [6].

Recent research supports the importance of this innovation. Substitution of wheat flour with corn up to 30% in bakery products can improve texture and nutritional value without significantly reducing sensory quality [7-8]. These findings show the great potential of using corn in pastry products to create products that are not only healthier, but also maintain the quality expected by consumers.

The urgency of this research is also based on the need for the food industry to continue to present innovative products that respond to health and sustainability trends. By using the method of dough characterization and texture analysis of puff pastry, this research can make a significant contribution to the development of food processing technology that utilizes local ingredients. In addition to strengthening the theory of the effects of ingredient substitution in bakery products, this research is expected to pave the way for diversification of healthier pastry products with high potential in the global market.

The contribution of this research is not only in a scientific context, but also in practical applications, where the use of corn as a substitute ingredient can be an interesting alternative to be developed in the future, both to meet the needs of consumers who are increasingly concerned about health aspects and to support the sustainability of local food production.

2. Methods

This study employed an experimental design to evaluate the effects of partial substitution of wheat flour with corn puree on the structural characteristics and quality of puff pastry. The experiment compared a control formulation prepared with 100% wheat flour and a treatment formulation in which a portion of the wheat flour was replaced with corn puree. The effects of the substitution were evaluated through microscopic observation, Scanning Electron Microscopy (SEM), proximate composition analysis, and antioxidant activity measurements. Samples were analyzed immediately after baking (Day 0) and after five days of storage (Day 5) to evaluate structural changes during storage [9-10].

2.1. Materials and Puff Pastry Formulation

Two puff pastry formulations were prepared: a control formulation containing 100% wheat flour and a treatment formulation containing partial substitution with corn puree. The ingredients used consisted of wheat flour, corn puree, egg, ice water, granulated sugar, salt, butter, and pastry margarine (korsvet). The detailed formulation is presented in Table 1.

Table 1. Formulation of puff pastry samples

Ingredients	Control (g)	Corn puree (g)
Wheat flour	500	350
Corn puree	–	150
Egg	50	50
Ice water	250	130
Granulated sugar	15	15
Salt	7.5	7.5
Butter	50	50
Pastry margarine (korsvet)	250	250

2.2. Preparation of Puff Pastry
Fresh corn kernels were steamed, blended, and filtered to obtain corn puree. Wheat flour, corn puree (for the substitution treatment), granulated sugar, salt, egg, and ice water were mixed until a homogeneous dough was obtained. Butter was then incorporated, and the dough was kneaded until partially developed. Separately, pastry margarine (korsvet) was flattened and chilled in a freezer for 10 min. The dough was rolled to approximately 1 cm thickness, laminated with the chilled pastry margarine, folded, and stored in a chiller for 15 min. The lamination process was repeated three times. The laminated dough was then cut into 10 × 10 cm squares, shaped into diamond forms, baked for 40 min, cooled to room temperature, and subsequently prepared for microscopic, SEM, proximate, and antioxidant analyses.

2.3. Research Instruments
The instruments used in this study included a light microscope and Scanning Electron Microscope (SEM) for microstructural observation of puff pastry layers [11], laboratory equipment for proximate analysis including moisture, ash, protein, fat, and carbohydrate determination [12], and conventional bakery equipment for dough preparation and baking [13-14].

2.4. Data Collection
Microscopic observations were conducted on the inner layer, outer layer, upper surface, lower surface, and cross-sectional structure of puff pastry samples. SEM analysis was performed at magnifications of 250×, 500×, and 1000× to evaluate changes in the internal microstructure during storage [15]. Proximate composition analysis included determination of moisture content (AOAC Method 925.10), ash content (AOAC Method 923.03), protein content using the Kjeldahl method (AOAC Method 979.09), fat content using the Soxhlet extraction method (AOAC Method 920.39), and carbohydrate content calculated by difference [16]. Antioxidant activity was determined using the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay. One gram of sample was extracted with 10 mL methanol and left overnight. The extract was filtered, concentrated using a rotary evaporator, and reacted with 0.1 mM DPPH solution. After incubation for 30 min, absorbance was measured at 517 nm using a UV-Vis spectrophotometer, and antioxidant activity was expressed as IC_{50} values.

2.5. Data Analysis
The obtained data were analyzed descriptively and comparatively. Microscopic and SEM observations were interpreted by comparing the structural characteristics of the control and corn puree-substituted puff pastry samples at Day 0 and Day 5. The proximate composition and antioxidant activity of both formulations were also compared to evaluate the effects of corn puree substitution on the physicochemical properties of puff pastry [17-18].

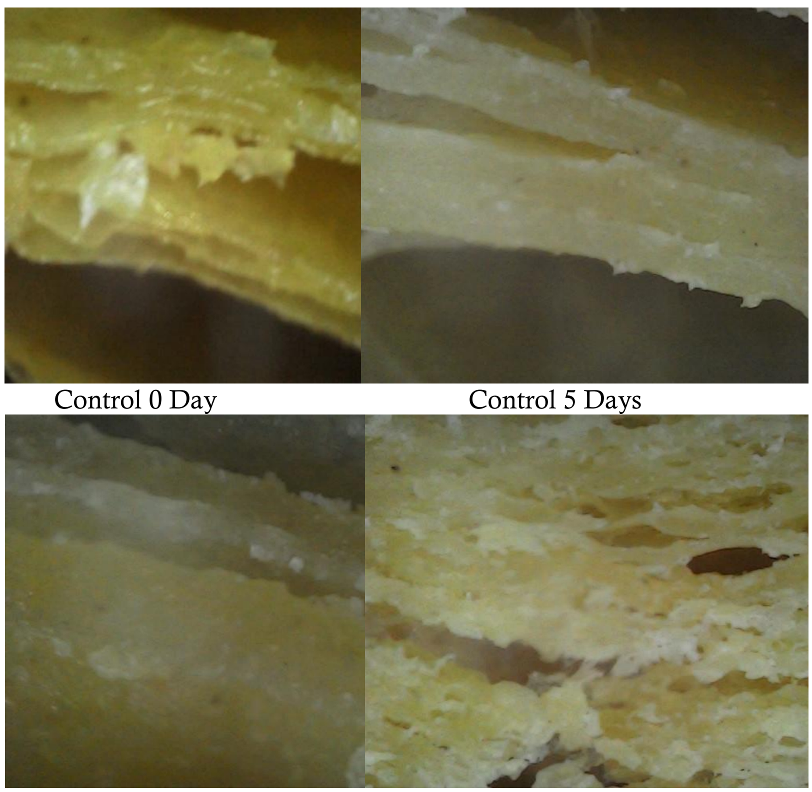
3. Results and Discussion

3.1 Microscopic Analysis

3.1.1 Inner Layer

Figure 1 shows the microscopic characteristics of the inner layer of the control and corn puree-substituted puff pastry on Day 0 and Day 5. The control sample exhibited clearer laminated layers immediately after baking, although small cracks were observed. After five days of storage, the laminated structure became less distinct. In contrast, the corn puree-substituted puff pastry showed a denser structure with fewer internal cavities on Day 0, whereas larger and more irregular pores developed after five days of storage.

These observations indicate that substitution with corn puree altered the internal microstructure of puff pastry by reducing the stability of the laminated layers and promoting greater porosity during storage. This structural change is likely associated with the reduced gluten network resulting from wheat flour substitution, leading to less uniform layer formation and increased cavity development.



Control 0 Day Control 5 Days

Corn 0 Day Corn 5 Days

Figure 1. Microscopic analysis from inner layer

3.1.2 Outer Layer

Figure 2 presents the microscopic characteristics of the outer layer of the control and corn puree-substituted puff pastry on Day 0 and Day 5. The control sample showed relatively separated laminated layers immediately after baking, while the layers became more compact and better defined after five days of storage. In contrast, the corn puree-substituted puff pastry exhibited a relatively dense outer structure with limited pores on Day 0, whereas a more porous structure with larger air cavities was observed after five days of storage.

These findings indicate that storage influenced the outer-layer microstructure of both formulations, with more pronounced structural changes occurring in the corn puree-substituted puff pastry. The increased porosity is likely associated with the weaker gluten network caused by partial substitution with corn puree, resulting in reduced layer integrity and greater cavity formation during storage.

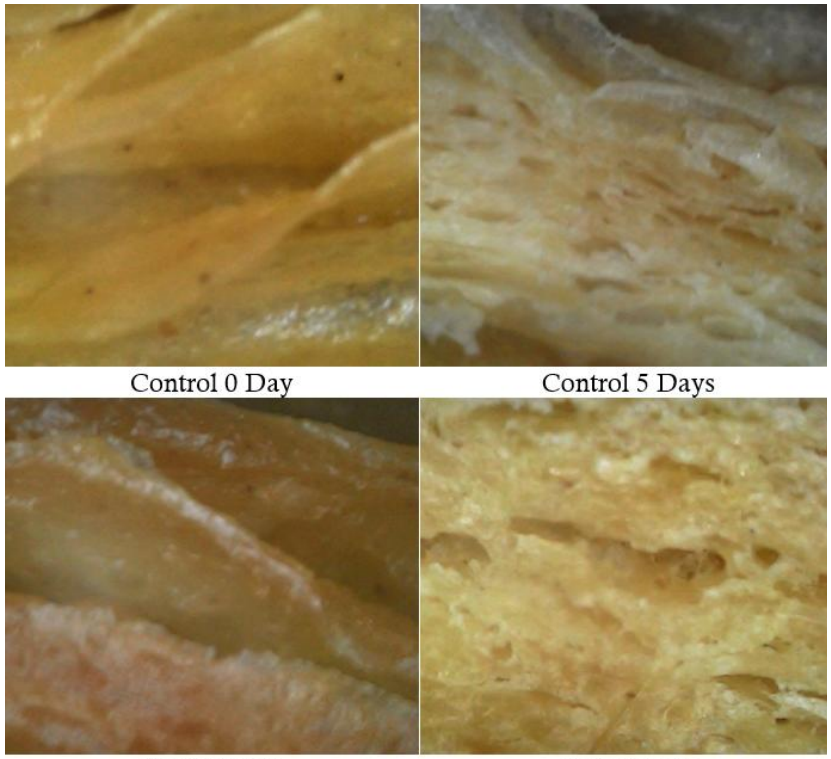


Figure 2. Microscopic analysis from outer layer

3.1.3 Top Surface

Figure 3 shows the microscopic characteristics of the top surface of the control and corn puree-substituted puff pastry on Day 0 and Day 5. The control sample exhibited a relatively smooth and homogeneous surface immediately after baking, whereas a rougher and more irregular texture was observed after five days of storage. Similarly, the corn puree-substituted puff pastry showed a relatively smooth surface on Day 0, while the Day 5 sample exhibited a darker surface with more pronounced roughness and visible dark spots.

These observations suggest that storage affected the surface morphology of both formulations by increasing surface roughness and color changes. The more pronounced surface irregularities in the corn puree-substituted puff pastry may be associated with moisture redistribution and structural changes occurring during storage, which altered the surface appearance and texture of the product.

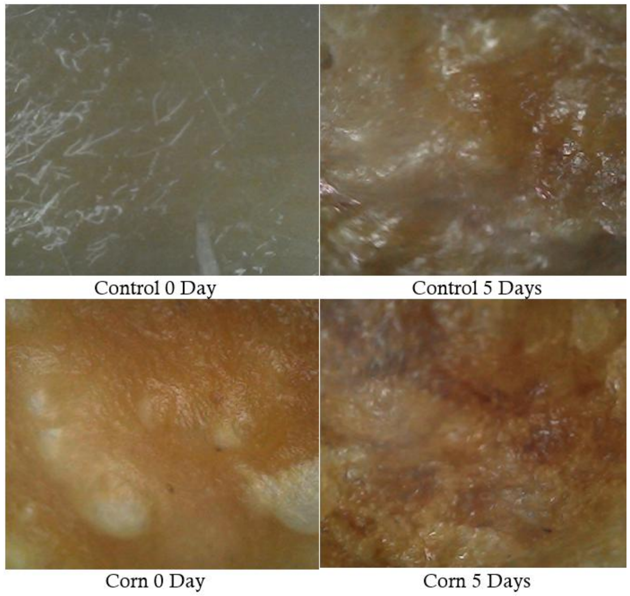


Figure 3. Microscopic analysis from top surface

3.1.4 Bottom Surface

Figure 4 illustrates the microscopic characteristics of the bottom surface of the control and corn puree-substituted puff pastry on Day 0 and Day 5. The control sample exhibited a relatively smooth and homogeneous surface immediately after baking, whereas a rougher texture was observed after five days of storage. Similarly, the corn puree-substituted puff pastry showed a smoother and lighter-colored surface on Day 0, while the Day 5 sample exhibited a darker appearance with a rougher texture and more visible cavities.

These results indicate that storage affected the bottom surface morphology of both formulations, with more pronounced structural changes occurring in the corn puree-substituted puff pastry. The increased roughness and cavity formation may be attributed to moisture migration and the weaker gluten network caused by partial substitution with corn puree, leading to reduced structural stability during storage.

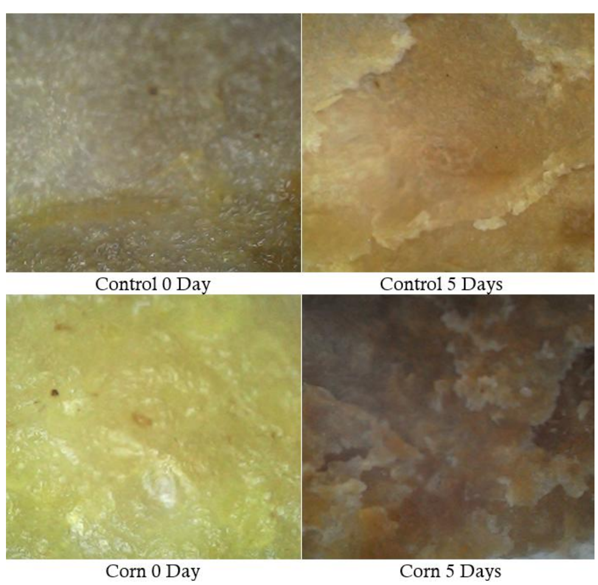


Figure 4. Microscopic analysis from bottom surface

3.1.5 Both Surface

Figure 5 presents the microscopic characteristics of both surfaces of the control and corn puree-substituted puff pastry on Day 0 and Day 5. The control sample exhibited a relatively smooth and uniform surface immediately after baking, whereas small cavities and slight surface disruption became evident after five days of storage. Similarly, the corn puree-substituted puff pastry showed a smooth and homogeneous yellowish surface on Day 0, while the Day 5 sample exhibited a darker brownish appearance with a rougher surface and more pronounced cavities.

These observations indicate that storage promoted structural deterioration in both formulations, particularly in the corn puree-substituted puff pastry. The darker color and increased cavity formation suggest moisture redistribution and weakening of the laminated structure during storage, which may be associated with the reduced gluten network caused by partial substitution with corn puree.

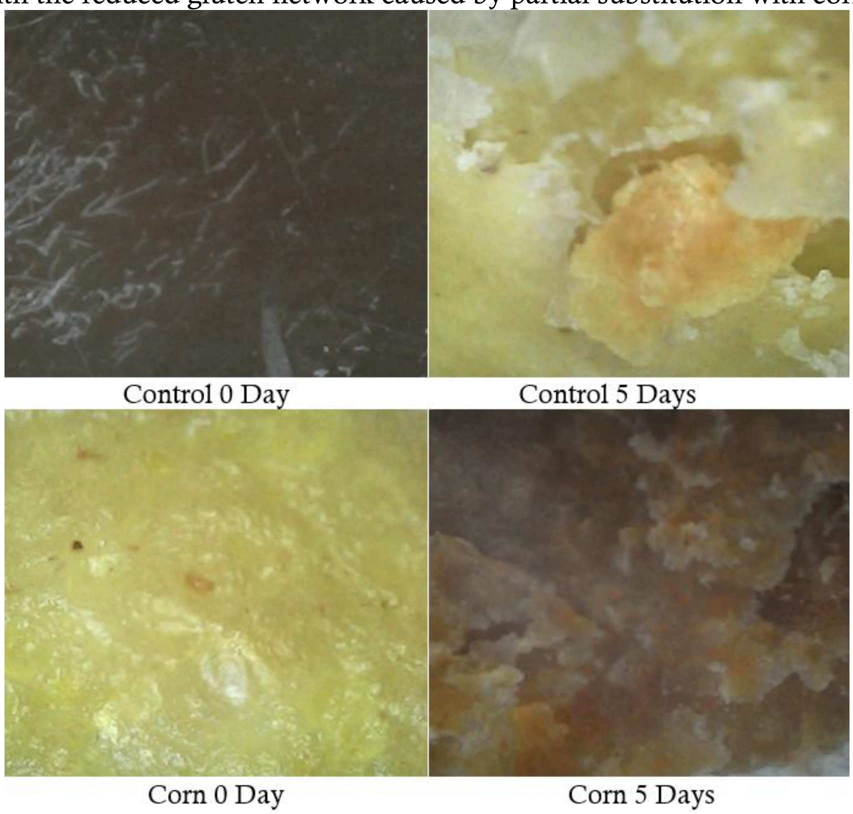


Figure 5. Microscopic analysis from both surface

3.1.5 Corn 30%

In 30% corn, the puff pastry looks like it has layers but it is not so clear and tends to be abstract. The cavity axis in the puff pastry looks small and not so hollow and is tighter. The results of microscopic observations showed significant differences in the texture of the control puff pastry (100% wheat flour) and the puff pastry substituted with corn. On the control day 0, the inner and outer layers of the puff pastry had not yet formed perfectly, but began to look more layered on the 5th day. In contrast, the puff pastry with corn substitution showed that on day 0, the layers were not hollow and less defined. However, on the 5th day, the corn layer began to show more hollow and porous characteristics than the control.

The interpretation of these results indicates that corn substitution affects the ability of the dough to form the expected layers in puff pastry. This is in line with the theory that the difference in gluten content between wheat flour and corn affects the ability of the dough to expand. Corn, which is low in gluten, has lower elasticity, so the dough cannot expand perfectly to form smooth layers like in wheat flour-based puff pastry. Gluten is a protein responsible for the ability of dough to hold air and form layers in bakery and pastry products [19-21].

However, over time (5 days), corn puff pastry showed an increase in layer formation and porosity. This may be due to moisture absorption which causes the dough structure to develop further, although the final result is not as good as the control. This also indicates that corn substitution can still produce decent puff pastry, although not as smooth as products that use wheat flour entirely [22-23].

Corn 1 Corn 2 Corn 3

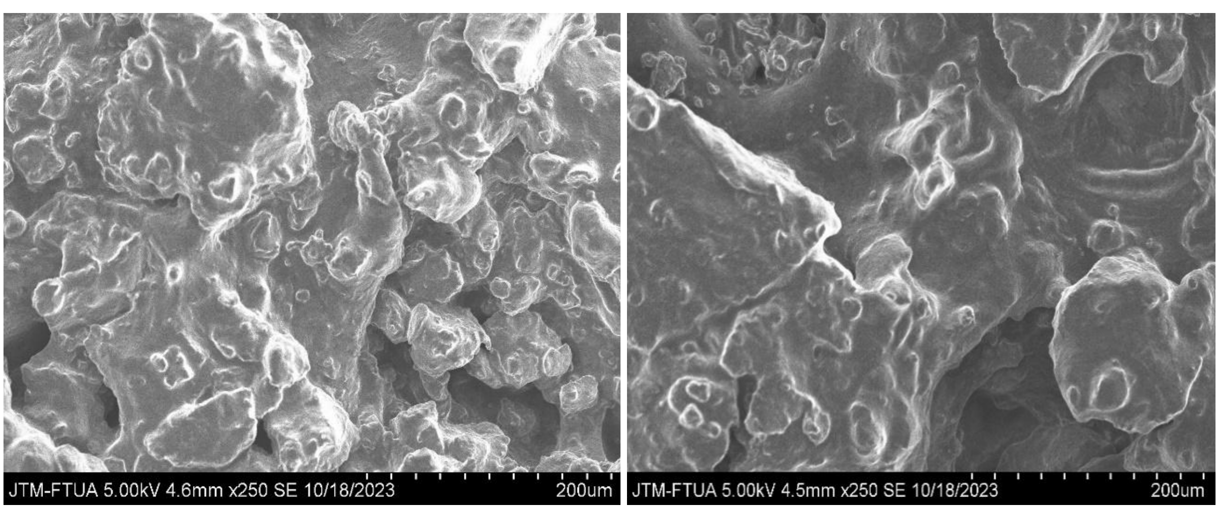
Figure 6. Microscopic analysis from corn 30%

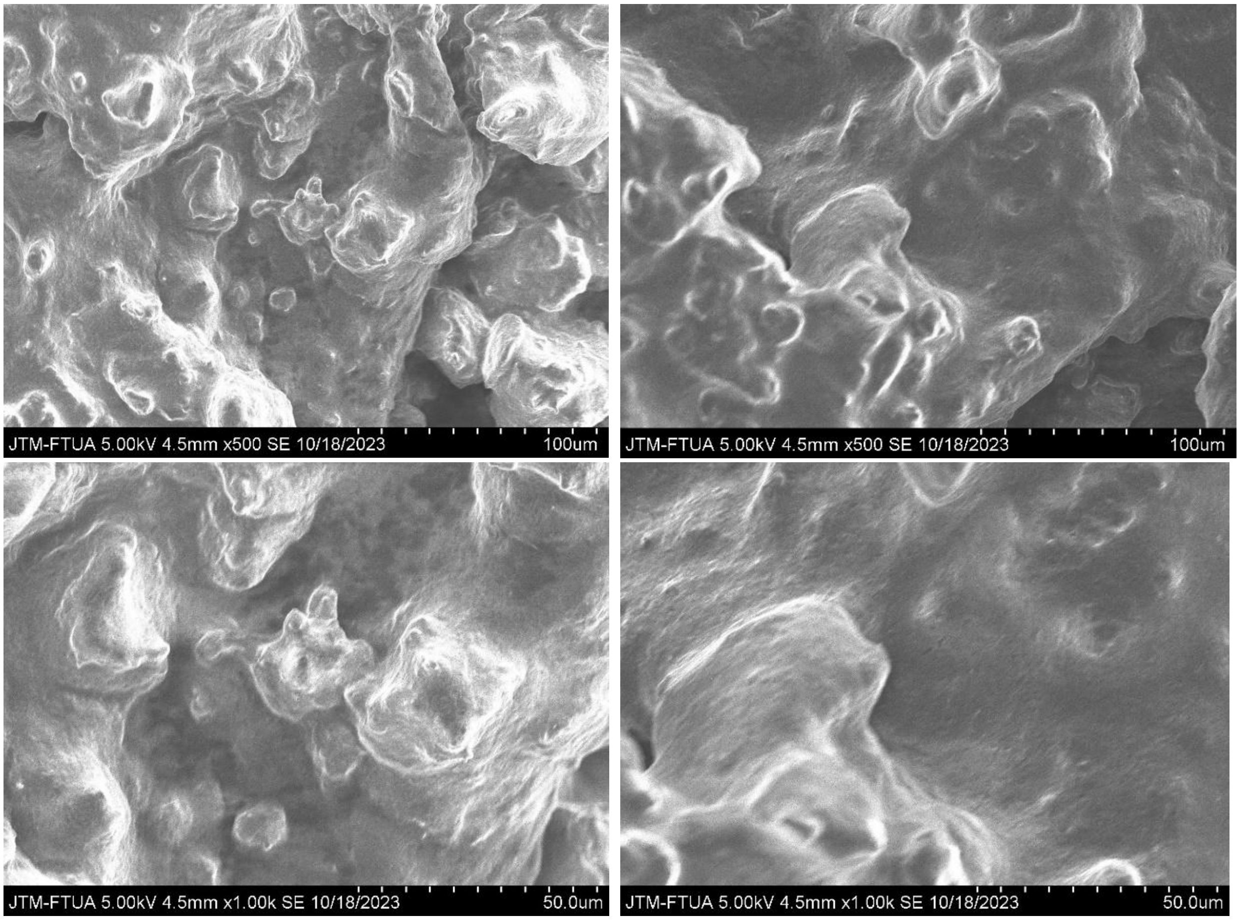
3.2 Scanning Electron Microscope (SEM) Analysis

3.2.1 Control

Cross-section of puff pastry analyzed using Scanning Electron Microspy (SEM). SEM instrument is most often used to study changes in the internal structure of puff pastry such as changes in cell size, density, uniformity, which affect the sensory properties of puff pastry. Structural analysis using SEM was carried out on the surface of "Puff Pastry" baked using a conventional oven with magnifications of 250, 500, 1000 times and resolutions of 50, 100, and 200 with a depth of field of ±4.5 mm.

Figure 7 shows the SEM analysis of the control puff pastry showing differences in the structure of puff pastry aged 0 days and 5 days. At magnifications of 250, 500 and 1000 the structure and curves of the puff pastry gradually decreased.





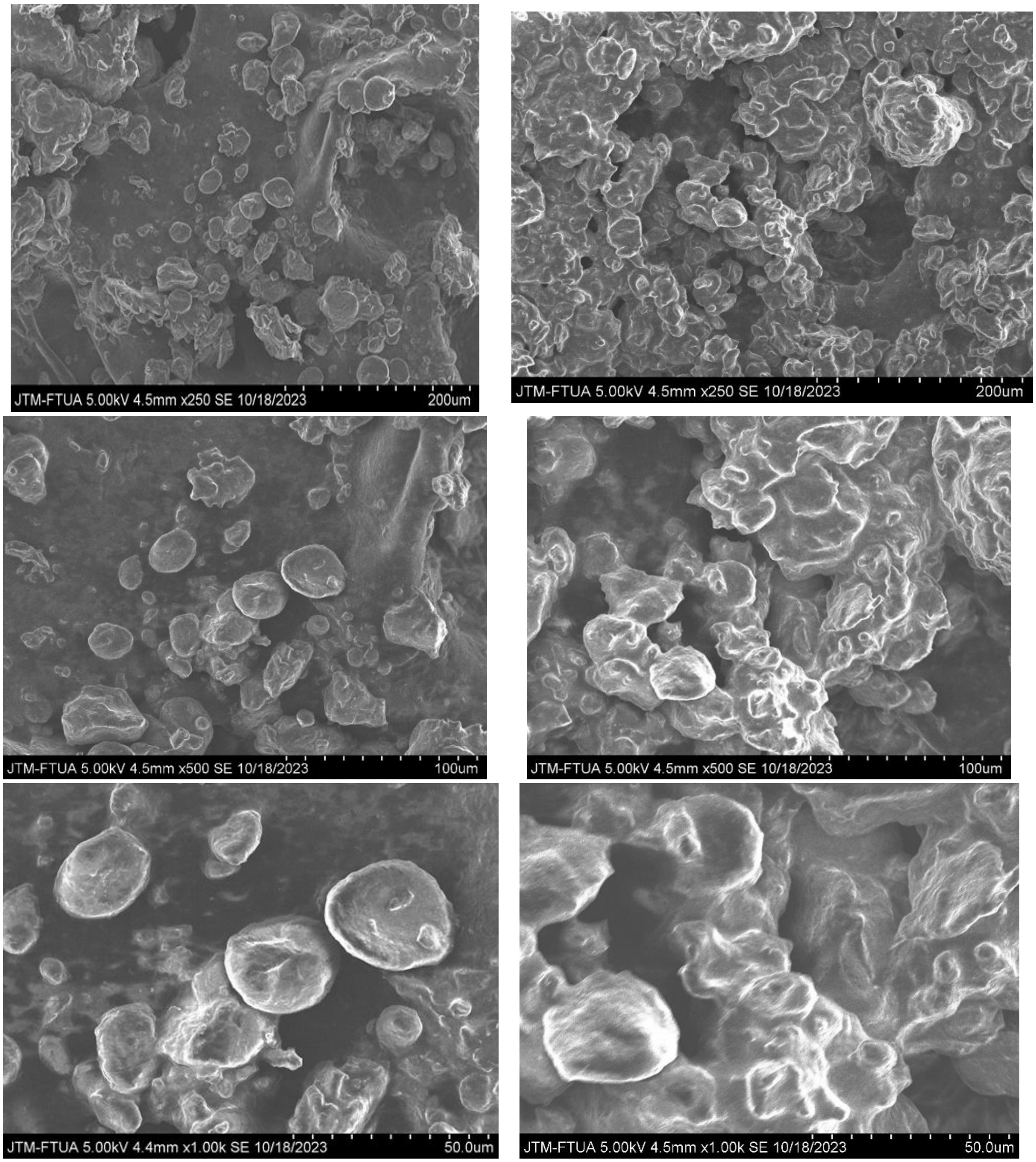
(a) (b)

Figure 7.**(a)** Scanning puff pastry control 0 day **(b)** Scanning puff pastry control 5 days

3.2.1 Corn

The results of the SEM analysis provide a deeper picture of the changes in the internal structure of the control and corn puff pastry. In the control puff pastry, the layer structure is seen more clearly with more defined gaps, especially on the 5th day. In contrast, corn puff pastry at magnifications of 250, 500, and 1000 times showed that the layer structure tends to be more porous and abstract, with non-uniform cavity sizes. The structure of corn on the 5th day showed an increase in porosity and clarity of the layer, but not as good as the control.

This finding can be explained by the theory of the effect of ingredient substitution on the microscopic structure of food products. Because corn has a higher starch content and lower gluten, its structure tends to be more fragile and inelastic, making it difficult to form the smooth layers required in puff pastry. The substitution of wheat flour with low-gluten ingredients resulted in a more porous and less stable structure [24-26].



(a) (b)

Figure 8.**(a)** Scanning puff pastry corn 0 day **(b)** Scanning puff pastry corn5 days

3.3 Nutritional Content

From the analysis of nutritional content, puff pastry with corn substitution showed an increase in water, ash, and protein content, but a decrease in fat and carbohydrate content compared to the control. The increase in water content may be due to the ability of corn to absorb more water than wheat flour, which directly affects the final texture of the product. The decrease in fat and carbohydrate content in corn puff pastry indicates that the use of corn can reduce the caloric value of the product, which can be an added value in the context of healthy food products.

Table 2. The analysis of nutritional content

	Water content (%)	Ash Content (%)	Fat Content (%)	Carbohydrate Content (%)	Protein Content (%)	Antioxidant Activity IC50 Value (ppm))
Control	3.30	0.41	31.09	58.42	6.77	38771.85
Corn	10.25	1.66	24.75	54.44	8.41	40626.86

The increase in protein content in corn puff pastry is a little surprising, considering that corn generally contains less protein than wheat flour [27-28]. However, this may be explained by an increase in the proportion of other components in the dough formula, or the presence of other factors in processing that affect the final chemical composition.

Corn substitution in puff pastry affects several important aspects of the product, including texture, layer structure, and nutritional content. This study was able to answer the research objective, namely to understand the impact of corn substitution on the quality of puff pastry. Although corn puff pastry is not fully able to match the structure of wheat flour-based puff pastry, these findings indicate that substitute products still have commercial potential, especially in the context of developing healthier local food products.

Substitution of wheat flour with corn in bakery products can increase nutritional value without significantly reducing sensory quality [29][30]. In addition, these findings also strengthen the theory of ingredient substitution in the food industry, which shows that changes in the composition of raw materials will affect the overall physical and chemical properties of the product [31-32].

In a practical context, the results of this study provide a strong foundation for the food industry to consider using corn as a substitute ingredient in pastry products. Although there are some challenges in terms of layer structure and texture, further development in processing techniques can help maximize the potential of corn as a basic ingredient for puff pastry.

4. Conclusion

The use of corn flour as a substitute for wheat flour in making puff pastry has a significant impact on the structure and texture of the product. The results of microscopic analysis showed that puff pastry with corn substitution had a less defined layer structure and higher porosity than the wheat flour-based control puff pastry. However, after 5 days of storage, the corn puff pastry showed better development of a hollow structure, although it was still not as smooth as the control puff pastry. Through SEM analysis, it was seen that the microscopic structure of the corn puff pastry had non-uniform cavities and porosity and was rougher than the control puff pastry. Over time, the corn structure tended to become more porous, but did not show the formation of smooth layers that are characteristic of wheat-based puff pastry.

In terms of nutritional content, puff pastry substituted with corn showed an increase in water, ash, and protein content, while fat and carbohydrate content tended to be lower compared to the control. This shows the potential of corn puff pastry as a lower-calorie food product, which may be more in line with consumer trends that prioritize healthy food products. Although corn substitution affects the texture and visual quality of puff pastry, this product still has potential for further development. This study supports the theory that substitution of raw materials in food products can affect physical properties, texture, and nutritional content. In the context of utilizing local food materials and diversifying healthier food products, corn shows great potential as a viable alternative raw material.

References

[1] Serna-Saldivar, S. O., & Carrillo, E. P. (2019). Food uses of whole corn and dry-milled fractions. In *Corn* (pp. 435-467). AACC International Press.

[2] Harmayani, E., Lestari, L. A., Sari, P. M., & Gardjito, M. (2017). Local food diversification and its (sustainability) challenges. *Sustainability Challenges in the Agrofood Sector*, 119-149.

[3] Rawat, N., & Indrani, D. (2015). Functional ingredients of wheat-based bakery, traditional, pasta, and other food products. *Food Reviews International*, *31*(2), 125-146.

[4] Dana, H., & Sonia, A. (2024). Substituting sugar in pastry and bakery products with functional ingredients. *Applied Sciences*, *14*(18), 8563.

[5] Zhang, R., Ma, S., Li, L., Zhang, M., Tian, S., Wang, D., ... & Wang, X. (2021). Comprehensive utilization of corn starch processing by-products: A review. *Grain & Oil Science and Technology*, *4*(3), 89-107.

[6] Pruett, A., Aramouni, F. M., Bean, S. R., & Haub, M. D. (2023). Effect of flour particle size on the glycemic index of muffins made from whole sorghum, whole corn, brown rice, whole wheat, or refined wheat flours. *Foods*, *12*(23), 4188.

[7] Chavan, J. K., Kadam, S. S., & Reddy, N. R. (1993). Nutritional enrichment of bakery products by supplementation with nonwheat flours. *Critical Reviews in Food Science & Nutrition*, *33*(3), 189-226.

[8] Gebreil, S. Y., Ali, M. I. K., & Mousa, E. A. M. (2020). Utilization of amaranth flour in preparation of high nutritional value bakery products. *Food and Nutrition Sciences*, *11*(5), 336-354.

[9] Balestra, F. (2009). Empirical and fundamental mechanical tests in the evaluation of dough and bread rheological properties.

[10] Khamidah, A., & Antarlina, S. S. (2022, December). Corn flour substitution at pastry production. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1107, No. 1, p. 012058). IOP Publishing.

[11] Sharma, V., & Bhardwaj, A. (2019). Scanning electron microscopy (SEM) in food quality evaluation. In *Evaluation technologies for food quality* (pp. 743-761). Woodhead Publishing.

[12] Patil, V., & Nikam, P. (2019). Development and quality evaluation of puff pastry (Fenugreek). *International Journal of Chemical Studies*, *7*(1), 2490-2493.

[13] Chlebana, R. A. (2025). *The Advanced Art of Baking and Pastry*. John Wiley & Sons.

[14] Lefébure, É., Ronkart, S., Brostaux, Y., Béra, F., Blecker, C., & Danthine, S. (2013). Investigation of the influence of processing parameters on physicochemical properties of puff pastry margarines using surface response methodology. *LWT-Food Science and Technology*, *51*(1), 225-232.

[15] Tanislav, A. E., Șandru, B., Man, S. M., Pușcaș, A., Mureșan, A. E., Păucean, A., ... & Mudura, E. (2024). Investigating the complete replacement of conventional fat with oleogel on the structural behavior of five different pastry products. *European Food Research and Technology*, *250*(7), 1933-1947.

[16] Abah, C. R., Ishiwu, C. N., Obiegbuna, J. E., & Oladejo, A. A. (2020). Nutritional composition, functional properties and food applications of millet grains. *Asian Food Science Journal*, *14*(2), 9-19.

[17] Renzetti, S., de Harder, R., & Jurgens, A. (2016). Puff pastry with low saturated fat contents: The role of fat and dough physical interactions in the development of a layered structure. *Journal of Food Engineering*, *170*, 24-32.

[18] Silow, C., Zannini, E., Axel, C., Lynch, K. M., & Arendt, E. K. (2016). Effect of salt reduction on wheat-dough properties and quality characteristics of puff pastry with full and reduced fat content. *Food Research International*, *89*, 330-337.

[19] Gómez, M. (2022). Gluten-free bakery products: Ingredients and processes. In *Advances in food and nutrition research* (Vol. 99, pp. 189-238). Academic Press.

[20] Houben, A., Höchstötter, A., & Becker, T. (2012). Possibilities to increase the quality in gluten-free bread production: an overview. *European Food Research and Technology*, *235*(2), 195-208.

[21] Casper, J. L., & Atwell, W. A. (2016). *Gluten-free baked products*. Elsevier.

[22] Haros, C. M., & Sanz-Penella, J. M. (2017). Food uses of whole pseudocereals. *Pseudocereals: chemistry and technology*, 163-192.

[23] Serna-Saldivar, S. O., & Carrillo, E. P. (2019). Food uses of whole corn and dry-milled fractions. In *Corn* (pp. 435-467). AACC International Press.

[24] Jan, N., Naik, H. R., Gani, G., Bashir, O., Amin, T., Wani, S. M., & Sofi, S. A. (2022). Influence of replacement of wheat flour by rice flour on rheo-structural changes, in vitro starch digestibility and consumer acceptability of low-gluten pretzels. *Food Production, Processing and Nutrition*, *4*(1), 9.

[25] Jongsutjarittam, N., & Charoenrein, S. (2013). Influence of waxy rice flour substitution for wheat flour on characteristics of batter and freeze-thawed cake. *Carbohydrate polymers*, *97*(2), 306-314.

[26] Biduski, B., Maçãs, M., Vahedikia, N., O'Connor, P. M., Hussey, K., Simpson, J. C., ... & Gallagher, E. (2024). Dough rheology and internal structure of bread produced with wheat flour partially substituted by buckwheat flour: A step towards enhancing nutritional value. *Food Structure*, *39*, 100364.

[27] Haros, C. M., & Sanz-Penella, J. M. (2017). Food uses of whole pseudocereals. *Pseudocereals: chemistry and technology*, 163-192.

[28] Serna-Saldivar, S. O. (Ed.). (2018). *Corn: chemistry and technology*. Elsevier.

[29] Siddiqui, S. A., Mahmud, M. C., Abdi, G., Wanich, U., Farooqi, M. Q. U., Settapramote, N., ... & Wani, S. A. (2022). New alternatives from sustainable sources to wheat in bakery foods: Science, technology, and challenges. *Journal of Food Biochemistry*, *46*(9), e14185.

[30] Alpaslan, M., & Hayta, M. (2006). The effects of flaxseed, soy and corn flours on the textural and sensory properties of a bakery product. *Journal of food quality*, *29*(6), 617-627.

[31] Sun-Waterhouse, D., Zhao, M., & Waterhouse, G. I. (2014). Protein modification during ingredient preparation and food processing: approaches to improve food processability and nutrition. *Food and Bioprocess Technology*, *7*(7), 1853-1893.

[32] Offiah, V., Kontogiorgos, V., & Falade, K. O. (2019). Extrusion processing of raw food materials and by-products: A review. *Critical reviews in food science and nutrition*, *59*(18), 2979-2998.