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# Water Activity, Color, and Sensory Properties of Cookies Made with Protein-Adjusted Wheat Flour and Gembili (*Dioscorea esculenta*) or Ganyong (*Canna edulis* Kerr.) Flour Substitution

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**A B S T R A C T**

This study evaluates the physicochemical and sensory properties of soft cookies formulated with composite flours from gembili (Dioscorea esculenta) and ganyong (Canna edulis Kerr.) as partial substitutes for wheat flour. Four cookie formulations were prepared using 100% low-protein wheat flour, 100% medium-protein wheat flour, a 1:1 blend of medium-protein wheat flour and gembili flour, and a 1:1 blend of medium-protein wheat flour and ganyong flour. The cookies were analyzed for water activity (aw), color parameters (L*, a*, b*), organoleptic attributes (color, aroma, taste, texture), and overall hedonic acceptability. Results showed no significant differences in aw across treatments. Color analysis revealed darker coloration in cookies with gembili and ganyong flour, attributed to browning reactions and polyphenol content. Sensory evaluations indicated that cookies with 100% wheat flour (P1 and P2) had higher acceptability in taste, texture, and overall preference. Cookies containing tuber flours (P3 and P4) exhibited bitter taste, darker color, and harder texture, reducing consumer preference. These findings suggest that although gembili and ganyong flours offer potential as local alternative ingredients, optimization of their usage levels and pretreatments is necessary to enhance the sensory quality and consumer acceptance of cookies.

Keywords: *Canna edulis Kerr.,* cookies*, Dioscorea esculenta,* protein, sensory

## 1. Introduction

Cookies are one of the most popular baked goods globally due to their long shelf life, diverse flavors, and convenience as ready-to-eat snacks. Traditionally, cookies are made from wheat flour, sugar, fat, and other ingredients. Among these, flour serves as the structural foundation and plays a critical role in determining the final texture, mouthfeel, and appearance of the cookies (Boz, 2019). The quality and characteristics of cookies are highly influenced by the type of wheat flour used, particularly its protein content. Medium-protein wheat flour (approximately 10–12%) and low-protein wheat flour (below 10%) contribute differently to the dough development and the resulting cookie texture, spread, and hardness (Punia et al., 2017; Nandiyanto et al., 2022).

In recent years, increasing attention has been given to the use of alternative, underutilized tuber-based flours to diversify functional ingredients in baked products and promote local food sources (Setyawati et al., 2024; Nofiani et al., 2021; Mubarok et al., 2020; Putra et al., 2024). Among these, *Canna edulis* Kerr (locally known as ganyong) and *Dioscorea esculenta* (gembili) have drawn interest due to their availability, carbohydrate content, and potential to be processed into flour (Histifarina et al., 2022; Purwitasari et al., 2023; Sumardiono et al., 2023). Ganyong flour has been studied for its digestibility, moderate amylose content, and potential as a gluten-free ingredient. Similarly, gembili flour, known for its fine granule structure and slightly sweet taste, has been explored as a flour substitute in various traditional foods.

While various studies have explored the use of tuber-based flours like cassava, taro, and yam in cookies and other baked goods, limited research has addressed the application of ganyong (*Canna edulis* Kerr.) and gembili (*Dioscorea esculenta*) flours, particularly in combination with medium-protein wheat flour (Nugraheni et al., 2019; Sulistyawati et al., 2024; Dilek and Bilgiçli, 2021; Njeri, 2024). Most existing work focuses on the physicochemical and functional properties of these tubers or their use in simple or non-bakery food products, without fully examining their performance in baked systems such as cookies. Furthermore, few studies provide an integrated evaluation of both instrumental quality attributes such as water activity ($a_w$), which relates to microbial stability, and color values (L*, a*, b*), which affect consumer appeal and sensory characteristics (Tapia et al., 2020; Spence, 2015).

Organoleptic assessments (color, aroma, taste, and texture) along with overall hedonic scores are essential to understand consumer acceptance (Silva-Paz et al., 2024). A combined analysis of these parameters offers a comprehensive perspective on both technical performance and market potential. Therefore, this study aims to evaluate cookies made with four flour compositions: (1) medium-protein wheat flour, (2) low-protein wheat flour, (3) a

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blend of medium-protein wheat flour and gembili flour, and (4) a blend of medium-protein wheat flour and ganyong flour. The cookies were analyzed for water activity, color, and sensory attributes—covering both hedonic preferences and descriptive organoleptic properties. The findings are expected to support the development of nutritionally relevant, locally sourced, and consumer-acceptable cookie products while addressing gaps in the application of these underutilized tuber flours.

## 2. Material and Methods

### *2.1. Material and Tools*

The materials utilized in this study included *Canna edulis* Kerr. flour (Ganyong flour) and *Dioscorea esculenta* flour (Gembili flour) (Hasil Bumiku, from Indonesian e-commerce platforms, Indonesia), low-protein wheat flour (Bogasari Kunci Biru, Indonesia), medium-protein wheat flour (Bogasari Segitiga Biru, Indonesia), margarine (Blue Band, Indonesia), corn starch (Maizenaku, Indonesia), granulated sugar (Rose Brand, Indonesia), commercial-grade chicken eggs, vanilla extract, baking powder (Koepoe-Koepoe, Indonesia), and table salt, all of which were procured from a local baking supply store (Sumber Rejeki, Banyumanik, Semarang, Indonesia).

The equipment and instruments employed comprised a digital kitchen scale (Taffware, Indonesia), an analytical balance (Ohaus, USA), $a_w$ meter (Novasina, Switzerland), colorimeter (Konica Minolta, Japan), lightbox (Puluz, China), baking oven (Kris, Indonesia), freezer (Gea, Indonesia), measuring spoons, mixing bowls, spatulas, whisk, ice cream scoop, baking trays, plastic wrap, and baking paper.

### *2.2. Cookies Production*

The production of soft cookies was based on Sulistyawati et al. (2024) and Wibisono et al. (2021) with several modifications. Initially, all ingredients were prepared and weighed in separate containers according to the formulation, which consisted of four treatments: P1 (100% low-protein wheat flour), P2 (100% medium-protein wheat flour), P3 (a 1:1 ratio of medium-protein wheat flour and gembili flour), and P4 (a 1:1 ratio of medium-protein wheat flour and ganyong flour).

Margarine (90 g) and granulated sugar (90 g) were creamed until well combined. Egg (40 g) was beaten and added to the mixture along with vanilla extract (2 g), and mixed thoroughly until a homogenous batter was achieved. Dry ingredients, including wheat flour (depending on the treatment, in total 150 g), corn starch (20 g), baking powder (4 g), and salt (1 g), were sifted into the dough and incorporated evenly. The cookie dough was then covered with plastic wrap and refrigerated in a freezer for 45–60 minutes.

Meanwhile, the oven was preheated to 160–170°C. The chilled dough was portioned using an ice cream scoop and arranged on a baking tray lined with baking paper. The cookies were baked at 160–170°C for approximately 15 minutes. Subsequently, all samples from each treatment group were subjected to analysis for several parameters, including water activity ($a_w$), color, organoleptic and hedonic properties.

### *2.3. Water Activity ($a_w$)*

This method refers to the procedure described by Aozora et al. (2022). Water activity ($a_w$) is measured using a water activity meter. Prior to measurement, the instrument is calibrated using a standard distilled water until the device registers an $a_w$ value of 1.000 ± 0.003. The sample is first homogenized through mashing, after which approximately 2 g are transferred into a designated sample cup. The cup is then placed inside the $a_w$ meter. During the measurement process, progress is shown on the device's display. The measurement continues until the $a_w$ value stabilizes, which is signaled by an audible beep from the instrument. This signal indicates the completion of the measurement, and the final $a_w$ value is then displayed on the screen.

### *2.4. Color Analysis*

Color evaluation was carried out using a colorimeter in conjunction with a lightbox, yielding L*, a*, and b* values. The L* value indicates lightness, with a scale ranging from 0 (black) to 100 (white), representing achromatic brightness. The a* value reflects the red-green spectrum, where positive values (a+ = 0 to 100) correspond to red tones and negative values (a– = 0 to –80) indicate green tones. Similarly, the b* value represents the blue-yellow axis, with positive values (b+ = 0 to 70) denoting yellow hues and negative values (b– = 0 to –70) corresponding to blue hues. Color measurements were performed in triplicate (Engelen, 2018).

### *2.5. Organoleptic Properties*

Organoleptic testing is a type of sensory evaluation that utilizes human senses to assess the acceptability of food samples, such as cookies, based on specific attributes and a defined scale (Zuhdi and Khairi, 2022; Pakpahan et al., 2025). The evaluation includes four attributes: color, aroma, taste, and texture. Cookies with different treatments are presented in identical containers labeled with randomly assigned three-digit codes. The test is conducted using 50 semi-trained panelists who are asked to complete a scoring form using a 1-to-4 scale for each attribute. The collected data are statistically analyzed to determine the significance of differences in characteristics among the treated cookie samples. The interpretation of the scale used for each attribute is presented in Table 1.

Table 1 - Scale Description for Organoleptic Attribute.

| Scale | Color | Aroma | Taste | Texture |
|---|---|---|---|---|
| 1 | Not brown | No typical tuber aroma | Not sweet | Not crispy and chewy |
| 2 | Slightly brown | Slightly typical tuber aroma | Slightly sweet | Slightly crispy and chewy |
| 3 | Brown | Typical tuber aroma | Sweet | Crispy and chewy |
| 4 | Very brown | Very typical tuber aroma | Very sweet | Very crispy and chewy |

### *2.6. Hedonic Properties*

Hedonic testing is employed to evaluate differences in the quality of several products subjected to different treatments, using a scale that reflects the degree of preference (Ningrum et al., 2023). Samples are presented in identical containers, each labeled with a randomly assigned three-digit code. The test involves 50 untrained panelists who assess the samples using a 1-to-4 scale, where 1 indicates the lowest level of liking and 4 the highest. The results are statistically analyzed to determine significant differences in overall preference among the cookie treatments.

### *2.7. Statistical Analysis*

Data analysis in this study was conducted using both parametric and non-parametric approaches (Trisyani and Syahlan, 2022). Parametric analysis was applied to water activity ($a_w$) and color parameters and included statistical tests such as normality testing, homogeneity testing, and Analysis of Variance (ANOVA). ANOVA was used to determine the effect of treatments at a significant level of $p<0.05$. When significant differences were observed, further analysis was carried out using Duncan's Multiple Range Test (DMRT). Non-parametric analysis was applied to organoleptic and hedonic parameters using the Kruskal-Wallis test to assess the effect of different treatments on the dependent variables, followed by the Mann-Whitney test for pairwise comparisons. Organoleptic parameters were presented using spider web charts, while water activity ($a_w$) and hedonic properties were visualized using bar charts generated with Microsoft Excel 365.

## 3. Results and Discussions

### *3.1. Water Activity ($a_w$)*

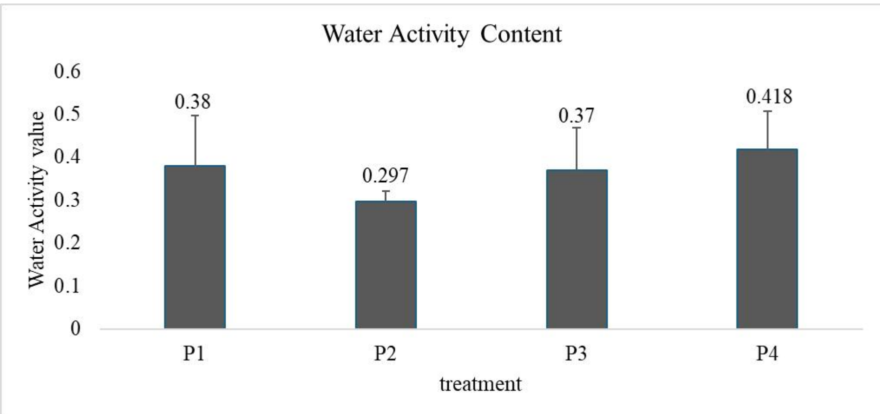


**Fig. 1 - Chart of Water Activity Cookies with Different Treatment of Flour.**

Water activity ($a_w$) is a critical parameter for determining the microbiological stability and shelf life of baked products, including cookies. Unlike moisture content, which measures the total water present, aw represents the availability of free water that can support microbial growth and chemical reactions (Tarlak, 2023). In this study, there were statistically significant differences ($p<0.05$) in $a_w$ values were observed among the four treatments, despite the variations in flour types used, ranging from low- and medium-protein wheat flour to partial substitution with gembili and ganyong flours. This result suggests that flour type alone did not play a major role in determining the final water activity of the cookies.

A likely contributing factor is the baking process itself, which induces considerable moisture loss and tends to standardize aw values across samples regardless of their flour composition (Channaiah *et al.*, 2021). Moreover, the water-binding capacities of the different flours used in the formulations might be relatively similar due to comparable starch structures. Another contributing factor is the presence of functional ingredients such as sugar and salt, which were held constant throughout all treatments. These ingredients are known to significantly affect water activity by binding free water and reducing its availability (Belokurova *et al.*, 2021). Therefore, it is likely that process conditions and other formulation components had a stronger influence on $a_w$ than the specific flour types used.

### *3.2. Color*

**Table 2 - Result of Color Analysis of Cookies with Different Treatment of Flour.**

| Treatment | L* | a* | b* | Appearance |
|---|---|---|---|---|
| P1 | 71.52 ± 1.984[a] | 7.98 ± 2.517 | 31.41 ± 3.065[a] |  |
| P2 | 67.77 ± 1.740[a] | 10.11 ± 1.842 | 29.57 ± 1.242[a] |  |
| P3 | 49.48 ± 9.023[b] | 9.23 ± 2.338 | 15.24 ± 3.441[b] |  |
| P4 | 41.19 ± 1.574[b] | 6.90 ± 1.572 | 12.86 ± 3.668[b] |  |

The color parameters (L*, a*, and b*) of cookies exhibited notable variations across the different flour substitution treatments. Based on one-way Analysis of Variance (ANOVA), there were statistically significant differences ($p$<0.05) in the L* and b* values among the four formulations, as shown in Table 2. Further analysis using Duncan's Multiple Range Test (DMRT) revealed that cookies made with low (P1) and medium protein wheat flour (P2) had significantly higher L* values indicating lighter appearance compared to those formulated with gembili (P3) and ganyong (P4) composite flours. The darker coloration in P3 and P4 can be attributed to browning reactions during processing and the intrinsic properties of the tuber-based flours (Retnowati *et al.*, 2018). Previous studies have noted that gembili flour is naturally darker than commercial wheat flour due to non-enzymatic browning processes, polyphenol oxidation, and the bioactive compounds in the form of diosgenin, dioscorin, and inulin (Wardani *et al.*, 2021; Aprianita *et al.*, 2014).

Similarly, b* values representing yellowness and showed significant differences ($p$<0.05) between treatments. P3 and P4 demonstrated higher yellowness compared to P1 and P2, likely due to the elevated phenolic content and active polyphenol oxidase enzymes present in gembili and ganyong tubers. In particular, the greyish white to brownish color shift in ganyong and gembili flour, exacerbated by oxygen exposure, is consistent with enzymatic browning via phenolase activity (Sulandari and Pangesthi, 2017). These biochemical reactions influenced not only the raw flour color but also the visual quality of the final baked cookies. Previous research has shown that gembili flour exhibits significantly lower L* values compared to wheat flour (Retnowati *et al.*, 2018) Since color is a critical determinant of consumer preference, such findings are relevant for the development of alternative cookie formulations using local tuber-based flours.

### *3.3. Organoleptic*

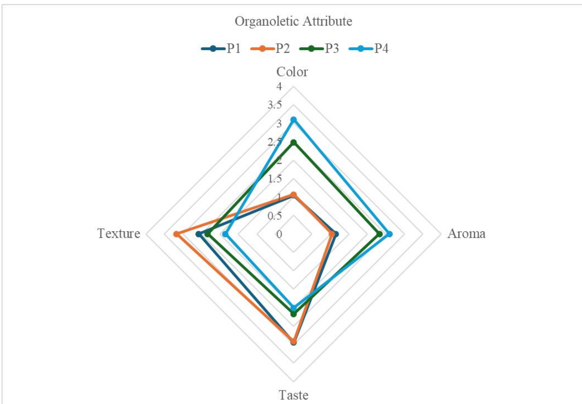


**Fig. 2 - Chart of Organoleptic Cookies with Different Treatment of Flour.**

The organoleptic evaluation revealed significant differences (*p*<0.05) among all treatments across color, aroma, taste, and texture attributes. Samples with low substitution levels (P1 and P2) received the highest scores for taste (2.94 and 2.91, respectively), indicating a more sweetness perception. In contrast, the incorporation of 50% gembili flour (P3) and 50% ganyong flour (P4) resulted in lower scores for taste (2.17 and 2.00, respectively as of Fig 2.), indicating less sweetness perception, which may be attributed to the bitter flavor imparted by gembili and ganyong flour, likely due to their phenolic, alkaloid, and saponin content (Wardani *et al.*, 2021; Ifandari *et al.*, 2018). Similarly, the aroma of P3 and P4 was rated higher (typical tubers aroma), due to the reduced presence of wheat-derived volatiles and the emergence of unfamiliar odors from the substituted flours (gembili and ganyong flour).

In terms of color and texture, significant variation was also observed. The darkest color was recorded in P4 (score = 3.09), indicating the darker color that reflects the naturally darker pigmentation of ganyong flour, which has a lower lightness (L*) value than wheat flour. As shown in Table 2., P4 has the lowest L* value (41.19), indicating lower lightness compared to the other treatments. While a darker hue may indicate a richer composition, it can also reduce consumer acceptance if perceived as burnt or non-standard flour (Retnowati *et al.*, 2018). Texture-wise, P2 exhibited the highest score (3.17) indicating crispy and chewy, suggesting an optimal balance between crispness and chewiness. Conversely, P4 scored the lowest (1.84), likely due to the limited gluten network and lower swelling capacity of ganyong flour (Harmayani *et al.*, 2011), resulting in a denser and harder texture. Crispiness in cookies is primarily influenced by the amylose content in starch, whereas amylopectin contributes to a stronger structural network (Elvandari *et al.*, 2020). The amylose content in gembili flour is approximately 20%, the lowest content recorded in ganyong flour is 24%, and in wheat flour is almost 30% (Bahlawan *et al.*, 2020; Hellemans *et al.*, 2020; Santoso *et al.*, 2015). These findings confirm that partial substitution with gembili or ganyong flours affects not only the structural but also the sensory characteristics of cookies and should be optimized to maintain consumer acceptability.

### *3.4. Hedonic*

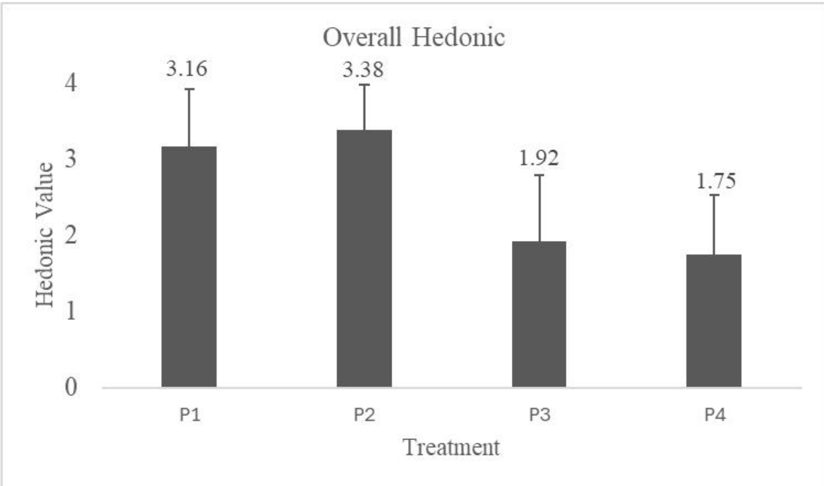


**Fig. 3 - Chart of Hedonic Cookies with Different Treatment of Flour.**

The overall hedonic test is a sensory evaluation method used to measure consumer preference based on overall liking of a product. The overall hedonic test showed significant differences (*p*<0.05), where cookies with no substitution (P1 and P2) were significantly more preferred than those with 50% gembili (P3) and ganyong (P4) flour, as shown in Fig 3. The lower acceptability of P3 and P4 is associated with darker color, off-flavor, harder texture, and bitter taste, likely due to saponins, phenolics, and lower starch swelling capacity in the tuber flours (Wardani *et al.*, 2021; Ifandari *et al.*, 2018). These findings align with the results of the organoleptic tests, which showed that P3 and P4 scored lower in taste and texture, potentially due to the bitter notes and dense structure caused by tuber bioactive compounds and limited gluten networks. Color attributes also supported this trend, where P3 and P4 showed significantly lower L* values (indicating darker appearance), which may have negatively influenced consumer perception. Although differences in flour composition were expected to affect moisture-related properties, the water activity ($a_w$) values among treatments were not markedly different, suggesting that the baking process and the consistent use of sugar and salt across all formulations played a larger role in controlling $a_w$. This reinforces the notion that acceptability was more strongly driven by sensory attributes like taste, texture, and visual appearance.

Previous research on cookie products made from various tuber flours has similarly reported lower consumer preference compared to those made with wheat flour (Mujahanah and Paramartha, 2024; Kurniawan *et al.*, 2018; Darmawan, 2017). These inherent characteristics of gembili and ganyong flours may negatively impact sensory attributes, limiting consumer preference at higher substitution levels. Therefore, refining processing techniques such as blanching or fermentation to reduce bitterness and off-flavors could be crucial. Blanching has been reported in previous studies to effectively reduce bitterness and off-flavor characteristics in cookies made from tuber-based flours (Najeeb *et al.*, 2021; Sanful *et al.*, 2016). Additionally, optimizing flour blends or incorporating flavor-masking agents may enhance overall sensory quality and consumer acceptance in future product development.

## 4. Conclusion

Cookies made with 50% substitution of gembili and ganyong flour exhibited significant differences in color, taste, texture, and overall acceptability compared to cookies made entirely with wheat flour. While the water activity of all treatments remained within acceptable ranges for microbial stability, cookies with tuber flour showed darker color, harder texture, and more bitter taste—factors that negatively influenced hedonic scores. These effects are likely due to the presence of bioactive compounds such as phenolics and saponins, as well as the lower gluten and amylose content of tuber flours. Among all treatments, cookies made with 100% medium-protein wheat flour (P2) achieved the best sensory and hedonic performance. Therefore, although gembili and ganyong flours hold promise as local and functional ingredients in bakery products, further research is required to improve their sensory qualities potentially through pretreatments like blanching or fermentation—and to determine optimal substitution levels for consumer-acceptable cookie formulations.

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