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Impact of Okara Tempe powder concentration and particle size on color and sensory properties of cookies

Kurnia Ramadhan*, Syifa Salsabillah, Nurul Asiah and Laras Cempaka

Department of Food Science and Technology, Universitas Bakrie, Jakarta 12920, Indonesia
**Corresponding author's E-mail address: kurnia.ramadhan@bakrie.ac.id*

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Abstract—Okara, a byproduct of soymilk production, is traditionally fermented into tempe and is rich in fiber, making it a cost-effective food ingredient. This study evaluates the color and sensory properties of cookies formulated with okara tempe powder (OTP) of varying particle sizes and concentrations. Results indicated that higher OTP concentrations and coarser particle sizes led to darker cookies, with significant changes in redness/greenness (a*), and yellowness/blueness (b*) values. Sensory attributes were evaluated using a hedonic scale, revealing that cookies with higher OTP concentrations received lower overall liking scores. Cookies with 30% OTP were the least favored, showing a wide range of scores. Conversely, cookies with 10% fine OTP particles were generally preferred, with no significant difference in mean hedonic scores compared to control samples. Principal Component Analysis (PCA) of hedonic data showed strong correlations among overall liking, aroma, texture, and taste, while appearance was distinct. Sensory descriptors highlighted differences in color, flavor, and texture between control and OTP-containing cookies. Control samples were characterized by "sweet" and "milky" flavors and a "smooth" texture, whereas OTP cookies had "nutty" flavors, a "coarse" mouthfeel, and a "crunchy" texture. Some panelists noted a "bitter" flavor and "gritty" sensation in cookies with 30% OTP. These findings suggest that OTP can influence the sensory properties of cookies, with potential applications in food product development.

***Keywords*—cookies, okara, tempe gembus, particle size, sensory.**

INTRODUCTION

Soymilk, a popular plant-based non-dairy alternative, has gained significant traction in recent years. However, its production process generates a substantial amount of solid residue known as "okara." Improper management of this residue could pose environmental risks. Okara is characterized by its high moisture content and primarily consists of fibers, along with significant amounts of proteins, lipids, and bioactive compounds. Researchers have extensively studied this nutritious byproduct for its potential as a valuable food ingredient. Various physical, chemical, and biological treatments have been explored to modify okara, enhancing its utilization (Kamble and Rani, 2020; Asghar et al., 2023).

Traditionally, Indonesian cuisine has incorporated okara primarily through fermentation processes. A prominent example is tempe gembus, a variant of okara tempeh produced by *Rhizopus oligosporus* fermentation, resulting in a flavorful and nutrient-dense food (Romulo and Surya, 2021; Rizal et al., 2024). Extensive research has consistently demonstrated that fungal fermentation significantly enhances okara's nutritional profile and sensory attributes (Vong et al., 2018; Lee et al., 2020; Wang et al., 2022).

Beyond enhancing taste and nutrition, microbial fermentation of okara also leads to increased antioxidant capacity and soluble fiber content (Gupta et al., 2018; Sitanggang et al., 2019; Hu et al., 2022). Furthermore, these fermentation processes confer additional functional properties and health benefits to okara (Vong et al., 2018; Tuly and Ma, 2024). Given these advantages and its low cost, okara presents a promising biomaterial with considerable potential for diverse food applications.

Cookies are a widely consumed snack food, and consumer demand for healthier options has driven research into innovative formulations. Incorporating functional ingredients like okara into cookies is a promising approach to enhance their nutritional value. Sinambela et al. (2020) demonstrated the potential of okara tempe powder as a dietary fiber-rich addition. The amount of okara incorporated into formulations is crucial, as it significantly influences not only the nutritional quality but also the textural and sensory properties (Ostermann-Porcel et al., 2017). Building upon this, Liu et al. (2021) investigated the influence of particle size on cookie characteristics, finding that smaller non-fermented okara particles led to improved product acceptability.

While previous studies have explored the incorporation of okara and okara tempe into cookies, the combined effects of particle size and concentration on color and sensory properties remain understudied. This research gap underscores the need for a comprehensive evaluation of these variables. The present study aims to address this knowledge gap by assessing the sensory quality of cookies

enriched with okara tempe powder across a range of particle sizes.

MATERIALS AND METHODS

Materials

Commercially available okara tempe was procured from a local supplier in West Jakarta and subsequently frozen for storage until it was processed into a powdered form. The ingredients for cookie preparation were sourced from the local market, including multi-purpose wheat flour (Kunci Biru, PT Bogasari Flour Mills, Jakarta, Indonesia), icing sugar (Claris, PT Mitra Unit Plastindo Cemerlang, Tangerang, Indonesia), margarine (Blue Band®, PT Upfield Manufacturing Indonesia, Bekasi, Indonesia), baking powder (Koepoe-Koepoe, PT Gunacipta Multirasa, Tangerang, Indonesia), and fresh eggs.

Preparation of okara tempe powder

Frozen okara tempe was thawed at room temperature and then sliced to an approximate thickness of 2 mm. The slices were subsequently dried in a preheated convection oven at 150°C. After the initial 10 minutes, the slices were flipped. The drying process continued at 150°C for a total of 20 minutes, until the okara tempe slices were completely desiccated. Once dried, the okara tempe was allowed to cool to room temperature outside the oven. It was then ground into a powder and sieved using two mechanical sieves: 30 mesh (595 µm) and 80 mesh (177 µm), yielding coarse and fine okara tempe powders, respectively. Any remaining large clumps were returned to the oven for brief reheating and then reground until they were completely pulverized into a powder. This step was included to ensure the final powder achieved the desired level of dryness. The powdered okara tempe was then sieved again using the 30 mesh and 80 mesh sieves as described above.

Preparation of cookies

In this study, coarse and fine okara tempe powders (OTP) were utilized to substitute wheat flour at proportions of 0%, 10%, 20%, and 30%. The samples were coded as C10, C20, C30 for samples containing coarse okara tempe powder, and F10, F20, and F30 for samples containing fine okara tempe powder. The sample without OTP was coded as the control sample.

The cookie preparation process began with the mixing of dry ingredients, including wheat flour, icing sugar, baking powder, and OTP. In a separate mixing bowl, fresh eggs and margarine were emulsified using a hand mixer. The pre-mixed dry ingredients were then gradually incorporated into the emulsion to form a homogeneous cookie dough. The dough was rolled out and cut into circular shapes with an 8 cm diameter and approximately 5 mm thickness. The shaped cookie doughs were baked in a convection oven at 150°C for 25 minutes, then cooled to room temperature before storage. The cookies were stored in food storage boxes at room temperature for up to three days prior to analysis.

Color analysis

The color properties of the cookies were measured using an AMT507 Colorimeter (AMTAST, China). The colorimeter was calibrated with the provided black and white calibration tiles before measurement. After calibration, the measurement aperture of the colorimeter was placed in contact with the surface of each cookie to measure its color properties. The degree of lightness, redness/greenness, and yellowness/blueness were recorded based on Hunter's Lab colorimetric system, denoted as L*, a*, and b*. Each measurement was taken three times and the mean values were calculated. Additionally, the color difference values (ΔE^*) between control and okara-containing samples were determined using the Lindbloom's CIE2000 color calculator (Lindbloom, 2012). CIE2000 was chosen for its improved accuracy over CIE76 and CIE94, as it incorporates corrections and refinements to better reflect human color perception.

Sensory analysis

A sensory analysis was conducted with a panel of 33 university students. Participants were selected based on their regular cookie consumption, good health, and absence of sensory impairments or allergies related to the study ingredients. All participants provided informed consent prior to the voluntary sensory evaluation, which took place in a controlled sensory testing environment. Before the evaluation, participants received a detailed briefing on the experimental procedure. Each participant was then presented with a complete set of seven cookie samples, each coded with a three-digit random number. Between evaluating each sample, participants were required to cleanse their palate by drinking water. They were instructed to assign hedonic scores to each sample using a seven-point scale, ranging from 1 ("dislike very much") to 7 ("like very much"). Scores were assessed for overall liking, as well as individual sensory attributes including appearance (considering all visual aspects such as color and shape), aroma, texture, and taste. In addition to the hedonic test, participants were also instructed to spontaneously articulate the perceived sensory attributes of each sample, including appearance, flavor, and texture, following the Free-choice profiling method described by Guàrdia et al. (2010).

Data analysis

Data analysis was performed using XLSTAT software (Lumivero, CO, USA). Analysis of variance (ANOVA) was employed to assess the collected data from color analysis and hedonic sensory test, followed by Tukey's Honestly Significant Difference test at a significance level of 0.05 for mean comparisons. All data are presented as mean ± standard deviation. Principal component analysis of mean hedonic sensory data, data visualization in the form of boxplots, and word cloud generation were also processed using XLSTAT software.

Table. 1 Color properties of cookies containing coarse and fine okara tempe powder at different levels

Samples	Images	Color Coordinates	
Control		*L**	98.90 ± 0.44^{d}
		*a**	-0.97 ± 0.06^{a}
		*b**	25.70 ± 0.17^{e}
C10		*L**	92.87 ± 0.75^{c}
		*a**	1.53 ± 0.25^{bc}
		*b**	22.17 ± 0.59^{d}
		Δ*E**	4.66 ± 0.60^{a}
C20		*L**	88.70 ± 0.44^{ab}
		*a**	1.93 ± 0.15^{cd}
		*b**	18.60 ± 0.17^{ab}
		Δ*E**	7.76 ± 0.33^{bc}
C30		*L**	87.70 ± 0.44^{a}
		*a**	2.47 ± 0.06^{d}
		*b**	18.20 ± 0.40^{a}
		Δ*E**	8.62 ± 0.27^{c}
F10		*L**	91.77 ± 0.75^{c}
		*a**	1.07 ± 0.25^{b}
		*b**	20.50 ± 0.61^{c}
		Δ*E**	5.37 ± 0.44^{a}
F20		*L**	89.97 ± 0.85^{b}
		*a**	1.93 ± 0.29^{cd}
		*b**	19.43 ± 0.38^{bc}
		Δ*E**	6.92 ± 0.38^{b}
F30		*L**	89.03 ± 0.51^{ab}
		*a**	2.43 ± 0.15^{d}
		*b**	19.37 ± 0.35^{bc}
		Δ*E**	7.63 ± 0.34^{bc}

Different letters within the same color coordinate category indicate statistically significant differences ($P < 0.05$) according to the Tukey HSD test

RESULTS AND DISCUSSIONS

Color properties

The color properties of the cookies were evaluated quantitatively, comprising the degree of lightness (L*), redness/greenness (a*), and yellowness/blueness (b*), along with color differences (ΔE*), as shown in Table 1. A significant decrease in lightness (L*) was observed in cookies with higher concentrations of OTP (C20, C30, F20, F30), resulting in a darker appearance. This darkening effect was more pronounced in cookies containing coarser OTP particles (C30 versus F30), indicating a particle size influence. Furthermore, a* values generally increased with higher OTP concentrations and coarser particle sizes, indicating a shift towards redder hues. Conversely, b* values tended to decrease, suggesting a reduction in yellowness. These findings align with previous research by Ostermann-Porcel et al. (2017), which demonstrated that increasing okara powder content in cookies significantly reduced lightness. Although raw okara possesses a characteristically whitish appearance, the high-temperature drying processes employed in powder production can facilitate the occurrence of Maillard reactions. These reactions involve the interaction of carbonyl and amino compounds, resulting in a darkening of the material (Muliterno et al., 2017). This phenomenon was evident in the present study, as the initially white okara tempe, distinguished by the presence of fungal mycelia, exhibited a noticeable darkening following high temperature drying. Furthermore, a recent study by Amelly et al. (2023) documented a substantial increase in browning index values upon incorporating soybean tempe powder into traditional confectionery product, further supporting the observed darkening effect in this investigation.

Color difference (ΔE*) values demonstrated that cookie samples incorporating higher concentrations of OTP (F20, F30, C20, C30) exhibited significantly greater color variations compared to the control sample, which served as the color reference. Notably, no significant color difference was observed between C10 and F10, suggesting that particle size exerted minimal visual impact at this inclusion level. While color itself contributes to overall color perception, it is important to acknowledge that surface roughness can also significantly influence color appearance, as previously reported by Chae (2022). Therefore, the observed greater color differences in the OTP-containing cookie samples are likely attributed, in part, to the increased surface roughness imparted by the incorporated particles. A more detailed examination of the roughness and texture-related properties of these cookies is provided within the sensory properties section of this paper.

Sensory properties

The sensory attributes of the cookies were evaluated for consumer acceptance using a hedonic scale. Figure 1 shows the hedonic score distribution of cookies containing OTP with coarse (C10-C30) and fine (F10-F30) particle sizes at different concentrations, presented in a boxplot format. As the concentration of OTP increased, the cookies generally received lower average hedonic scores for overall liking compared to the control sample. Among the OTP-containing samples, the F10 sample was generally preferred by the consumer panel, exhibiting a mean hedonic score closest to that of the control sample. There was no significant difference in the mean hedonic scores for overall liking between F10 and the control samples, with both means approaching 6 (liked moderately). This indicates a general consensus among the panelists regarding the acceptability of these samples. The boxplot divides the panelist population into quartiles: 50% in the middle, 25% in the upper quartile, and 25% in the lower quartile. For the F10 sample, 50% of the panelists rated their liking between 5 and 6. Additionally, 25% of panelists scored between 4 and 5, and another 25% scored between 6 and 7. This suggests a range of individual preferences for this specific sample, a pattern also observed in the control sample.

Cookies with the highest OTP concentration (30%), regardless of particle size (C30 and F30), were the least favored by the consumer panel, as indicated by the lowest mean hedonic scores. Furthermore, these samples exhibited the widest range of scores for overall liking, varying from 1 (dislike very much) to 7 (like very much). Fifty percent of the consumer panel rated these cookies between 4 (neither like nor dislike) and 6 (like moderately), indicating diverse perceptions among the panelists. This finding aligns with another study by García-Gómez et al. (2022), which demonstrated that lower mean hedonic scores tend to be associated with a wider range of individual scores and less consensus among respondents.

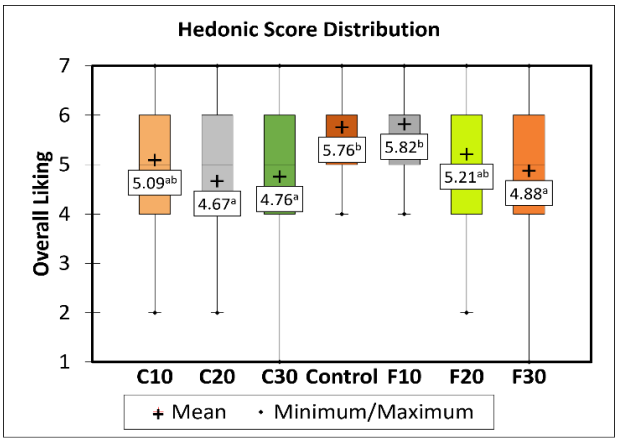

Fig.1. Hedonic score distribution of cookies containing okara tempe powder with coarse and fine particle size at different concentrations

To investigate the relationships between mean hedonic scores across different sensory attributes, Principal Component Analysis (PCA) was conducted, as visualized in Figure 2. The first two principal components explained a substantial 93.05% of the total variance, indicating that these components effectively capture the major patterns within the hedonic data. A notable observation from the biplot is the strong correlation between four sensory attributes: overall liking, aroma, texture, and taste. Their vector lines converge in the lower right quadrant, suggesting a close inter-dependency among these attributes in influencing consumer preferences.

Furthermore, the positions of the samples on the biplot are consistent with their mean hedonic scores. The control sample and F10, both characterized by relatively high scores across key sensory attributes, cluster together in the lower right quadrant. The sample C10 occupies a central position, with closer proximity to F20 in the upper right quadrant and F30 in the upper left quadrant, followed by C20. Notably, C30 is the most distinct sample, positioned furthest away from the others in the lower left quadrant. This spatial distribution on the biplot reflects the unique sensory profiles of the samples, suggesting that C30 differs significantly from the others in terms of its overall hedonic appeal.

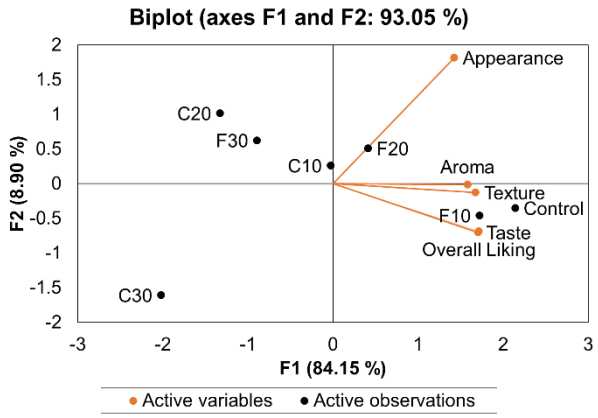

Fig.2. Principal component analysis biplot of cookie samples based on mean hedonic scores for overall liking, appearance, aroma, taste, and texture

In contrast, the appearance attribute is positioned along a slightly different vector direction, residing in the upper right quadrant of the biplot. This distinct positioning suggests that appearance may contribute to hedonic perception in a manner that is somewhat independent of the other sensory attributes. This observation aligns with the multifaceted nature of appearance, encompassing a range of visual characteristics such as color, shape, and surface properties like porosity and homogeneity. The variation in appearance scores likely reflects the diverse ways these visual cues influence overall liking. Appearance often acts as a pre-consumption cue, shaping initial expectations and judgments. However, post-consumption, the influence of other sensory attributes (aroma, taste, texture) may become more dominant for some consumers (Motoki et. al., 2023). This can lead to a shift in overall liking, potentially aligning it more closely with the hedonic scores of these other sensory attributes rather than the initial visual impression.

Descriptive sensory analysis plays a crucial role in providing a comprehensive understanding of sensory properties, complementing hedonic evaluations. Figure 3 presents the sensory attribute descriptors of cookies in the form of a word cloud. Larger font sizes indicate descriptors that were mentioned more frequently by the panelists, while smaller font sizes indicate less frequently mentioned descriptors. In addition to font size, font color is used to visually represent frequency, with dark green indicating the most frequent descriptors, transitioning to yellow for less frequent descriptors, and finally to orange and red for the least frequent descriptors. From the word cloud, it is evident that the most frequently cited sensory attributes are related to cookie color. "Yellowish" was predominant in the control

Fig.3. Word cloud illustrating sensory attribute descriptors for color, mouthfeel, texture, and flavor of cookie samples, including a control and cookies with coarse and fine okara tempe powder at 10, 20, and 30% concentrations.

sample, while "brownish" was prominent in all OTP-containing cookie samples. Interestingly, "yellowish" characteristics were still mentioned in the F10 sample, alongside "brownish," suggesting some degree of similarity between F10 and the control sample in terms of color perception. Overall, these findings suggest a consensus among the sensory panelists regarding the color perception of cookies.

The control sample exhibited distinct sensory attributes compared to the OTP-containing cookies. In addition to color differences, flavor profiles shifted gradually with increasing OTP particle size and concentration. The control sample was characterized by "sweet" and "milky" flavors, and a "smooth" and "soft" texture. In contrast, OTP-containing cookies leaned towards "nutty" flavors, a "coarse" mouthfeel, and a "crunchy" texture. These findings align with previous studies that have also reported the presence of a "nutty" flavor in okara-based food formulations (Aussanasuwannakul et al., 2024). The "coarse" mouthfeel may be attributed to the dietary fiber content of okara, which can interfere with the structure of wheat-based cookie matrices (Ostermann-Porcel et al., 2017).

Notably, some panelists detected a "bitter" flavor in cookies with 30% OTP, regardless of particle size, and a "gritty" sensation was more pronounced in cookies with 30% coarse OTP. The presence of bitterness in both non-fermented and fermented okara has been previously reported (Shi et al., 2020). However, the C10 sample, containing 10% fine OTP particles, shared some similarities with the control, including "buttery" and "smooth" attributes. This could explain why the C10 sample was not significantly different in terms of mean hedonic score for overall liking compared to the control samples.

CONCLUSIONS

The study demonstrated that the incorporation of okara tempe powder (OTP) significantly influenced the color and sensory attributes of cookies. Higher concentrations and coarser particle sizes of OTP resulted in darker cookies with increased redness and decreased yellowness, aligning with previous findings on the effects of high temperature drying on okara. Sensory evaluation revealed that cookies with 10% fine OTP particles were generally preferred, showing no significant difference in overall liking compared to the control samples. However, higher OTP concentrations, particularly at 30%, led to lower average hedonic scores and a wider range of individual preferences, indicating diverse consumer perceptions. Principal Component Analysis highlighted the strong correlation between overall liking, aroma, texture, and taste, while appearance emerged as a distinct attribute influencing consumer preferences. The presence of "nutty" and "bitter" flavors, along with a "coarse" mouthfeel in OTP-containing cookies, was consistent with previous studies on okara-based formulations. These findings suggest that while moderate levels of fine OTP can be incorporated into cookies without compromising consumer acceptance, higher concentrations may require further optimization to enhance sensory appeal.

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