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The effect of utilizing palm oil brown sugar and red chili extract (*Capsicum annuum L.)* in the production of sweet and spicy palm kernel meal sauce

Hotnida Sinaga*, Mimi Nurminah and Olivia Abira Rajagukguk

Department of Food Science, Faculty of Agriculture, Universitas Sumatera Utara, Medan, Indonesia

KEYWORDS

Fermentation
Palm oil brown sugar
Palm kernel meal
Red chili
Elaeis guineensis

ABSTRACT

Palm kernel meal is a by-product of palm oil processing that is abundant and has not been optimally utilized. This study aimed to investigate the impact of incorporating palm oil brown sugar and red chilies in the production of palm kernel meal (PKM) sauce for improving desirable physical, chemical, and organoleptic qualities. This research began with palm kernel meal fermentation to optimize the quality of palm kernel meal. Then, koji and moromi were fermented and followed by the cooking of palm kernel meal sauce. This study employed a completely randomized factorial design, with two factors: palm oil brown sugar concentration (60%, 75%, and 95%) and red chili concentration (0%, 10%, 20%, and 30%). The results showed that the interaction between palm oil brown sugar concentrations and red chili extract concentrations had a significant different effect ($P<0.01$) on °*Hue*, a*, b*, total soluble solids (TSS), protein, vitamin C, sensory attributes (i.e., aroma, taste, viscosity). While non-significant ($P>0.05$) effects were found on the value of L color, pH, reducing sugars, color, and general acceptance of palm kernel meal sauce.

Introduction

Indonesia is one of the world's largest palm oil producers, with a significant increase in production each year. The country's oil palm plantations have consistently demonstrated high productivity, contributing to the industry's growth. In 2021, Indonesia's Crude Palm Oil (CPO) production reached 46.88 million tons. Furthermore, Palm Kernel Oil (PKO) is a valuable oil derived from processing palm fruit kernels. According to data from the Indonesian Palm Oil Association (IPOA), Indonesia is projected to produce 4.412 million tons of Crude Palm Kernel Oil (CPKO) in 2021, with an export volume of 1.487 million tons of PKO and its processed products. These figures indicate significant growth and positive development in Indonesia's PKO industry. The processing of palm kernel oil typically yields around 50-52%, meaning that for every ton of palm kernel produced, approximately 520 kg of PKO can be obtained. The remaining 480 kg are considered a by-product of PKO production.

Palm kernel meal (PKM) is a byproduct derived from palm kernel oil processing. Its composition includes 14.19% crude protein, 13.59% true protein, and 21.70% crude fiber content. Due to its high fiber content, PKM is primarily used as animal feed rather than for human consumption. The presence of crude fiber in PKM can impede its digestibility in humans. The breakdown of cellulose and hemicellulose into simple sugars is challenging for the human body. Therefore, additional treatments, such as fermentation, are necessary to reduce the fiber content and enhance the quality of PKM for potential use as a food source (Pasaribu et al., 2019).

Soy sauce is a fermented condiment that derives its flavor from proteins. As long as the production adheres to the regulations specified in Standard Quality of Goods No. 25/DSNPM/78, modifications can be made to the production process, including the substitution of protein sources. By fermenting PKM, the protein content in the material transforms into simpler forms, thereby increasing its digestibility and making it suitable for use as a raw material in soy sauce production. Additionally, the processing of PKM sauce products can serve as an alternative to soybeans, which the import values have been increasing annually.

*Corresponding author
E-mail address: hotnida@usu.ac.id

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The modification of sweet soy sauce products has become increasingly diverse, including the introduction of spicy variants. Red chili is a key ingredient that provides a spicy flavor in sweet soy sauce. Red chili belongs to the Capsicum genus, both as a plant and a fruit. Red chilies contain various nutrients such as protein, fat, fiber, mineral salts, and vitamins (i.e., A, D3, E, C, K, B2, and B12). Capsaicin is one of the active compounds responsible for the spiciness in red chilies (Xiang et al., 2021). The production and processing of red chilies offer potential benefits for improving farmers' economic conditions and minimizing crop losses through food diversification. Red chili is a valuable food commodity. However, it is known to have a relatively short shelf life, which often leads to spoilage and underutilization. Environmental factors such as temperature, diseases, humidity, etc. The spoilage of red chilies results in financial losses for farmers and can contribute to environmental pollution (Setyabudi, et al, 2019) Therefore, it is essential to explore processed products or alternatives that utilize red chilies, such as incorporating them into the production of sweet and spicy soy sauce. Moreover, the inclusion of red chilies in soy sauce production is expected to impact the final product’s vitamin C content .

Studies on the fermentation of PKM sauce with palm oil brown sugar and red chili extract should focus on ensuring high-quality production with considering physical, chemical, and sensory aspects. It is crucial to carefully consider various processing stages, including pre-treatment, fermentation, and packaging. The study aimed to explore the addition of red chilies for innovative sauce production using PKM and examine their impact on the vitamin C content in soy sauce. The utilization of PKM was to optimize its usage, as it is currently primarily used as animal feed. This study seeks to develop sauce innovations based on PKM that meet quality standards, have market potential, and could reduce reliance on soybean imports. Additionally, consumer research has been conducted to assess the acceptance of sweet and spicy PKM sauce with red chili extract. This research may facilitate the successful commercialization of PKM sauce products and offer an alternative to commercially available soy sauce.

Research Methods

Materials

PKM, which served as the primary material, was sourced from PT. Okta Palm Oil located in Tanjung Morawa, North Sumatera. Red chilies, salt, and spices were obtained from the Medan Market in Medan Selayang, North Sumatera. The red chilies used in the study were of vibrant red color and free from any signs of disease or damage. The microbial strains (*Aspergillus* sp and *Trichoderma viriide*) were supplied by the Indonesian Institute of Science (LIPI). Various chemicals (such as urea, molasses, KCl, alkaline lime, ethanol, PDA medium, Nelson A solution, Nelson B solution, arsenomolybdate, potassium chromate, NaOH, starch, iodine, phenolpethalein indicator, and silica gel) were provided by PT Rudang Jaya located in Medan, North Sumatera. All chemicals used in the study were of technical grade (i.e., ethanol, NaOH, and phenolpethalein indicator) and food grade (i.e., urea, molasses, KCl, alkaline lime, and starch). Distilled water was used throughout the research. The nutritional content of palm kernel meal can be found in Table 1.

Methods

The study was conducted using a completely randomized factorial design, consisting of two factors: palm oil brown sugar concentration (G) with three levels (60%, 75%, and 90%) and red chili extract concentration (C) with four levels (0%, 10%, 20%, and 30%). The study was replicated three times, resulting in a total sample size of 36. The processing process flowchart for the sweet and spicy PKM sauce can be seen in Figure 1.

Table 1. Nutritional contents of palm kernel meal per 100 g

Parameters	Values
Fat (%)	7.98
Coarse fiber (%)	17.97
Protein (%)	15.83
Water content (%)	5.13

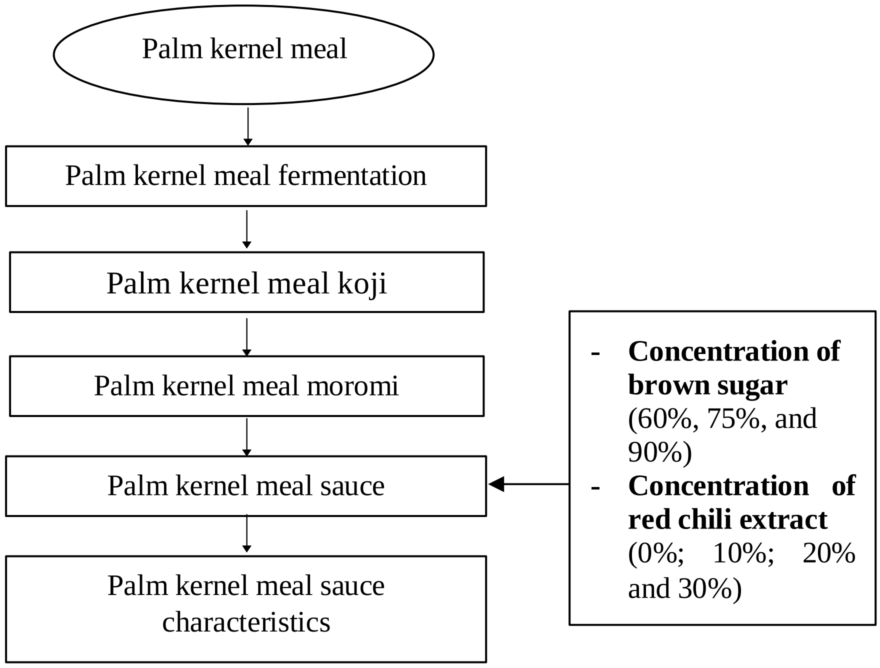


Figure 1. Process flowchart of processing sweet and spicy palm kernel meal sauce

Production of red chili powder

Cleaned fresh red chilies were dried in an oven at 40ºC for 96 hours or until moisture content of 8-10%. This low-temperature long-time drying (LTLT) method preserved the components of red chilies (i.e., vitamin C). A previous study found that vitamin C degradation is minimized at 40ºC (Sapei and Hwa, 2014). Dried red chilies were crushed using a disk mill to obtain a powder with a particle size of 40 mesh. The resulting red chili powder was then used to make extracts.

Red chili extract

The extraction process of red chili powder was conducted using the percolation method. Ten grams of the powder and 500 mL of 96% ethanol solvent were placed in a 2000 mL Erlenmeyer flask. The mixture was stirred using a magnetic stirrer at 200 rpm and heated on a hot plate at 50ºC. The extraction process was carried out for 4 hours. Afterward, the extracted solution was filtered using a filter cloth to separate the solid residue from the filtrate. The dregs were then extracted by the same percolation extraction method. The percolation extraction was carried out three times. The filtrate was then separated from the solvent through evaporation in a rotary evaporator at 70ºC until no solvent droplets remained. Any remaining solvent was removed by flowing nitrogen gas. The resulting extract was stored at -4 ºC before use.

Palm kernel meal profiling

In this study, the raw material for palm kernel meal was carefully selected, and its profile was assessed through a Certificate of Analysis (COA). An initial test was conducted to evaluate the parameters of protein, fiber, carbohydrates (starch and reducing sugars), and fat in the raw material. These parameters were used to compare and to ensure the quality of the raw material used in the study.

Palm kernel meal fermentation

The preliminary fermentation process was conducted to improve the quality of PKM (Sukaryana et al., 2013). This process involved the addition of 600 ml of water and 4% alkaline lime per kg of palm kernel meal. The addition of alkaline lime could o reduce the aflatoxin content in PKM (Rubak and Purawisastra, 2011; Arifin et al., 2009). The mixture was then steamed and left for 30 minutes before cooling to 70°C. Subsequently, 4 g of molasses, 5 g of KCl, and 15 g of inorganic nitrogen (urea) per kg of PKM were added and thoroughly mixed (Nurhayati et al., 2006). The mixture was then inoculated with 10 g of *Aspergillus niger* per kg of PKM and transferred to a bamboo tray for fermentation. Fermentation was carried out at 30°C for 3 days. After fermentation, the material was compacted in a vacuum plastic bag and subjected to enzymatic treatment for 2 days at room temperature. Finally, the sample was dried in an oven at 60°C for 2 days.

Koji fermentation
The process of making sauce from PKMl was carried out by combining various procedures to develop the recipe by Herlina et al. (2014), Meutia (2015), and Pratiwi et al. (2012). First, prepared a working culture using a pure culture of *Aspergillus tamarii*. The culture was inoculated into PDA media and incubated at room temperature for 3-5 days. The resulting working culture is ready for use, while the remaining culture was stored at 4°C. Then, the powdered inoculum was made from 15 g of rice and 15 mL of distilled water and mixed in a petri dish wrapped in paper. The rice substrate was sterilized by autoclaving at 121°C for 15 minutes. The sterile rice substrate was then incubated at 30℃ for 3 days. The substrate with the inoculum was dried at 40°C for 3 days and then pulverized with a blender to produce powdered inoculum. The powdered inoculum was used and the remaining was put into the bottle at 4°C. After that, the fermented palm kernel meal was placed on an aluminum tray, covered with a layer of perforated aluminum foil and sterilized at 121°C, 1 atm for 15 minutes. The powdered inoculum was inoculated into palm kernel meal and then incubated at 30℃ for 3 days in a room with 70-80% humidity.

Palm kernel meal moromi
The resulting koji was finely chopped and dried at 40℃ for 3 days and then soaked in 20% salt solution (NaCl) for 4 weeks (Pratiwi et al., 2012). The humidity and temperature were maintained at a range of 70-80% and 30-37℃. The mixture was also exposed to sunlight during fermentation. After the soaking process, the mixture was filtered and the filtrate is referred as moromi sauce.

Palm kernel meal sauce production
The moromi sauce was added to water with a ratio of 2:3 and brought to a boil. The heat was then reduced to approximately 85°C or maintained at a simmer. The study follows a completely randomized factorial design with two factors of palm oil brown sugar concentrations (G1 = 60%, G2 = 75%, and G3 = 90%) and the red chili extract concentrations (C1 = 0%, C2 = 10%, C3 = 20%, and C4 = 30%). Each treatment was also supplemented with additional ingredients, including 1% garlic, 0.1% cinnamon, 1% keluwak, 0.5% sesame, 0.5% candlenut, 0.08% coriander, 0.12% galangal, 0.05% lemongrass, 0.08% kaffir lime leaves, 0.14% bay leaves, 1% salt, and 0.08% pekak (Herlina et al., 2014). After the mixing and stirring, the mixture was periodically stirred for 2-3 hours until it thickened or reached half of its initial volume. The sauce was then subjected to final filtering and chilled to produce palm kernel meal soy sauce. The parameters were tested following SNI 2013, including physical properties (such as color, pH, and total soluble solids/TSS) and chemical properties (such as reducing sugar, protein, and vitamin C). The organoleptic tests were conducted to evaluate color, aroma, taste, viscosity, and general acceptance. The sweet and spicy PKM sauce was then packaged in sterilized bottles. The packaged sauce was stored at room temperature and analyzed for its physical, chemical, and sensory quality.

Liquid yield
The chilies were washed, dried, and ground to become simplicia. The simplicia was weighed to determine its initial weight. The simplicia was extracted with ethanol solvent for up to 3 maceration times and then evaporated to obtain a concentrated extract. The concentrated extract was weighed to determine the final weight. The liquid yield was calculated using Eq. 1:

$$\text{Liquid yield (\%)} = \frac{\text{Final weight (g)}}{\text{Initial weight (g)}} x\ 100\% ...... (1)$$

Color
Color measurement was conducted using a chromameter to obtain the L, a*, and b* values. The sample was placed on a white plate and photographed using the chromameter. The resulting photo was opened to obtain the material’s L, a, and b values. The L value expresses the brightness of the color, ranging from black (0) to white (±100). The symbol "a*" indicates the chromatic color from a combination of red to green, where values of "+a" from 0 to +100 indicate red and "-a" from 0 to -80 indicate green. The symbol "b*" describes the chromatic combination of blue to yellow, with "+b" from 0 to +70 indicating yellow and "-b" from 0 to -80 indicating blue. The L symbol can indicate the sharpness of a color . The higher the L value, the higher the sharpness of the color. The values of a* and b* can be calculated as *ºHue*.

pH
The pH value was analyzed using a pH meter. Before use, the pH meter was calibrated using buffer solutions with pH 4 and 7 (Pakale et al., 2018). The pH meter was turned on and allowed

to stabilize for 15-30 minutes. The pH meter electrode was rinsed with distilled water and dried with a tissue. The electrode was then inserted into the sample solution until the pH readings on the pH meter remained unchanged. The sample's pH value was recorded.

***Total soluble solid* (TSS)**

TSS measurement was conducted using a refractometer. The sample filtrate was carefully dropped onto the prism of the refractometer, and the reading was taken. Prior to and after use, the refractometer prism was cleaned using alcohol. The TSS value was indicated by the numbers located between the blue and white lines on the refractometer scale, expressed in °Brix units of sucrose. The dilution factor (DF) used in the calculation was determined by dividing the final volume of the sample by its initial volume. The TSS was calculated using Eq. 2:

$$TSS\ (^{\circ}Brix) = \text{refractometer number}\ x\ DF \text{..} (2)$$

Protein

A sample weighing 10 g was mashed and mixed with 100 mL of distilled water until fully dissolved. The mixture was stirred using a stirrer for 15 minutes and subsequently filtered. The obtained filtrate was further diluted with distilled water in a 100 mL measuring flask. From the diluted solution, 10 mL was taken and combined with 20 mL of distilled water, 0.4 ml of potassium oxalate, and 1 mL of indicator. The solution was then titrated with 0.1 N NaOH until it turned pink. In a separate step, 2 mL of 40% formaldehyde and PP indicator were added to the filtrate, followed by another titration with 0.1 N NaOH. The titration volume used was recorded and the protein content was calculated using Eq. 4. The DF was calculated on the basis of the final volume per sample initial volume.

$$\text{N (\%)} = \frac{\text{mL titration x N NaOH x 14,008 x DF}}{\text{Sample weight (g)}\ x\ 10}\ x\ 100\% \text{......(3)}$$

$$\text{Protein (\%)} = \%\ \text{N}\ x\ CF \text{................................. (4)}$$

Where, N is normality (0.1) and Cf is conversion factor (6.25)

Reducing sugar

The reducing sugar was analysed using the Nelson-Samogyi method, involving the measurement of reducing sugar and starch. First, 5 mL of the sample was mixed with 143.75 mg of amylase enzyme and left to stand for 6 hours. Then, 1 mL of the amylase-treated sample and 1 mL of the sample without amylase were separately mixed with distilled water to a total volume of 10 mL. From each mixture, 1 mL was taken and combined with 9 mL of distilled water, then vortexed to ensure thorough mixing. Next, 1 mL of the sample was added to 1 mL of Nelson's solution, which is a mixture of Nelson A and Nelson B solutions at a 25:1 ratio. The mixture was then heated in a water bath at 100°C for 20 minutes. After cooling to room temperature, 1 mL of arsenomolybdate solution was added and mixed. Subsequently, 7 mL of distilled water was added and the solution was mixed again. The absorbance of visible light was then measured at a wavelength of 540 nm using a spectrophotometer. The absorbance value of the sample was subtracted by the absorbance value of the blank to obtain the corrected absorbance value. This corrected absorbance value was then converted to mg/mL of reducing sugar using a calibration curve. The reported reducing sugar content indicates the amount of reducing sugar present in the sample, excluding the contribution from the amylase enzyme.

Vitamin C

The vitamin C content was analysed using the iodometric method, starting with adding 10 g of the refined material to 15 mL of distilled water. The mixture was then transferred to a volumetric flask and diluted with additional distilled water to reach a total volume of 100 mL. Thorough stirring was performed to ensure homogeneity, followed by filter paper filtration to obtain a clear filtrate. Next, 10 mL of the filtrate was transferred to an Erlenmeyer flask, and 2-3 drops of a 1% starch solution were added. The solution was then titrated using 0.01 N iodine solution. The titration process continued until the color changed to a stable blue, indicating the completion of the reaction. The vitamin C content was calculated using Eq. 5.

$$\text{Vitamin C content (\%)} = \frac{\text{mol iodine 0.01 N x 0.88 x DF}}{\text{Sample weight (g)}}\ x\ 100\% \text{ .... (5)}$$

Sensory

The hedonic preference test was conducted to evaluate the organoleptic qualities of taste, aroma, color, viscosity, and general acceptance. The respondents were 105 semi-trained panelists, consisting of male and female students aged 18-22 years from the Food Technology Study Program.

The panelists had prior experience consuming soy sauce. The samples were provided to the panelists in a non-sequential manner, with each sample marked for identification. The PKM sauce samples were served in clear plastic cups. The sensory evaluation was performed using a numerical scale ranging from 1 to 7, where 1 represented "strongly dislike" and 7 represented "strongly like".

Statistical analysis

Data analysis was done using a factorial analysis of variance (ANOVA). The results of the final PKM sauce products were presented as mean values ± standard deviation. Rhe Duncan Multiple Range Test (DMRT) was employed to determine the homogeneity among the samples and identify statistically significant differences. The DMRT was used to compare the means of all treatments with a confidence interval of 95% and 99%. The statistical analysis was performed using Microsoft Excell 2010.

Results and Discussion

Palm kernel meal profiling

The results of the analysis of the raw materials used are shown in Table 1. The data indicate that PKM is made up of 7.98% fat, 17.97% crude fiber, 15.83% protein, and 5.13% water content.

Liquid yield of red chili

The red chili extract yield was obtained through maceration using ethanol solvent for 3 cycles, followed by evaporation to obtain a concentrated extract. The concentrated extract was weighed and divided by the initial weight of the red chili used, resulting in a yield of 23.05%. The extract has a viscous consistency, a blackish-brown color, and a characteristic odor with a bitter taste. Ethanol was chosen as the solvent for extracting active compounds from the red chili due to its ability to filter various compounds with varying polarities, from nonpolar to polar compounds (Salamatullah et al., 2022).

Color a*

Table 2 and Figure 2a indicate that the interaction between palm oil brown sugar concentration and red chili extract concentration had a highly significant effect (P<0.01) on the a* value of PKM sauce. Therefore, the DMRT test was conducted. Previous studies by Kim and Lee (2008) have shown that the color of PKM sauce was influenced by the browning reaction, which is affected by the heating process of the sugar. This process can also impact the color, flavor, and natural pigments in the extracted ingredients. Another study by Rivera and Alejo (2020) mentioned that adding red chilies contributes to the red color of the sauce due to the presence of carotenoids, such as beta-carotene and capsanthin, as well as gluten and antioxidants. However, excessive amounts of chili extract can lead to a darker color.

Color b*

Table 2 and Figure 2b indicate that the interaction between palm oil brown sugar concentration and red chili extract concentration had a highly significant effect (P<0.01) on the (b) value of PKM sauce. Therefore, the DMRT test was conducted. The yellow color observed in sweet and spicy PKM sauce is attributed to the presence of carotene pigment naturally found in PKM. As stated by Ruswanto et al. (2021), carotenoids are hydrogenated unsaturated hydrocarbon compounds that contribute to the yellow color. Supporting literature by Berry et al. (2021) suggests that the yellow color, in this case, is influenced by carotenoids, particularly those found in red chili. that the findings confirmed that an increased concentration of red chili extract intensifies the yellow color of the sauce.

Index color (ºHue)

Table 2 dan Figure 2c reveal that the interaction between palm oil brown sugar concentration and red chili extract concentration had a highly significant effect (P<0.01) on the index color value (º*Hue*) of PKM sauce. Therefore, the DMRT test was conducted. This finding is consistent with Smith (2014), who reported that the º*Hue* value represents the color angle measurement. Specifically, a º*Hue* of 0º signifies a red color, whereas a º*Hue* of ≥90º indicates a yellow color.

Total soluble solids (TSS)

Table 3 and Figure 3a illustrate that the interaction between palm oil brown sugar concentration and red chili extract concentration had a highly significant effect (P<0.01) on the TSS of PKM sauce. The DMRT test was subsequently conducted to analyze the results further. It was observed that the higher concentration of sugar (90%) in the G3C1 treatment resulted in a higher TSS value of 89.484 ºBrix. This finding is consistent with Nilar and Myint (2012), that the amount of sugar used directly influences the TSS content of the sauce. Furthermore, adding spices, such as red chili extract, increases the TSS in PKM sauce. The dissolved solids content is closely associated with the turbidity or brightness level of the sauce.

Table 2. The palm kernel meal sauce characterizations: color

Code	Color (L) Value^{ns}	Color (a) Value**	Color (b) Value**	Index Color (°*Hue*) **
G1C1	30.88±0.76	7.68±0.53^{bcBC}	3.12±0.33^{dC}	22.21±2.85^{cCD}
G1C2	31.92±1.80	9.86±0.38^{efEF}	6.63±0.16^{efDE}	33.63±6.44^{dE}
G1C3	27.40±0.73	9.68±0.15^{efDEF}	7.49±0.31^{fgEF}	37.72±1.56^{dEF}
G1C4	28.06±0.23	10.42±0.09^{fgEF}	8.20±0.09^{gF}	38.21±0.28^{dEF}
G2C1	28.91±0.43	7.27±0.61^{bB}	1.31±0.25^{abAB}	10.20±1.31^{aA}
G2C2	29.88±0.22	9.45±0.12^{eDE}	2.49±0.57^{cdBC}	14.77±3.34^{abAB}
G2C3	30.42±0.03	9.35±0.34^{deDE}	3.17±0.12^{dC}	18.76±1.12^{bcBCD}
G2C4	30.21±2.14	12.68±0.27^{hG}	5.59±0.20^{eD}	23.77±0.42^{cD}
G3C1	28.83±0.78	8.57±0.48^{dCD}	0.63±0.45^{aA}	16.57±2.65^{bABC}
G3C2	29.18±1.64	5.93±0.67^{abA}	1.55±0.08^{bcAB}	23.50±3.11^{cD}
G3C3	27.45±0.08	5.27±0.28^{aA}	5.76±0.13^{eD}	47.52±1.34^{eG}
G3C4	28.32±0.32	10.83±0.67^{gF}	10.44±0.13^{hG}	44.06±2.06^{eFG}

Note: ** means within the same column, followed by different letter notations show significantly different effects at the 5% level (p < 0.05) (lowercase letters) and highly significant 1% (p > 0.01) (uppercase letters) according to Duncan Multiple-Range Test. ±S.D., standard deviation; G1 = 60% sugar; G2 = 75% sugar; G3 = 90% sugar; C1= chili 0%; C2= chili 10%; C3= chili 20%; C3= chili 30%. ns = no significant difference.

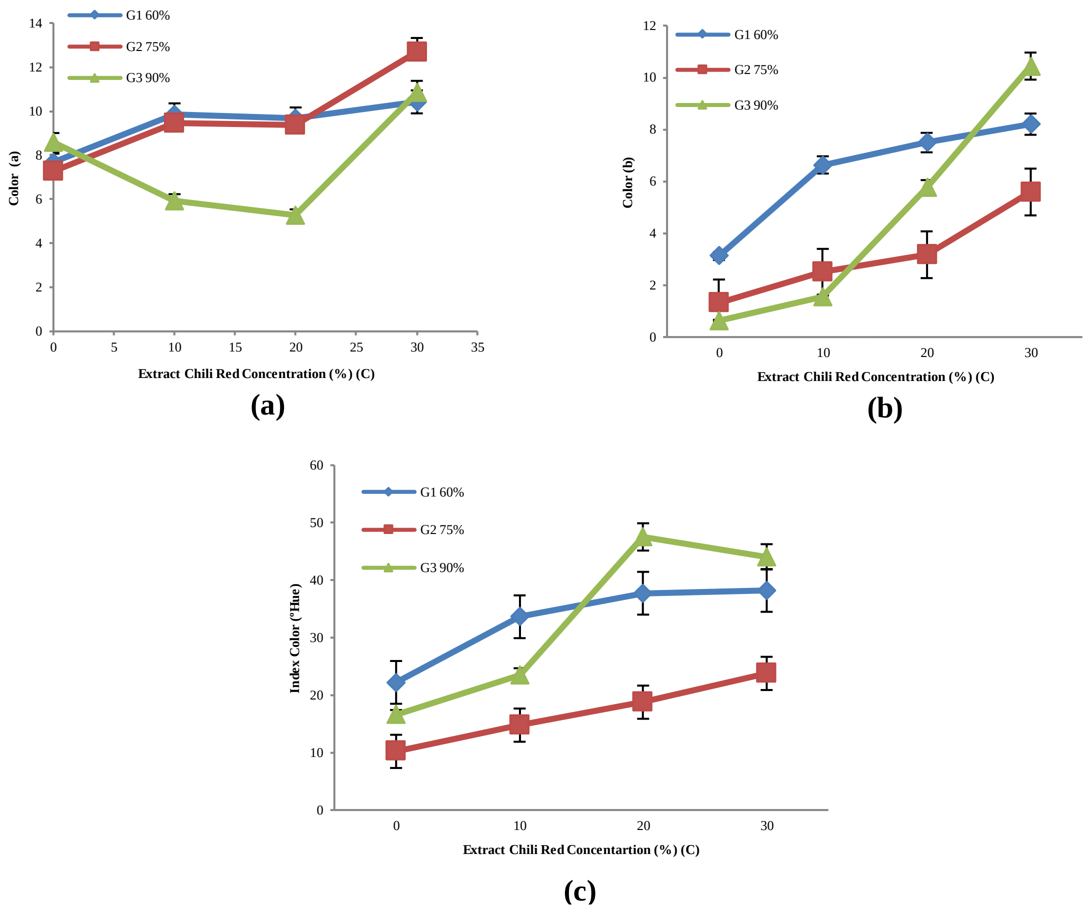
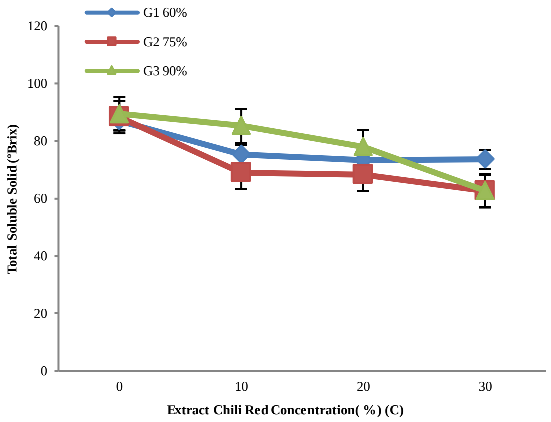


Figure 2. The effect of palm oil brown sugar concentration and red chili concentration on the a* value (a) b* value (b) °*Hue* value (c) of PKM sauce. G1= 60% palm oil brown sugar, G2= 75% palm oil brown sugar, G3= 90% palm oil brown sugar

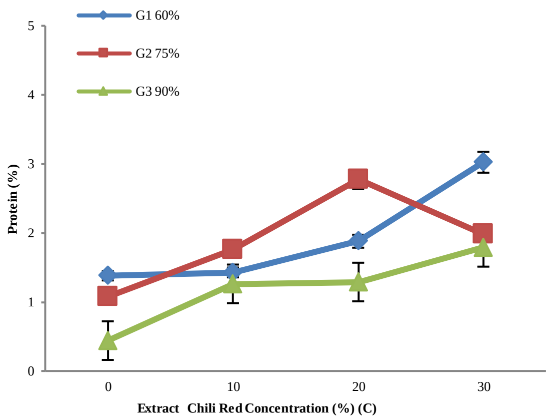
Table 3. The palm kernel meal sauce characterizations: pH, TSS, protein, reducing sugar, and vitamin C

Code	pH^{ns}	TSS^{**}	$Protein^{**}$	$Reducing\ Sugar^{ns}$	$Vitamin\ C^{**}$
G1C1	4.28±0.21	87.00±0.50^{ijEF}	1.38±0.70^{bcAB}	27.73±4.23	1.38±0.70^{bB}
G1C2	3.67±0.17	75.28±0.25^{efgCD}	1.42±0.70^{bcB}	33.95±1.23	1.42±0.70^{bBC}
G1C3	3.40±0.17	73.31±0.23^{eC}	1.88±0.73^{cBC}	29.29±6.49	1.88±0.73^{bcBCD}
G1C4	3.38±0.05	73.50±0.50^{efC}	3.02±0.77^{eD}	29.15±3.10	3.02±0.77^{dD}
G2C1	4.56±0.30	88.28±0.05^{jkEF}	1.07±0.65^{abAB}	29.08±10.38	1.07±0.65^{bBC}
G2C2	3.61±0.26	68.91±0.63^{cdB}	1.75±0.67^{bcBC}	39.22±14.30	1.75±0.67^{bBC}
G2C3	3.57±0.26	68.11±3.07^{cB}	2.77±0.72^{deCD}	35.74±12.44	2.77±0.72^{bB}
G2C4	3.60±0.25	64.63±1.12^{aA}	1.97±0.55^{cdBCD}	39.63±11.30	1.97±0.55^{dD}
G3C1	4.46±0.24	89.48±0.40^{kF}	0.44±0.52^{aA}	50.18±18.42	0.44±0.52^{aA}
G3C2	3.57±0.17	85.19±0.37^{iE}	1.26±0.26^{bcAB}	48.29±10.75	1.26±0.26^{bBC}
G3C3	3.45±0.20	77.97±1.83^{hD}	1.28±0.26^{bcAB}	31.46±9.21	1.28±0.26^{bcBCD}
G3C4	3.45±0.14	62.71±1.85^{abA}	1.79±0.08^{bcBC}	30.72±13.25	1.79±0.08^{cdCD}

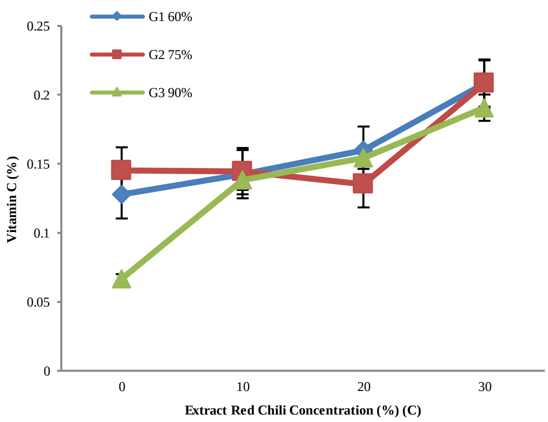
Note: ** means within the same column, followed by different letter notations show significantly different effects at the 5% level ($p < 0.05$) (lowercase letters) and highly significant 1% ($p > 0.01$) (uppercase letters) according to Duncan Multiple-Range Test. ±S.D., standard deviation; G1 = 60% sugar; G2 = 75% sugar; G3 = 90% sugar; C1= chili 0%; C2= chili 10%; C3= chili 20%; C3= chili 30%. ns = no significant difference. TSS = total soluble solids



(a)



(b)



(c)

Figure 3. The effect of palm oil brown sugar concentration and red chili concentration on the *Total Soluble Solid* (a) protein (b) vitamin C (c) of palm kernel meal sauce. G1= 60% palm oil brown sugar, G2= 75% palm oil brown sugar, G3= 90% palm oil brown sugar

Protein

Table 3 and Figure 3b reveal that the interaction between palm oil brown sugar concentration and red chili extract concentration had a highly significant effect (P<0.01) on the protein content of PKM sauce. The DMRT test results confirmed that palm oil brown sugar concentration did not significantly affect the protein value (P>0.05). However, the concentration of red chili extract exhibited a highly significant effect on the protein content. Notably, the G1C4 treatment, with a higher concentration of red chili extract (30%), displayed a higher protein value of 3.02%.

These findings align with Chakrabarty et al. (2017)that red chili contains various nutritional components, including carbohydrates, fats, calcium, vitamins, and protein. The protein content in red chili is estimated to be around 1.9% (Food Data Central Search Result, 2018). Hence, it is evident that increasing the concentration of red chili extract in PKM sauce enhances its protein content.

Vitamin C

Table 3 and Figure 3c present the highly significant interaction effect (P<0.01) of palm oil brown sugar concentration and red chili extract concentration on the vitamin C content of PKM sauce. The DMRT test results show that palm oil brown sugar concentration have no significant effect on the vitamin C content (P>0.05). However, the concentration of red chili extract exhibited a highly significant effect on the vitamin C content. According to the United States Department of Agriculture, red chilies contain a substantial amount of vitamin C, approximately 143.7 mg per 100 g of material. This finding aligns with Azlan et al. (2022), which states that red chilies have high levels of vitamin C (ascorbic acid) and beta carotene, surpassing commonly consumed fruits in terms of content. Additionally, Dedin et al. (2006) stated that soy sauce contains ascorbic acid, polyphenols, and furfural in minute amounts, and the Maillard reactions occurring in soy sauce are primarily influenced by sugars and amino acids. Consequently, adding a higher concentration of red chili extract to soy sauce may increase the vitamin C content.

Sensory analysis results

Aroma

Table 4 and Figure 4a illustrate the highly significant interaction effect (P<0.01) of palm oil brown sugar concentration and red chili extract concentration on the aroma of PKM sauceThe DMRT test results also reveal that the interaction between the concentration of palm oil brown sugar and red chili extract had a highly significant effect on the aroma. The G2C1 treatment (75% palm oil brown sugar and 0% red chili extract) obtained the highest value of 6.091, while the G2C4 treatment (75% palm oil brown sugar and 30% red chili extract) obtained the lowest value of 5.616. The addition of brown sugar and red chili extract significantly influenced the aroma of the sweet and spicy PKM sauce. Adding red chili extract with a higher concentration of brown sugar intensifies the aroma due to the presence of volatile compounds in chilies. Forde and Graaf (2022) emphasize that aroma is a sensory attribute determined by an individual's sense of smell and is considered a key factor in determining the product's overall appeal that inform like and dislike. This finding aligns with Kiliroong et al. (2021), who state that sugar used in the production of sweet PKM sauce impacts color and provides sweetness, taste, and aroma.

Moreover, Liu et al. (2022) noted that the cooking process of brown sugar imparts a delightful aroma that remains in the sugar and contributes to the distinct aroma of soy sauce. Also, adding red chili extract influences the aroma of PKM sauce. Berry et al. (2021) stated that the presence of oleoresin in red chili, could provide a unique aroma. Oleoresin contains resins, volatile essential oils, and other active ingredients.

Taste

Table 4 and Figure 4b demonstrate the highly significant interaction effect (P<0.01) of palm oil brown sugar concentration and red chili extract concentration on the taste of PKM sauce. The DMRT test results indicate that the interaction between the concentration of palm oil brown sugar and red chili extract significantly affected the taste. The G2C1 treatment (75% palm oil brown sugar and 0% red chili extract) obtained the highest value of 6.135, while the G1C4 treatment (60% palm oil brown sugar and 30% red chili extract) obtained the lowest value of 5.525. In sweet and spicy PKM sauce, sugar concentration plays a significant role in determining the taste. Maina (2018) emphasized that taste greatly influences a consumer's final decision to accept a product. Zhou et al. (2019) mentioned that soy sauce produces a distinct taste and amino acid contents depending on the ingredients used and the taste-forming enzymes produced by bacteria and yeast during moromi fermentation.

Table 4. The palm kernel meal sauce characterizations: hedonic

Code	Color^{ns}	Aroma**	Taste**	Viscosity**	General Acceptance**
G1C1	5.66±0.11	5.66±0.05^{abcAB}	5.64±0.11^{bcdABC}	5.54±0.11^{abAB}	5.71±0.08
G1C2	5.73±0.04	5.69±0.10^{bcAB}	5.62±0.00^{abcABC}	5.58±0.10^{abcABC}	5.71±0.03
G1C3	5.73±0.06	5.66±0.04^{abcAB}	5.56±0.03^{abA}	5.53±0.06aA	5.78±0.11
G1C4	5.72±0.08	5.63±0.07^{abAB}	5.52±0.18^{aA}	5.55±0.00^{abABC}	5.61±0.04
G2C1	6.12±0.03	6.09±0.05^{dC}	6.13±0.07^{eD}	5.95±0.06^{hG}	5.95±0.36
G2C2	6.04±0.02	6.05±0.07^{dC}	6.08±0.08^{eD}	5.88±0.02^{ghFG}	5.89±0.29
G2C3	5.78±0.09	5.61±0.09^{aA}	5.62±0.07^{abcABC}	5.62±0.07^{abcdABCD}	5.68±0.16
G2C4	5.76±0.08	5.64±0.02^{abcAB}	5.57±0.02^{abAB}	5.64±0.00^{bcdABCD}	5.81±0.15
G3C1	5.78±0.05	5.71±0.04^{cB}	5.74±0.08^{dC}	5.70±0.02^{defCDE}	5.74±0.14
G3C2	5.83±0.04	5.69±0.01^{bcAB}	5.71±0.04^{cdBC}	5.80±0.05^{fgEFG}	5.67±0.18
G3C3	5.77±0.03	5.71±0.03^{cB}	5.65±0.06^{bcdABC}	5.67±0.05^{cdeBCDE}	5.66±0.04
G3C4	5.87±0.07	5.69±0.09^{bcAB}	5.74±0.08^{dC}	5.76±0.07^{efDEF}	5.73±0.05

Note: ** means within the same column, followed by different letter notations show significantly different effects at the 5% level (p < 0.05) (lowercase letters) and highly significant 1% (p > 0.01) (uppercase letters) in the same column according to Duncan Multiple-Range Test. ±S.D., standard deviation; G1 = 60% sugar; G2 = 75% sugar; G3 = 90% sugar; C1= chili 0%; C2= chili 10%; C3= chili 20%; C3= chili 30%. ns = no significant difference

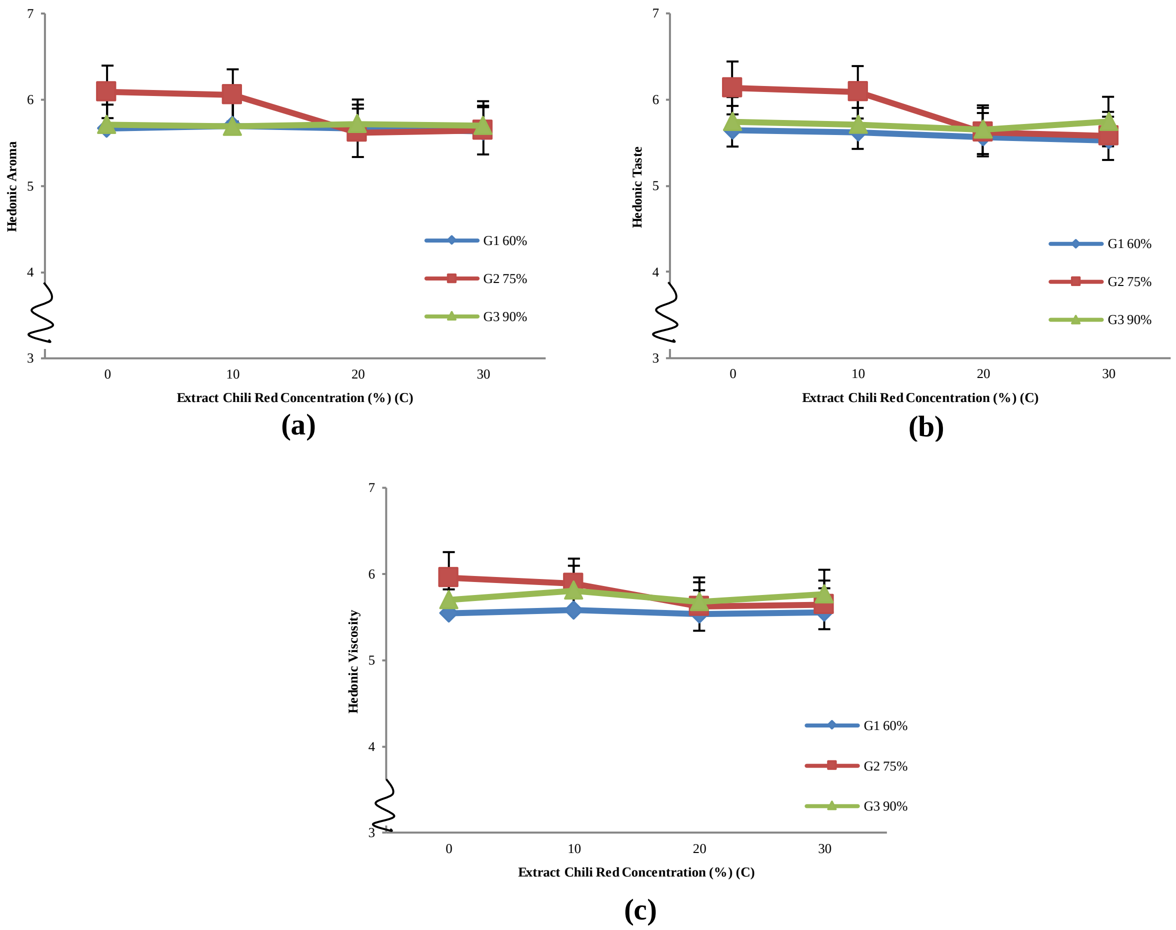


Figure 4. The effect of palm oil brown sugar concentration and red chili concentration on aroma (a), taste (b), and viscosity (c) of palm kernel meal sauce. G1= 60% palm oil brown sugar, G2= 75% palm oil brown sugar, G3= 90% palm oil brown sugar

Wang et al. (2023) noted that the sweet taste of soy sauce is derived from ingredients containing 75-90% sucrose. The reducing sugars content determines the sweetness of soy sauce. A higher content of reducing sugar may lead to a sweeter taste that can be influenced by sugar concentration and heating time. Furthermore, adding red chili extract also impacts the hedonic value of palm kernel meal sauce, as stated by Saleh et al. (2018). They further added that the spicy taste of chili is attributed to the presence of capsaicin, an alkaloid found in chili seeds and the placenta. Capsaicin acts as an appetite enhancer, contributing to the overall sensory experience of the sauce.

Viscosity

Table 4 and Figure 4c indicate that the interaction effect of palm oil brown sugar concentration and red chili extract concentration had a highly significant effect ($P<0.01$) on the viscosity of PKM sauce. The DMRT test results show that adding brown sugar and red chili extract influences the viscosity of sweet and spicy PKM sauce. Each panelist has a plastic spoon for each sample in the viscosity evaluation. The samples were presented, and the panelists dipped the spoon into the sauce sample and observed its viscosity as they lifted the spoon. The highest viscosity value of 5.955 was obtained in the G2C1 treatment (75% palm oil brown sugar and 0% red chili extract) . While the lowest viscosity value of 5.534 was recorded in the G1C3 treatment (60% palm oil brown sugar and 20% red chili extract). According to Retnaningsih et al. (2017), viscosity is vital in the hedonic testing for sauce products as it can serve as a control parameter in the manufacturing process. An increase in brown sugar concentration leads to higher viscosity, which is also influenced by the cooking process of the PKM sauce.

Conclusions

The interaction between variations in the concentration of palm oil brown sugar and red chili extract had a highly significant effect ($P<0.01$) on color (*ºHue*), color value (a), color value (b), TSS, aroma, taste, viscosity of PKM sauce. These factors also had a significantly different effect on protein and vitamin C content of PKM sauce ($P<0.01$). However, no significant effects were found on L* color value, pH, reducing sugars, color, and general acceptance of PKM sauce ($P>0.05$) .

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Declarations

Conflict of interests The authors declare no competing interests.

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