

PHYSICAL, CHEMICAL CHARACTERISTICS, AND MICROSTRUCTURE OF WHEAT-MOCAF COOKIES WITH ADDITION OF BLACK TEA POWDER

[*Karakteristik Fisik, Kimia, dan Struktur Mikro Cookies Terigu-Mocaf dengan Penambahan Bubuk Teh Hitam*]

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ABSTRACT

Typically made from wheat flour, cookies can also be prepared using alternative ingredients such as tubers, nuts, or fruit flour. A promising substitute for wheat flour is mocaf. Since black tea powder is highly antioxidants, it can be a potential source as the ingredients in the nutritional cookies. This study aims to evaluate the effects of adding black tea powder of different grades—Broken Orange Pekoe (BOP), Broken Orange Pekoe Fanning (BOPF), and Pekoe Fanning (PF)—at concentrations of 2%, 4%, and 6% on the physical and chemical properties, antioxidant activity, and microstructure of wheat–mocaf cookies. The experimental design of this study used a completely randomized design. Cookies were tested for its hardness, spread ratio, color (L^* , a^* , b^*), antioxidant activity, and microstructure. The results reveal that hardness increases with the addition of black tea powder concentration at each grade, with the highest being 6% BOP at 3,871.83 g. The increase in tea concentration reduces the expansion rate of cookies in all tea grades. The addition of black tea powder decreases the L^* , a^* , b^* values, making the product darker, less red, and less yellow. Wheat-mocaf cookies with 4% PF added yielded cookies with a compact microstructure and high antioxidant activity of 28.45% RSA. Thus, cookies made with mocaf substitution and the addition of black tea powder affect the physical and chemical properties and enhance the nutritional value, making them functional cookies.

Keywords: antioxidant activity, black tea, cookies, microstructure.

ABSTRAK

Cookies umumnya terbuat dari tepung terigu, namun juga dapat dibuat menggunakan bahan alternatif seperti tepung umbi-umbian, kacang-kacangan, atau buah-buahan. Salah satu alternatif tepung terigu yang menjanjikan adalah mocaf. Bubuk teh hitam kaya akan antioksidan sehingga berpotensi sebagai bahan pembuatan cookies bernutrisi. Penelitian ini bertujuan untuk mengevaluasi pengaruh penambahan bubuk teh hitam dengan kualitas berbeda—Broken Orange Pekoe (BOP), Broken Orange Pekoe Fanning (BOPF), dan Pekoe Fanning (PF)—pada konsentrasi 2%, 4%, dan 6% terhadap sifat fisik, kimia, aktivitas antioksidan, serta mikrostruktur cookies terigu–mocaf. Rancangan percobaan dalam penelitian ini menggunakan Rancangan Acak Lengkap. Cookies diuji kekerasan, tingkat pengembangan, warna (nilai L^* , a^* , b^*), aktivitas antioksidan, serta mikrostrukturnya. Hasil penelitian menunjukkan bahwa kekerasan meningkat seiring dengan penambahan konsentrasi bubuk teh hitam semua kualitas, dengan nilai tertinggi dicapai oleh BOP 6% sebesar 3.871,83 g. Peningkatan konsentrasi teh menurunkan daya kembang cookies pada semua kualitas teh. Penambahan bubuk teh hitam menurunkan nilai L^* , a^* , b^* , sehingga produk menjadi lebih gelap, kurang merah, dan kurang kuning. Cookies terigu-mocaf dengan penambahan 4% PF menghasilkan cookies dengan mikrostruktur kompak dan aktivitas antioksidan tinggi sebesar 28,45% RSA. Dengan demikian, cookies terigu-mocaf dengan penambahan bubuk teh hitam memengaruhi karakteristik fisik dan kimianya serta meningkatkan nilai gizi, sehingga menjadikannya cookies fungsional.

Kata Kunci: Aktivitas antioksidan, cookies, mikrostruktur, teh hitam.

INTRODUCTION

Cookies are flour-based food products widely consumed by people of all ages due to their appealing taste, crisp texture, and relatively long shelf life. Generally, cookies are made using wheat flour derived from wheat (Kristanti et al., 2020). The high consumption of wheat flour-based products in Indonesia is reflected in the volume of wheat imports, which reaches 11.4 million tons per year (Badan Pusat Statistik Indonesia, 2023). This situation arises because Indonesia is not a wheat-producing country, so the entire demand for wheat flour raw materials remains dependent on imports. Additionally, wheat flour consumption in Indonesia is reported to have increased by up to 500% over the past 30 years (Pradeksa et al., 2016).

The use of wheat flour as the main ingredient in cookies has several limitations, one of which is its gluten content, which cannot be consumed by individuals who are gluten-sensitive. Therefore, it is necessary to substitute wheat flour with gluten-free flour so that cookies can be enjoyed by a wider audience. One potential alternative is modified cassava flour (mocaf) (Hasmi et al., 2021). Mocaf is known to have a higher fiber content and has the potential to enhance nutritional value and support digestive health (Zaman et al., 2019). Additionally, the use of mocaf contributes to the utilization of local food resources (Sari, 2020). To improve the functional characteristics of cookies, it is necessary to add other ingredients rich in bioactive compounds, one of which is black tea powder. Black tea is the most widely consumed type of tea in Indonesia and is known to contain polyphenolic compounds such as theaflavins and thearubigins, which act as antioxidants (Nugraha et al., 2017; Wibowo et al., 2022).

Several previous studies have reported the development of mocaf-based cookies with the addition of green tea powder. Sari (2020) reported that the addition of 2%, 4%, and 6% green tea powder to mocaf cookies had a significant effect on protein and carbohydrate content, antioxidant activity, total polyphenols, and textural properties, but did not significantly affect moisture, ash, and fat content. Ahmad et al. (2015) also reported that green tea powder can be used as a natural additive in bakery products, capable of improving viscoelastic properties, dough stability, as well as sensory characteristics and antioxidant activity. Additionally, Diniyah et al. (2019) stated that the addition of green tea to cookies can inhibit the fat oxidation process. However, research on wheat-mocaf cookies with the addition of black tea powder remains limited. Variations in tea types—Broken Orange Pekoe (BOP), Broken Orange Pekoe Fanning (BOPF), and Pekoe Fanning (PF)—and concentrations (2%, 4%, and 6%) of black tea powder are suspected to influence the physical and chemical properties, antioxidant activity, and microstructure of the resulting wheat-mocaf cookies; therefore, further research is needed.

MATERIALS AND METHODS

Materials

The ingredients used in this study were wheat flour (Kunci Biru) and Mocaf (Point), as well as three grades of black tea: BOP (Broken Orange Pekoe), BOPF (Broken Orange Pekoe Fanning), and PF (Pekoe Fanning) produced by PT. Pagilaran. Butter (Royal Krone), sugar, salt, baking powder (Kopoe), and skim milk (Lactona) used in the production of cookies purchased at commercial retail stores.

Equipment used includes electric oven (Kirin, Japan), blender (Miyako, Japan), 60-mesh sieve, mixer (Miyako, Japan), mixing bowls, baking pans, and cookie cutters. The analytical instruments used include analytical balance, texture analyzer (CT3 Texture Analyzer Brookfield, USA), desiccator, mini UV-Vis spectrophotometer (Shimadzu 1240, Japan), High Quality Colorimeter (NH 310, China), and Scanning Electron Microscope (JEOL SM 6510 SEM, Japan).

Methods

This study was conducted using a completely randomized design (CRD) with 10 treatments. The experimental design for the study on wheat-mocaf cookies with added black tea is shown in Table 1. All treatments were replicated twice, resulting in a total of 20 experimental units.

Table 1. Experimental Design for Wheat-Mocaf Cookies with Added Black Tea

Code	Flour and Black Tea Formulations (Black Tea Grade and Concentration)
P1	Wheat 100% (Control)
P2	Wheat 75% : Mocaf 25% + BOP 2%
P3	Wheat 75% : Mocaf 25% + BOP 4%
P4	Wheat 75% : Mocaf 25% + BOP 6%
P5	Wheat 75% : Mocaf 25% + BOPF 2%
P6	Wheat 75% : Mocaf 25% + BOPF 4%
P7	Wheat 75% : Mocaf 25% + BOPF 6%
P8	Wheat 75% : Mocaf 25% + PF 2%
P9	Wheat 75% : Mocaf 25% + PF 4%
P10	Wheat 75% : Mocaf 25% + PF 6%

Note: BOP = Broken Orange Pekoe, BOPF = Broken Orange Pekoe Fanning, PF = Pekoe Fanning

Production of Wheat-Mocaf Cookies with Added Black Tea

The ingredients for making wheat-mocaf cookies with added black tea were weighed based on the formulation in Table 2. Butter, salt, powdered sugar, baking soda, and skim milk, were mixed with a mixer on medium speed until smooth. Then vanillin was added and mixed at medium speed; next, eggs were added and mixed at low speed; and finally, wheat flour and mocaf were added and mixed at low speed. The next step involved adding black tea that had been sifted through a 60-mesh BOP, BOPF, or PF sieve (at 2%, 4%, and 6% of the total flour amount). After that, the dough is shaped into circles weighing 5 g each, arranged on a baking sheet, and then baked in an electric oven at 170°C for 20–25 minutes until cookies are produced.

Table 2. Formulation of Wheat-Mocaf Cookies with Added Black Tea

Ingredients (g)	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
Wheat flour	100	75	75	75	75	75	75	75	75	75
Mocaf	0	25	25	25	25	25	25	25	25	25
BOP powder	0	2	4	6	0	0	0	0	0	0
BOPF powder	0	0	0	0	2	4	6	0	0	0
PF powder	0	0	0	0	0	0	0	2	4	6
Powdered sugar	30	30	30	30	30	30	30	30	30	30
Butter	45	45	45	45	45	45	45	45	45	45
Salt	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5
Skim milk	4	4	4	4	4	4	4	4	4	4
Egg	60	60	60	60	60	60	60	60	60	60
Vanillin	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5
Baking powder	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6
Total	300,6	302,6	304,6	306,6	302,6	304,6	306,6	302,6	304,6	306,6

Characterization of Wheat-Mocaf Cookies with Added Black Tea

1. The rate of cookie expansion was determined by measuring the diameter of raw and baked cookies using a caliper (Oktaviana et al., 2017). The average cookie expansion rate was then calculated using Equation (1).

$$\text{Expansion rate (\%)} = \frac{\text{diameter of baked cookies (cm)}}{\text{diameter of raw cookies (cm)}} \times 100\% \quad (1)$$

2. The hardness testing of wheat-mocaf cookies with added black tea was conducted using a texture analyzer (Brookfield CT3 Texture Analyzer). The measurement results, presented as graphs, can be saved or printed.
3. Color testing was conducted using a High-Quality Colorimeter NH 310 to measure the L, a, and b values of wheat-mocaf cookies with added black tea. The L* value (0–100) indicates lightness; a

positive a* value (0–80) indicates red, while a negative a* value indicates green. The b* value (0–70) indicates that a positive b value means yellow, while a negative b value means blue (Budoyo, 2017).

- The antioxidant activity of wheat-mocaf cookies with added black tea was determined using a modified method (Xu and Chang, 2007). A 0.2 mL sample was mixed with 0.1 mM DPPH solution, vortexed for 1 minute, and incubated at room temperature in the dark for 30 minutes. Absorbance was measured at λ 517 nm. A blank (control) was prepared using ethanol as a substitute for the sample. Free radical scavenging capacity is expressed as %RSA (Radical Scavenging Activity), which is the percentage of DPPH decolorization. %RSA was calculated using Equation (2).

$$\%RSA = 1 - \frac{\text{Sample absorbance}}{\text{Control absorbance}} \times 100\% \quad (2)$$

- The results of the wheat-mocaf cookies with the addition of selected black tea (samples with optimal physical and chemical test results for each grade and a 4% black tea addition concentration) were examined using SEM (Scanning Electron Microscopy) to determine the surface structure of the wheat-mocaf cookies with black tea added. SEM is an imaging technique that uses an electron beam to produce high-resolution (up to <1 nm) topographic images of a sample's surface. SEM not only reveals the shape and outer surface but also exposes pores, cracks, density, and particle interactions (Meti et al., 2023).

Data Analysis

This study was designed as a completely randomized design (CRD). All treatments were replicated twice, resulting in 20 experimental units. The data were analyzed using univariate analysis and ANOVA (analysis of variance) with SPSS 23. If the differences between parameters were significant, a Duncan Multiple Range Test (DMRT) was conducted at the 5% significance level.

RESULTS AND DISCUSSION

Expansion Rate of Wheat-Mocaf Cookies with Added Black Tea

The expansion rate is used to measure the expansion capacity of flour-based or starch-based products (Herlina et al., 2021). Based on Table 3, the expansion rate of cookies in the BOP grade ranged from 107.19–108.99%, while the BOPF and PF grades showed expansion rates of 109.83–111.22% and 108.24–111.46%, respectively. This indicates that with each addition of black tea grade and an increase in concentration, the expansion rate of the cookies decreases.

Table 3. Expansion Rate and Hardness of Wheat-Mocaf Cookies with Added Black Tea

Treatment	Expansion Rate (%)	Hardness (g)
Wheat 100% (Control)	105,02±2,15 ^a	2742±42,00 ^e
Wheat 75% : Mocaf 25% + BOP 2%	108,99±2,61 ^c	2160,67±96,11 ^c
Wheat 75% : Mocaf 25% + BOP 4%	108,45±2,37 ^{bc}	2151,67±140,47 ^c
Wheat 75% : Mocaf 25% + BOP 6%	107,19±1,62 ^b	3871,83±190,39 ^f
Wheat 75% : Mocaf 25% + BOPF 2%	111,22±1,54 ^{de}	1574,17±123,01 ^a
Wheat 75% : Mocaf 25% + BOPF 4%	110,98±2,71 ^{de}	1568,33±81,58 ^a
Wheat 75% : Mocaf 25% + BOPF 6%	109,83±1,32 ^{cd}	2626,83±5,39 ^{de}
Wheat 75% : Mocaf 25% + PF 2%	111,46±1,79 ^f	1854,17±74,68 ^b
Wheat 75% : Mocaf 25% + PF 4%	109,14±1,65 ^c	2491,83±54,5 ^d
Wheat 75% : Mocaf 25% + PF 6%	108,34±1,06 ^{bc}	2423±252,24 ^d

Note: BOP = Broken Orange Pekoe, BOPF = Broken Orange Pekoe Fanning, PF = Pekoe Fanning. Different lowercase superscripts indicate significant differences within the same column ($p < 0.05$).

Girard et al. (2016) confirmed that catechins have several positive effects on improving gluten elasticity in dough due to their monomeric structure. It is possible that the addition of catechins

contributes to improved bread rise if their function is maintained well during the baking process, consistent with the control cookies, which exhibited lower rise due to the absence of black tea compared to the wheat-mocaf cookies with added black tea.

According to Ning et al. (2017), green tea powder at a concentration of 2–4 g per 100 g of flour significantly reduces bread rise. There are several possible reasons for this reduction in bread rise: green tea powder dilutes the gluten and reduces the interaction between the fiber, fat, water, and gluten components.

Hardness of Wheat-Mocaf Cookies with Added Black Tea

Based on Table 3, generally, as the concentration of black tea added increased, the cookie's hardness tended to increase. The highest hardness value with added BOP was found in the wheat-mocaf cookie sample with 6% BOP concentration, at 3,871.83 g, while the lowest value was found in the wheat-mocaf cookie sample with 2% BOP concentration, at 2,160.67 g. The highest hardness value with added BOPF was found in the wheat-mocaf cookie sample with 6% BOPF concentration, at 2,626.83 g, while the lowest value was found in the wheat-mocaf cookie sample with 4% BOPF concentration, at 1,568.33 g. The highest hardness value with added PF was found in the wheat-mocaf cookie sample with 4% PF concentration, at 2,491.83 g, and the lowest at 2% PF concentration, at 1,854.17 g.

There was no significant difference between the wheat-mocaf cookies with 2% BOP and those with 4% BOP, whereas wheat-mocaf cookies with 6% BOP concentration were significantly different from wheat-mocaf cookies with 2% BOP concentration, 4% BOP concentration, and the control. There was no significant difference between the wheat-mocaf cookies with 2% BOPF and those with 4% BOPF, whereas wheat-mocaf cookies with 6% BOPF concentration were significantly different from those two treatments. There was also no significant difference between the wheat-mocaf cookies with 4% PF and those with 6% PF, whereas wheat-mocaf cookies with 2% PF concentration were significantly different from those two treatments.

Cookies with increasingly hard or soft textures indicate poorer quality (Sari et al., 2022). The texture of cookies is influenced by the ingredients and preparation techniques. Sugar content, flour type, fat content, and dough temperature determine whether the cookies will be crispy, soft, or chewy (Ardian et al., 2022). According to Ning et al. (2017), the addition of green tea powder caused the cellulose fibers to intertwine, forming a denser network structure. Similar to the bread's firmness, its chewiness gradually increased with the amount of green tea powder added. Texture can be assessed by biting, chewing, and touching (Imawan et al., 2020). Adding green tea powder to cookies can increase hardness. The more green tea powder added, the higher the hardness value obtained (Sari, 2020).

Color of Wheat-Mocaf Cookies with Added Black Tea

The color of wheat-mocaf cookies with added black tea was measured using a colorimeter, yielding three parameters: L*, a*, and b*. The L* (Lightness) value indicates the brightness or lightness of a color on a scale of 0 to 100. The higher the a* value, the redder the measured color. Conversely, the lower the a* value, the less red or greener the color (Mudau et al., 2021). The b* value (Yellowness) measures how yellow or blue an object is. A positive value indicates a tendency toward yellow, while a negative value indicates a tendency toward blue. Higher values indicate a lighter color, while lower values indicate a darker color, as shown in Figure 1.

Based on Table 4, the L*, a*, and b* values of the wheat-mocaf cookies with 2% BOP showed a fairly light color, with a reddish and yellowish hue. The wheat-mocaf cookies with 4% BOP showed a slightly darker color, with less of a reddish and yellowish hue. Wheat-mocaf cookies with a 6% BOP concentration were darker in color than the previous ones, with a further reduction in the intensity of the red and yellow hues. The wheat-mocaf cookies with 2% BOPF or PF also appeared darker than

the control, with a slightly reddish and yellowish hue. The wheat-mocaf cookies with 4% and 6% BOPF/PF showed increasingly darker colors, with the intensity of the reddish and yellowish hues continuously decreasing as the concentration of added black tea increased.

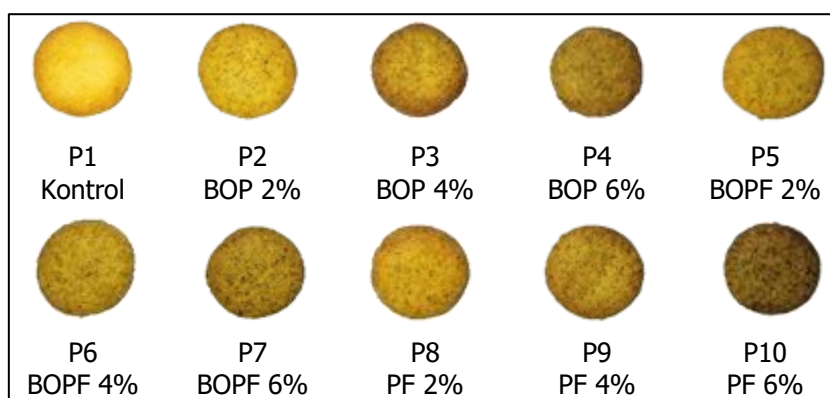


Figure 1. Wheat-mocaf cookies with added black tea

Table 4. Results of Colorimeter Tests on Wheat-Mocaf Cookies with Added Black Tea

Treatment	L* (lightness)	a* (redness)	b* (yellowness)
Wheat 100% (Control)	66.89±0.02 ^j	8.77±0.08 ^h	23.26±0.07 ⁱ
Wheat 75% : Mocaf 25% + BOP 2%	57.22±0.09 ^f	7.36±0.04 ^g	18.64±0.04 ^f
Wheat 75% : Mocaf 25% + BOP 4%	56.58±0.14 ^e	5.58±0.01 ^e	16.83±0.1 ^d
Wheat 75% : Mocaf 25% + BOP 6%	53.9±0.07 ^b	5.20±0.04 ^c	15.05±0.03 ^b
Wheat 75% : Mocaf 25% + BOPF 2%	59.88±0.12 ^h	6.32±0.07 ^f	19.34±0.04 ^g
Wheat 75% : Mocaf 25% + BOPF 4%	57.72±0.12 ^g	5.57±0.08 ^e	17.7±0.11 ^e
Wheat 75% : Mocaf 25% + BOPF 6%	54.45±0.09 ^c	5.04±0.02 ^b	15.83±0.02 ^c
Wheat 75% : Mocaf 25% + PF 2%	60.70±0.19 ⁱ	5.40±0.08 ^d	19.91±0.18 ^h
Wheat 75% : Mocaf 25% + PF 4%	55.20±0.13 ^d	5.16±0.01 ^c	15.95±0.09 ^c
Wheat 75% : Mocaf 25% + PF 6%	52.81±0.17 ^a	4.80±0.04 ^a	14.80±0.13 ^a

Note: BOP = Broken Orange Pekoe, BOPF = Broken Orange Pekoe Fanning, PF = Pekoe Fanning. Different lowercase superscripts indicate significant differences within the same column ($p < 0.05$).

Compounds formed as a result of the Maillard reaction contribute to a decrease in brightness (Salma et al., 2024). The Maillard reaction occurs due to the interaction between the carbonyl groups of sugars, particularly reducing sugars, and amino acids. Peptide groups cause the formation of a brown crust or skin during the baking process (Herawati et al., 2024). According to Ulandari et al. (2019), flavonoids give the brew a yellowish-brown color, which turns dark brown if further oxidation occurs.

The L* values of the wheat-mocaf cookies ranged from 52.81 to 66.89. The higher the concentration of tea added, the darker the cookies become, which means the L* value decreases. The a* (redness) values of mocaf cookies range from 4.8 to 8.77. Increasing the concentration of black tea powder in each grade results in a decrease in the a* (redness) value, meaning the color becomes less red. This is thought to be related to the increased content of black tea polyphenols (theaflavins and thearubigins) that undergo oxidation during baking, thereby dominating the dark brown color and suppressing the intensity of the red color. In this study, as the concentration of added black tea powder increased, the color of the cookies shifted toward dark brown rather than bright red. This change is believed to indicate the occurrence of the Maillard reaction and more intense oxidation of phenolic compounds during the baking process, thereby affecting the visual appearance of the cookies.

The b* values of wheat-mocaf cookies range from 14.8 to 23.26. The addition of black tea powder at various concentrations across each grade affects the Yellowness (b*) value. Rohdiana et al. (2013) state that black tea contains theaflavins and thearubigins, which can produce yellow and reddish-brown colors in the resulting products.

Antioxidant Activity of Wheat-Mocaf Cookies with Added Black Tea

Antioxidants, at certain concentrations, can inhibit or slow down damage caused by oxidative processes. Free radicals are reactive; if not neutralized, they can damage the macromolecules that make up cells—such as proteins, carbohydrates, fats, and nucleic acids—thereby potentially leading to degenerative diseases (Sayuti and Yenrina, 2015). The results of the antioxidant activity study on mocaf-substituted cookies with added black tea are presented in Table 5.

Table 5. Expansion Rate and Hardness of Wheat-Mocaf Cookies with Added Black Tea

Treatment	Antioxidant Activity (% RSA)
Wheat 100% (Control)	8.64±1.10 ^a
Wheat 75% : Mocaf 25% + BOP 2%	17.69±1.57 ^b
Wheat 75% : Mocaf 25% + BOP 4%	26.06±1.81 ^{cd}
Wheat 75% : Mocaf 25% + BOP 6%	26.71±1.87 ^{cd}
Wheat 75% : Mocaf 25% + BOPF 2%	18.33±0.54 ^b
Wheat 75% : Mocaf 25% + BOPF 4%	25.15±1.50 ^c
Wheat 75% : Mocaf 25% + BOPF 6%	29.89±1.81 ^e
Wheat 75% : Mocaf 25% + PF 2%	16.93±1.56 ^b
Wheat 75% : Mocaf 25% + PF 4%	28.45±1.22 ^{de}
Wheat 75% : Mocaf 25% + PF 6%	34.24±2.34 ^f

Note: BOP = Broken Orange Pekoe, BOPF = Broken Orange Pekoe Fanning, PF = Pekoe Fanning. Different lowercase superscripts indicate significant differences within the same column (p<0.05).

The antioxidant activity of wheat-mocaf cookies with added BOP black tea ranged from 17.69% to 26.71% RSA. Furthermore, the antioxidant activity of wheat-mocaf cookies with the addition of BOPF black tea was 18.33–29.89 %RSA, and for wheat-mocaf cookies with the addition of PF black tea, it was 16.91–34.24 %RSA. These results indicate that increasing the concentration of added black tea can enhance the antioxidant activity of the resulting wheat-mocaf cookies, whereas compared to the control cookies, they exhibit the lowest antioxidant activity. This is also consistent with the study by Anand et al. (2020), which found an increase in antioxidant activity in cookies with the addition of green tea at concentrations of 1 g (78.07%), 2 g (80.46%), 3 g (92.76%), 7 g (92.89%), and 10 g (94.35%), while the control group had 52%.

Microstructure of Wheat-Mocaf Cookies with Added Black Tea

Typical electron micrographs of cross-sections of each type of wheat-mocaf cookie with added black tea are shown in Figure 2. The effects of formulation variables and black tea grade influenced the appearance of the selected cookies; based on the results of physical and chemical tests, the optimal grade and concentration were set to 1, resulting in a total of three samples for microstructural analysis.

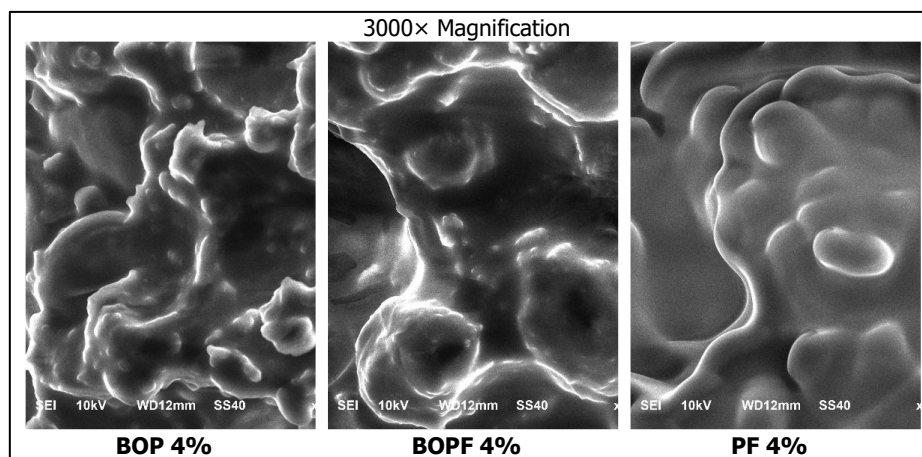


Figure 2. Scanning Electron Microscope images of wheat-mocaf cookies with added black tea

As the SEM magnification increases, it becomes apparent that the fibers form a more regular and denser network. This structure is influenced by the inherent porous nature of mocaf (Indrianingsih et al., 2024). The surface morphology of wheat-mocaf cookie with 4% BOP showed uneven particle distribution with large pores and tea-protein aggregates. The network structure exhibited microcracks resulting from the interaction of tea polyphenols with gluten. Mocaf starch crystals were observed to have irregular polyhedral shapes.

The pores in the wheat-mocaf cookies with 4% BOPF were smaller and more evenly distributed due to the fine particle size of the BOPF tea. The formation of protein-polyphenol complexes increased surface hardness. The structure of the wheat-mocaf cookies with 4% PF was the most compact, as evidenced by the PF particles being perfectly incorporated into the wheat-mocaf gluten network. According to Ahmad et al. (2015), the structural differences may be due to the presence of fibers and other components of green tea or the differential response of tea powder compared to wheat flour to the baking process. The presence of green tea in the cookies appears to disrupt the gluten-starch matrix.

CONCLUSION

Increasing the concentration (2%, 4%, and 6%) of three black tea grades in wheat-mocaf cookies can improve the antioxidant activity with the highest value of 34.24% RSA, increase the hardness to a maximum of 3,871.83 g, and reduce the expansion rate to a minimum of 107.19%. BOP and BOPF black tea grades caused microcracks due to polyphenol-gluten interactions and reduced homogeneity. The PF grade formed the most compact structure with the lowest surface roughness. The optimal formulation—wheat-mocaf cookies with a 4% PF addition—yielded cookies with a compact microstructure and high antioxidant activity of 28.45% RSA. This formulation supports the use of mocaf and black tea as alternatives to wheat flour, enhancing the functional value of fortified cookie products. Thus, cookies made with mocaf substitution and the addition of black tea powder affect the physical and chemical properties and enhance the nutritional value, making them functional cookies.

DECLARATION

Authors Contributions

All authors contributed equally as primary authors to this manuscript. All authors have read and approved the final version of the article.

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Conflict of Interest

The authors declare that they have no financial interests or competing personal relationships that could influence the content or results of this research.

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