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Red Palm Olein Oil-Enhanced Instant Noodle: A Functional Food Innovation for Diabetes-friendly Formulation

Budiyanto Budiyanto[1#], Devi Silsia[2], Ulfah Anis[2], Arina Fatharani[2], Fauzan Azima[3], Yana Cahyana[4], Addion Nizori[5]

[1]*Department of Coffee Science, University of Pat Petulai, JL. Basuki Rahmat No.13, Dwi Tunggal, Curup, Rejang Lebong, 39119, Indonesia*
[2]*Department of Agricultural Technology, Faculty of Agriculture, University of Bengkulu, Jl. WR. Supratman No.1, Kandang Limun, Bengkulu, 38122, Indonesia*
[3]*Department of Food Technology and Agricultural Product, Universitas Andalas, Limau Manis, Padang, 25175, Indonesia*
[4]*Department of Food Technology, Faculty of Agro-Industrial Technology, Universitas Padjajaran, Bandung, 45363, Indonesia*
[5]*Department of Agricultural Product Technology, Faculty of Agriculture, Universitas Jambi, 36361, Indonesia*

[#]*Corresponding author: E-mail:* budi.budiyanto@gmail.com

***Abstract*— The global rise in type-2 diabetes has increased interest in functional foods that can help prevent or manage the disease. Red Palm Olein Oil (RPOO), rich in antioxidants such as tocotrienols, tocopherols, and β-carotene, has shown promise in reducing oxidative stress and improving insulin sensitivity. This study aimed to develop a low-calorie, functional instant noodle using RPOO to provide anti-diabetic benefits while retaining consumer appeal. Konjac flour, a low-calorie ingredient, was combined with RPOO to create a nutritious noodle product. The production of RPOO involved fractionating crude palm oil (CPO) to yield a product rich in antioxidants, which were measured for their antioxidant activity. The noodles were formulated by replacing conventional oils with RPOO-based seasoning, and their physical, chemical, and sensory properties were analyzed. Results showed that the RPOO-substituted noodles had significantly higher vitamin E content, contributing to antioxidant effects. Sensory evaluation indicated that the 75:25 RPOO-seasoning oil ratio received the highest acceptance regarding color, aroma, and taste. Proximate analysis revealed that the noodles were low in calories (73.81 kcal per 100g), making them suitable for health-conscious consumers. The findings suggest that RPOO-enhanced instant noodles could serve as a functional food for diabetes-friendly formulation, providing a novel approach to integrating health benefits into widely consumed food products.**

***Keywords*— antioxidant food; diabetes-friendly formulation; functional noodles; konjac; red palm olein oil**

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I. INTRODUCTION

The global escalation in type-2 diabetes, a degenerative disease, poses significant health and economic challenges. Diabetes results from chronic hyperglycemia, frequently driven by oxidative stress that impairs pancreatic beta-cell function and insulin production. The oxidative stress exacerbates diabetes and is linked to heightened risks of cardiovascular disease, hypertension, and certain cancers. It ranks diabetes among the leading causes of mortality worldwide [1-5] In recent years, studies have explored antioxidants as a dietary strategy for regulating diabetes, as they help counteract oxidative damage and strengthen insulin regulation (Field [6, 7]). In addition, antioxidants present in *A. ilicifolius* leaf extract were suggested to possess the potential to effectively inhibit the activity of α-glucosidase and α-amylase, key enzymes involved in the hydrolysis of starch into monosaccharides and their subsequent absorption in the intestine. Such inhibitory activity may have contributed to the modulation of postprandial blood glucose levels, thereby supporting glycemic control [8].

Red palm olein oil (RPOO), a fraction of crude palm oil rich in tocotrienols, tocopherols, and beta-carotene, has emerged as a promising candidate for diabetes-friendly formulations [5], [9]. Tocotrienols, in particular, have shown the potential to lower blood glucose levels and improve insulin sensitivity by

reducing oxidative stress in vascular tissues [8,9]. However, challenges remain: tocotrienols in RPOO are susceptible to oxidative degradation during processing and storage, which can affect their stability and bioavailability [10,11]. Additionally, RPOO's characteristic taste can impact its acceptance, making it essential to explore innovative, acceptable food formulations for broader consumption [9,10], [12,13].

This study aims to develop a low-calorie, functional instant noodle incorporating RPOO to provide anti-diabetic benefits in a widely consumed product, combining RPOO with konjac noodles, a low-calorie ingredient. This study aims to create a calorie-conscious food that meets health needs while retaining consumer appeal. This work contributes to functional food research and provides a novel dietary tool for diabetes prevention, with potential applications for mitigating other oxidative stress-related conditions. This study's outcomes will also extend the knowledge base on RPOO applications, potentially guiding further innovations in health-focused food products.

II. Material and Methods

A. Materials

Crude Palm Oil (CPO) was obtained from local palm oil producers and analyzed for its initial quality attributes. Konjac noodles (commercial-grade) were purchased from local markets and used without further modification. All chemicals, including methanol, acetonitrile, iso-octane, KOH (50% w/v), glacial acetic acid, and ethanol, were of analytical grade. Reagents for HPLC, Folin–Ciocalteu, and aluminum chloride assays were supplied by Sigma-Aldrich (USA). Characterization of CPO and RPOO (DOBI Value, Carotene Content, Total Phenolics, Total Flavonoids, and Antioxidant Activity) using a Spectrophotometer UV Vis Agilent 60. Vitamin E Analysis using Method 18-5-1/MU/SMM-SIG (HPLC-PDA) and a Thermo Scientific™ Vanquish™ Horizon UHPLC system coupled to a Thermo Scientific™ Orbitrap™ Exploris 240 high-resolution mass spectrometer. Chromatographic separation used an Accucore™ C18 column (100 × 2.1 mm, 2.6 µm) with a mobile phase of water and acetonitrile (both with 0.1% formic acid) under a 25-min gradient program. The HRMS operated in positive electrospray ionization mode with full MS/dd-MS² acquisition. Sample preparation followed a methanol-based extraction involving vortexing, sonication, centrifugation, dilution, and filtration prior to injection.

B. Methods

Selection of Crude Palm Oil (CPO) for Red Palm Olein Oil (RPOO) Production

Crude Palm Oil (CPO) samples were collected from nine palm oil processing industries located in Bengkulu Province. Each sample was homogenized and analyzed to determine its suitability as raw material for Red Palm Olein Oil (RPOO) production. The assessment was based on two key quality parameters: free fatty acid (FFA) content, expressed as acid value, and DOBI (Deterioration of Bleachability Index). FFA was determined using the standard alkaline titration method, while DOBI values were measured spectrophotometrically according to the recommended palm oil quality evaluation procedures. CPO samples that met the criteria of low FFA content and high DOBI values, indicating good oxidative stability and better carotenoid retention potential, were classified as high-quality oils. Based on the results, three CPO samples fulfilled the quality requirements and were subsequently used as raw materials for RPOO production.

Preparation of RPOO

The selected high-quality CPO samples were processed into Red Palm Olein Oil (RPOO) via double fractionation and subsequent refining. Fractionation was carried out using temperature differences, following the method of [16]. The CPO was first heated to 70°C and then cooled to 23°C to induce crystallization. The solid stearin fraction was removed, and the liquid olein fraction was collected. The olein fraction was then reheated to 70°C and cooled again to 20°C for a second crystallization step. The resulting stearin fraction was separated, and the final olein fraction was used for refining. The refining process began with degumming, in which the olein fraction was heated to 60°C for 30 min. Acid degumming was performed by adding 0.09% (w/w) phosphoric acid (85%) under continuous stirring. The degummed olein was then neutralized by adding 0.15 N NaOH (8% v/v of the total volume). The mixture was heated to 60°C and stirred for 25 min. The neutralized oil was washed twice using water equivalent to 15% of the sample weight in a separatory funnel, followed by centrifugation at 2700 rpm for 10 min to remove remaining impurities [12], [15], [18].

The final step was deodorization. Deodorization was carried out to remove volatile compounds responsible for undesirable flavors and odors. The washed olein fraction was heated to 100°C for 30 min, with nitrogen gas introduced every 10 min at a flow rate of 5 m/s. This deodorization step was repeated three times to ensure optimal removal of off-odor compounds and to obtain high-quality Red Palm Olein Oil (RPOO) [19]. After deodorization, Red Palm Olein Oil (RPOO) is obtained.

Characterization of CPO and RPOO

Determination of DOBI and FFA

0.1 g of CPO or RPOO was weighed and dissolved in 25 mL of iso-octane. The solution was analyzed using UV-Vis spectrophotometry at wavelengths of 446 nm and 269 nm to calculate the DOBI value [20]. The formula used for DOBI calculation was as follows:

$$DOBI = \frac{Abs\ 446}{Abs\ 269} \quad \text{eq (1)}$$

FFA content was determined by titration with a standardized sodium hydroxide (NaOH) solution, using phenolphthalein as an indicator [21].

Carotene quantification

Approximately 0.1 g of CPO was heated to melt the oil, after which 25 mL of hexane was added. The solution was then measured using a UV–Vis Spectrophotometer at a wavelength of 446 nm [22].

Total phenol content

Total phenolic content was determined by the Folin-Ciocalteu method [23]. A 0.1 g sample of RPOO was extracted with methanol, and the resulting extract was mixed with 2 mL of Folin-Ciocalteu reagent. After a 5-minute reaction period, 2 mL of 20% sodium carbonate (Na_2CO_3) solution was added, and the mixture was left to stand for 30 minutes at room temperature. The absorbance of the solution was measured at 740 nm using a UV-Vis spectrophotometer. The total phenolic content was calculated and expressed as milligrams of gallic acid equivalent per 100 g of dry sample (mg GAE/100 g).

Total Flavonoid content

Total flavonoid content was determined by the aluminum chloride colorimetric method [23]. A 1 mL aliquot of the RPOO sample was mixed with 1 mL of methanol and 0.1 mL of a 10% aluminum chloride solution. The mixture was allowed to react, and the absorbance was measured at 415 nm using a UV-Vis spectrophotometer. The flavonoid content was quantified by interpolating the absorbance value against a calibration curve prepared using quercetin as the standard.

Antioxidant activity

Antioxidant activity was determined by the DPPH (2,2-diphenyl-1-picrylhydrazyl) method [24]. A 1 mL aliquot of RPOO extract at various concentrations was mixed with 1 mL DPPH solution (0.15 mM in ethanol). The reaction mixture was incubated in the dark at room temperature for 30 minutes. After incubation, the absorbance was measured at 517 nm using a UV-Vis spectrophotometer. The antioxidant activity was expressed as the Ascorbic Acid Equivalent Antioxidant Capacity (AEAC), calculated using the following formula:

$$AEAC\ \left(\frac{mg\ AA}{100g}\right) = \frac{IC_{50}(asorbic\ acid)\ .100{,}000}{IC_{50}(sample)} \qquad \text{Eq (2)}$$

Production of instant fried noodles

RPOO derived from the selected CPO was used as a substitute for seasoning oil (garlic-infused frying oil) commonly used in instant fried noodle seasonings. Konjac noodles were used as the noodle base for their low-calorie and functional characteristics.

Vitamin E (α-tocopherol and α-tocotrienol) analysis

Analysis was performed using liquid chromatography (Thermo Scientific™ Vanquish™ Horizon UHPLC with Binary Pump (Germany) and OrbitrapTM Exploris 240 HRMS (Bremen, Germany). Chromatographic separation was performed using a Thermo Scientific™ Accucore™ C18 analytical column (100 mm × 2.1 mm i.d., 2.6 µm particle size; Lithuania). A binary solvent system was used, in which mobile phase A was MS-grade water supplemented with 0.1% (v/v) formic acid, and mobile phase B was MS-grade acetonitrile supplemented with 0.1% (v/v) formic acid. A 500 µL aliquot of the sample was mixed with 1.0 mL of 70% HPLC-grade methanol and vortexed for 2 min, then sonicated for 30 min at 25 °C. The mixture was centrifuged at 12,000 × g for 5 min, and 300 µL of the resulting supernatant was transferred into a new microcentrifuge tube and diluted with 1.0 mL of MS-grade water. The solution was incubated at 4 °C for 15 min and centrifuged at 12,100 × g for 30 min at 25 °C. The final supernatant was filtered through a 0.2 µm nylon membrane filter and subsequently used for LC injection [25].

Selection of Seasoning Formula

A preliminary sensory assessment was conducted to select the most preferred commercial instant fried noodle seasoning to serve as the base for the Konjac fried noodles. Several seasoning sachets available on the market were presented to panelists, and the seasoning with the highest preference score was selected for use in this study.

Preparation of Instant Fried Konjac Noodles

The noodle preparation process was adapted from the method described in [15]. A total of 90 g of Konjac noodles were boiled for 8 min in boiling water, then drained to remove excess moisture. The selected seasoning powder was added, followed by the application of seasoning oil (SO). The seasoning oil used in this study consisted of garlic-flavored frying oil, in which palm oil was partially or fully substituted with Red Palm Olein Oil (RPOO). The substitution was carried out at the following ratios (RPOO:SO) 100:0, 75:25, 50:50, 25:75, and 0:100. The seasoned Konjac fried noodles were then mixed thoroughly and prepared for organoleptic evaluation.

Chemical, Physical, and Organoleptic Evaluation of Instant Fried Noodles

Moisture content

Moisture content in the noodles was determined by the thermogravimetric method. The sample was oven-dried at 105°C for 24 hours until a constant weight was achieved. The moisture content was calculated using the following formula [26]:

$$Moisture\ Content(\%) = \frac{W_0 - W_i}{W_0}.100 \qquad \text{Eq (3)}$$

where W_0 is the initial weight and W_i is the weight after drying.

Proximate analysis

Proximate analysis was conducted following AOAC official procedures, in which protein, fat, ash, and crude fiber contents were quantified using standardized analytical methods [27].

Organoleptic testing

The sensory evaluation was conducted in a controlled sensory laboratory environment to minimize distractions. Before testing, the researcher explained the evaluation procedure to all panelists. Panelists were instructed to drink mineral water between samples to cleanse their palate and reduce carry-over effects. A panel of 30 semi-trained panelists, aged 20-22 years, assessed the organoleptic properties of the instant fried noodles, including appearance, aroma, texture, and overall acceptability. Each parameter was scored on a scale from 1 to 7 (1 = strongly dislike, 2 = dislike, 3 = slightly dislike, 4 = neutral, 5 = slightly like, 6 = like, 7 = strongly like) [28].

Data Analysis

The data obtained were analyzed using Analysis of Variance (ANOVA) at a significance level of ≤ 5% for sensory data only. If significant differences were found, further testing was conducted using Duncan's Multiple Range Test (DMRT).

III. Result and Discussion

C. *The Characterization of RPOO*

The physicochemical and bioactive characteristics of the three RPOO samples are presented in **Table 1**. The parameters analyzed included free fatty acid (FFA) content, β-carotene, flavonoids, polyphenols, antioxidant activity, and vitamin E components (α-tocopherol and γ-tocotrienol). These characteristics were measured to determine the quality, nutritional properties, and functional potential of the RPOO produced from each selected CPO sample. The results of the RPOO characterization are presented in **Table 1.**

Table 1.
Bioactive compounds and antioxidant activity of red palm olein oil (RPOO) samples

Sample	FFA (%)	β-Carotene (ppm)	Flavonoid (mg/L)	Polyphenol (mg GAE/g)	IC_{50} (ppm)	α-Tocopherol (ppm)	γ-Tocotrienol (ppm)	Total Vitamin E (ppm)
RPOO 1	1.28	398.76	1.12	0.44	82.88	208.80	68.69	889.49
RPOO 2	0.84	488.00	1.67	0.53	56.30	230.50	751.43	981.93
RPOO 3	1.91	402.67	1.44	0.49	99.16	190.41	620,74	811.15

The FFA values of the RPOO samples ranged from 0.84 to 1.91%, with RPOO 2 showing the lowest value (0.84%) and RPOO 3 the highest (1.91%). The variation in FFA levels is typically associated with the degree of hydrolysis of triacylglycerols, which can occur due to lipase activity or prolonged exposure to heat and moisture during processing and storage [29]. A higher FFA value, such as in RPOO 3, suggests a greater extent of lipid hydrolysis, which may subsequently influence oxidative stability.

The β-carotene content of the RPOO samples ranged from 398.76–488.00 ppm, with RPOO 2 showing the highest concentration. As the principal carotenoid in red palm oil, variation in β-carotene levels is likely associated with differences in processing conditions, particularly thermal exposure, given the susceptibility of carotenoids to heat and oxidation [30]. Variability may also arise from pre- and post-harvest factors, including fruit maturity, processing temperature, and duration [31], as well as heterogeneity in CPO sources.

Despite these differences, the β-carotene concentrations obtained are generally aligned with recommended levels for RPO, which range from 500–700 ppm, with β-carotene constituting approximately 80% of total carotenoids [32]. Consistent with previous findings by [30], β-carotene levels in the olein fraction of RPO were reported to be approximately 500 ppm, which corresponds with the values observed in this study **(Table 1**). Overall, these results indicate effective carotenoid retention in RPOO, supporting its potential as a functional ingredient with nutritional and antioxidant benefits.

Flavonoid concentrations ranged from 1.12–1.67 mg/L, while polyphenols were between 0.44–0.53 mg GAE/g, with RPOO 2 again showing the highest levels. Palm oil generally contains higher phenolic content than coconut oil (21.44 - 82.69 mg GAE/kg) [33], the presence of these compounds is still relevant due to their ability to donate hydrogen atoms and scavenge free radicals [34]. The relatively higher phenolic content in RPOO 2 may enhance its oxidative stability.

Antioxidant activity varied substantially among samples, ranging from 56.30 to 99.16 ppm, with RPOO 3 exhibiting the highest activity despite having lower β-carotene and vitamin E levels compared to RPOO 2. This observation indicates that antioxidant activity does not depend solely on the absolute concentration of individual bioactive compounds, but rather on their synergistic interactions. Previous studies have emphasized that combinations of carotenoids, tocopherols, tocotrienols, and phenolics act additively or synergistically in lipid systems [12], [35]. The elevated activity in RPOO 3 may result from more effective interactions among its minor components.

Total vitamin E content ranged from 811.15–981.93 ppm, with RPOO 2 containing the highest concentration. Tocotrienols, particularly γ-tocotrienol, were dominant across all samples, aligning with typical profiles of palm-based oils. Tocotrienols possess higher antioxidant potency compared to tocopherols due to their better distribution in lipid bilayers and enhanced free-radical quenching efficiency [36]. Although RPOO 2 had the highest vitamin E levels, this did not translate into the highest antioxidant activity, suggesting that compound ratios, matrix effects, and oxidative interactions likely influence the overall antioxidant performance.

According to [37], the concentrations of vitamin E, represented by tocopherols and tocotrienols, in RPO are 255.342 ppm and 744.143 ppm, respectively. Tocopherols and tocotrienols

constitute groups of vitamin E that commonly occur in the α-, β-, γ-, and δ-isomeric forms. In comparison, the present study identified only α-tocopherol and γ-tocotrienol (**Table 1**). According to [32], one teaspoon (5 g) of red palm oil contains approximately 0.8 g of α-tocopherol and 0.4 g of γ-tocotrienol, indicating that red palm oil is a considerable source of vitamin E homologs. Furthermore, [30] reported that the tocotrienol content in the olein fraction of red palm oil was approximately 700 ppm, which is comparable to the results obtained in this study (**Table 1**). Overall, the vitamin E content (tocopherol and tocotrienol) remains within the acceptable range, as reported by [38].

The SO was identified as containing only γ-tocotrienol, whereas the RPOO and the SO–RPOO blend contained both γ-tocotrienol and α-tocopherol. The chromatographic profiles of α-tocopherol and γ-tocotrienol are presented in **Figures 1 and 2**, respectively**. Figure 1** shows that the α-tocopherol compound is dominant at 16.482 min RT. The mass spectrum at 16.482 min confirmed the presence of α-tocopherol, as indicated by the experimental molecular weight (410.35) and the dominant ion at m/z 443.38800 corresponding to the $[M+H+MeOH]^+$ adduct. The formation of this adduct is typical for tocopherols analyzed in positive ESI with methanol-containing solvents. Minor ions observed in the m/z 410–440 range likely represent dehydration and desaturation fragments, which are commonly reported for tocopherol derivatives under MS conditions. These spectral features are consistent with previous findings demonstrating the characteristic fragmentation behavior of α-tocopherol in ESI-MS ([36,37].

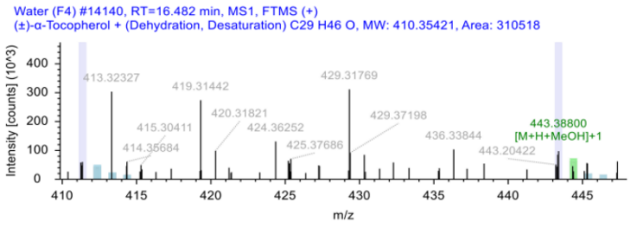

Fig 1. LC-HRMS chromatogram of α-tocopherol

Figure 2 shows the γ-tocotrienol compound shown with an RT of 15.858 min. The mass spectrum obtained at a retention time of 15.858 min confirmed the presence of γ-tocotrienol, as evidenced by the experimental molecular weight (372.28), which corresponds to its theoretical value. A dominant ion at m/z 808.57605, corresponding to the $[2M + ACN + Na]^+$ adduct, was detected with the highest intensity, suggesting dimer formation and adduct association with acetonitrile and sodium. Additional low-abundance ions in the m/z 809–811 range are likely related adducts or in-source fragments generated through dehydration and desaturation, which are characteristic fragmentation pathways of tocotrienols under mass spectrometric conditions [41]. These spectral features support the structural identification of γ-tocotrienol in the sample and are consistent with previously reported MS behavior of vitamin E homologs.

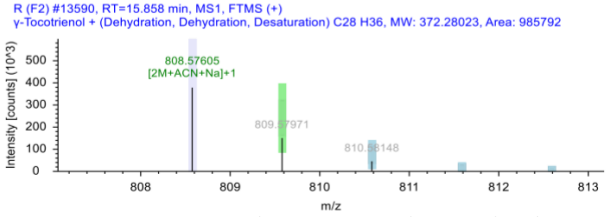

Fig 2. LC-HRMS chromatogram of γ-tocotrienol

D. Vitamin E Testing of Seasoning Oil Substituted with RPOO

The seasoning oil for Konjac noodles was made in various formulations. Each formulation's polyphenol, flavonoid, and antioxidant activity were determined using a spectrophotometer, while the vitamin E content (α-tocopherol) was analyzed using LC-HRMS. The test results for the various formulations are shown in **Table 2**.

TABLE 2.
ANTIOXIDANT PROPERTIES AND VITAMIN E CONTENT OF SEASONING OIL SUBSTITUTED WITH RPOO

RPOO : SO	Polyphenol (ppm)	Flavonoid (ppm)	IC_{50} (ppm)	α-Tocopherol (ppm)	γ-Tocotrienol (ppm)	Total Vitamin E (ppm)
100 : 0	0.86	1.67	82.88	204.70	667.32	872.02
75 : 25	0.49	0.43	247.50	218.30	711.66	929.96
50 : 50	0.31	0.32	284.29	212.20	691.77	903.97
25 : 75	0.29	0.31	308.69	201.20	655.91	857.11

Polyphenol and flavonoid levels decreased with increasing dilution of RPOO, as expected, since RPOO contributed the majority of these components. Nonetheless, even at the lowest substitution level (25:75) (**Table 2**), detectable amounts of phytonutrients remained in the oil.

The dietary antioxidants in the oil seasoning containing RPOO (polyphenols, flavonoids, vitamin E) suggest that the oil may help reduce diabetic symptoms [39-41]. Additionally, Tocotrienol-Rich Fraction (TRF) was given orally to diabetic mice to reduce blood glucose levels. 10 µL TRF was provided to diabetic mice once a day. TRF contains 12.3% α-tocopherol, 2.1% β-tocotrienol, 5.8% δ-tocotrienol, 13.1% α-tocotrienol, and 19.4% γ-tocotrienol [45]. In addition, TRF was administered orally at up to 200 mg/kg body weight/ day on diabetic rats. TRF demonstrated its ability to lower blood glucose levels in these rats. TRF prevented oxidative damage through reducing increases in Malondialdehyde + hydroxynonenal (MDA + HNE) levels, and inhibiting DNA damage in diabetic mice [46].

Other studies have shown that vitamin E supplementation can improve HbA1c and insulin resistance in people with diabetes. Vitamin E was associated with lower fasting blood glucose in participants in this study [11]. Other studies have shown that vitamin A can work with vitamin E and zinc to improve beta-

cell function, insulin secretion, and blood glucose control in patients with type 2 diabetes mellitus [47]. Thus, integrating RPOO into seasoning oil formulations for instant Konjac noodles may contribute functional antioxidant benefits that support dietary management of diabetes. The high γ-tocotrienol levels strengthen the value of RPOO as a healthier alternative to conventional noodle seasoning oils.

E. Organoleptic Results of Konjac Noodles with RPOO-substituted seasoning oil

The organoleptic evaluation of konjac noodles formulated with various ratios of Red Palm Olein Oil (RPOO) and commercial seasoning oil is presented in **Table 3**. Sensory attributes assessed included color, aroma, taste, and overall acceptability. The results indicate that the 75:25 (RPOO: seasoning oil) formulation obtained the highest preference scores across most attributes, particularly color, aroma, and overall acceptability.

TABLE 3.
ORGANOLEPTIC RESULTS OF KONJAC NOODLES WITH RPOO-SUBSTITUTED SEASONING OIL

RPOO:SO (%)	Colour	Aroma	Taste	Overall
100:0	2.40^{b}	3.37^{b}	4.20^{c}	3.67^{b}
75:25	1.87^{a}	2.20^{a}	2.73^{a}	2.33^{a}
50:50	2.57^{b}	2.80^{b}	3.27^{ab}	2.87^{a}
25:75	4.07^{c}	3.20^{b}	3.37^{ab}	3.60^{b}
0:100	4.37^{c}	2.80^{b}	3.73^{bc}	3.50^{b}

Note: numbers followed by the same letter in the same column show no significant difference

Based on the data in **Table 3**, the most preferred formula by panelists in terms of color, aroma, and overall appeal is the 75:25 (RPOO: seasoning oil) formula. The formula with the highest score is the most preferred by the panelists. In this study, acceptance of RPOO substitution was higher than in a previous study [48], in which panelists accepted only 50% of RPOO substitutions. The greater the RPOO substitution, the higher the vitamin E content (**Table 2**).

The improved color is likely attributable to the natural carotenoid pigments (β-carotene and α-carotene) in RPOO, which impart an attractive yellow–orange hue. Previous studies have similarly shown that carotenoid-rich palm oils enhance consumer acceptance due to their distinctive color and associated health benefits [12].

Aroma and taste attributes in the 75:25 formulation also received favorable scores. This may be linked to the retention of volatile flavor compounds during RPOO processing and the balanced integration with the original garlic seasoning oil. Studies have reported that moderate substitution of palm-based oils in noodle seasoning maintains flavor desirability while enriching nutritional quality.[15].

Compared to previous findings, panelists in this study tolerated a higher proportion of RPOO. A previous report indicated that substitution levels above 50% reduced acceptability of roasted meatball sauce [49]. In contrast, the current study demonstrates that a 75% substitution level remains widely accepted, likely due to the compatibility of RPOO with konjac noodles' neutral flavor profile and the oil's antioxidant-rich nature.

Importantly, increasing the RPOO proportion positively contributes to nutritional functionality, particularly by increasing intake of vitamin E (tocopherols and tocotrienols) and carotenoids. Tocotrienols, especially γ- and α-tocotrienol, exhibit strong antioxidant and anti-diabetic properties [6], [45], [46], [50]. Thus, the 75:25 formulation represents an optimal balance between sensory quality and functional benefits, making it suitable for health-oriented instant noodle applications.

F. Proximate analysis of Konjac noodles with RPOO Substitution

The most preferred RPOO-substituted Konjac noodles were subjected to proximate analysis to determine their nutritional content. The average proximate analysis results are shown in **Table 4**.

The proximate composition of the selected Konjac noodles formulated with RPOO is shown in **Table 4**. Moisture content was 57.81%, which falls within the typical range for konjac-based gel products. Konjac glucomannan (KGM) is known for its high water-binding capacity, owing to its ability to form a thermo-stable, elastic gel network, resulting in products with high moisture retention [51]. The addition of RPOO at the selected substitution level did not disrupt the gel matrix, indicating good compatibility between RPOO and the KGM hydrocolloid system.

The ash content was 2.41%, slightly below the previously reported value for other Konjac noodles (2.75%) [52]. This may be associated with the mineral contribution from konjac flour and minor mineral components naturally present in RPOO fractions. The result suggests that RPOO incorporation may contribute marginally to the overall mineral profile without significantly altering product stability.

Glucose content was 11.22%. This is expected, as Konjac noodles rely on hydrocolloid gel formation rather than starch-driven structure. Low carbohydrate levels are a distinguishing characteristic of Konjac-based functional foods and contribute to their low caloric value.

Protein content was 3.79%, slightly higher than typical Konjac noodles (0.25%) [52]. Although Konjac flour naturally contains low protein, the increase suggests that RPOO fortification contributed additional nitrogen-containing compounds or facilitated better retention of protein-containing ingredients in the formulation. Previous studies have reported that sausages formulated with RPO exhibit increased protein content [53]. Even at low incorporation levels, RPOO contains minor

bioactive components associated with carotenoid-rich fractions and may enhance the overall nutritional profile.

Fat content was 1.53%, sourced primarily from RPOO. Despite this, the product remains classified as a low-fat food. The fat level is significantly lower than in black bean sauce noodles (3,33-9,23%) [54], consistent with the targeted development of a low-calorie, health-oriented product.

Dietary fiber content reached 4.50%, consistent with the high fiber characteristics of Konjac-based foods. KGM contributes soluble dietary fiber, which is well known for its physiological benefits, including glycemic control, improved satiety, and cholesterol-lowering activity [55]. The fiber content also supports categorizing the product as a functional food.

TABLE 4.
PROXIMATE ANALYSIS RESULTS OF SELECTED KONJAC NOODLES WITH RPOO SUBTITUTION

Parameter	Analysis Results (%)
Water content	57.81
Ash	2.41
Carbohydrate (glucose)	11.22
Protein	3.79
Lipid	1.53
Crude Fiber	4.50

Based on the data in **Table 4**, the total calorie content of the Konjac noodles with RPOO substitution was calculated. Carbohydrates provide four calories per gram, protein provides four calories per gram, fat provides nine calories per gram. The total calorie content calculated was 73.81 kcal/100g. With a serving size of 90g, the calorie content is 66.429 kcal per serving.

IV. CONCLUSION

The results showed that Konjac noodles substituted with RPOO had a high vitamin E content, which acts as an antioxidant and may offer benefits for diabetes-friendly formulations and other oxidative stress-related conditions. Panelists gave the RPOO-substituted seasoning oil positive responses for color, aroma, taste, and overall evaluation, with the 75:25 (RPOO: seasoning oil) formula scoring the highest. Additionally, proximate analysis revealed that the Konjac noodles were low in calories, with only 66.429 kcal per 90 g serving. This makes them an attractive alternative for consumers mindful of their calorie intake who still want to enjoy tasty, nutritious food. This research contributes significantly to functional food studies and opens the potential for the application of RPOO in health-focused food products. As such, the findings not only have the potential to reduce the risk of diabetes but also to help prevent various oxidative stress-related conditions. The outcomes of this study can serve as a foundation for further innovation in the development of healthy food products, leveraging RPOO as a beneficial ingredient for health.

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ETHIC STATEMENTS

This study was approved by the Research Ethics Committee of the Institute for Research and Community Service, University of Bengkulu (Approval No. 72/KER-LPPM/EC/2024). Written informed consent was obtained from all participants prior to data collection.

AUTHOR CONTRIBUTIONS

Budiyanto Budiyanto conceived and designed the experiments, developed the methodology, performed the data analysis, and wrote the manuscript. Ulfah Anis contributed to the development of the methodology, performed the data analysis, and assisted in writing the manuscript. Arina Fatharani contributed to writing the manuscript and reviewing the final version. Devi Silsia conceived and designed the experiments, developed the methodology, and reviewed the manuscript. Fauzan Azima, Yana Cahyana, and Addion Nizori contributed to the data analysis and reviewed the manuscript. All authors have read and approved the final version of the manuscript.

CONFLICT OF INTEREST

Authors declared that there was no conflict of interest related to this article.

Declaration of generative AI in the scientific writing process. During the preparation of this work, the author(s) used AI tools. including ChatGPT and QuillBot to assist in translating certain parts of the manuscript into English. The author(s) have reviewed and edited the content as needed. The author(s) will take(s) full responsibility for the content of the published article.

REFERENCES

[1] K. Jomova, R. Raptova, S. Y. Alomar, S. H. Alwasel, E. Nepovimova, and K. Kuca, *Reactive oxygen species , toxicity , oxidative stress , and antioxidants : chronic diseases and aging*, vol. 97, no. 10. Springer Berlin Heidelberg, 2023. doi: 10.1007/s00204-023-03562-9.

[2] T. Aryanugraha, D. Sargowo, A. F. Rahimah, and C. T. Tjahjono, "The Role of Antioxidants dan Anti-Inflammatory Agents in Cardiometabolic Disease," *Hear. Sci. J.*, vol. 5, no. October 2023, pp. 10–13, 2024, doi: https://doi.org/10.21776/ub/hsj.2024.005.01.3.

[3] Y. Kayama, U. Raaz, A. Jagger, M. Adam, and I. N. Schellinger, "Diabetic Cardiovascular Disease Induced by Oxidative Stress," *Int. J. Mol. Sci.*, vol. 16, pp. 25234–25263, 2015, doi: 10.3390/ijms161025234.

[4] C. Ni, X. Wang, Y. Zhou, Y. Chen, Y. Liu, and Z. Sun, "Association of oxidative balance score , cardiovascular , and all- cause mortality among patients with type 2 diabetes mellitus," *Front. Endocrinol. (Lausanne).*, no. August, pp. 1–10, 2024, doi: 10.3389/fendo.2024.1429662.

[5] O. F. Adewale, O. O. Isaac, M. T. Tunmise, and O. O. Omoniyi, "Palm oil and ground nut oil supplementation effects on blood glucose and antioxidant status in alloxan-induced diabetic rats," no. January, 2019.

[6] S. P. Muharis, A. G. M. Top, D. Murugan, and M. R. Mustafa, "Palm oil tocotrienol fractions restore endothelium dependent relaxation in aortic rings of streptozotocin-induced diabetic and spontaneously hypertensive rats," *Nutr. Res.*, vol. 30, no. 3, pp. 209–216, 2010, doi: 10.1016/j.nutres.2010.03.005.

[7] R. Dalan *et al.*, "Impact of Vitamin E supplementation on vascular function in haptoglobin genotype strati fi ed diabetes patients (EVAS Trial): a randomised controlled trial," *Nutr. Diabetes*, vol. Nutrition, 2020, doi: 10.1038/s41387-020-0116-7.

[8] Y. E. Puspitasari, Y. A. Sholichah, N. R. Defransyah, and T. Dwi, "In silico approaches to analyse Acanthus ilicifolius leaves extract as α - glucosidase and α - amylase inhibitors," *Canrea J. Food Technol. Nutr. Culin.*, vol. 8, no. 2, pp. 425–447, 2025, doi: 10.20956/canrea.v8i2.1165.

[9] L. M. Gomes, A. M. R. Freitas, T. Dias, and R. B. M. Cavalcante, "Vegetables and their by-products: total phenolic compound content, total flavonoids, and antioxidant activity," *Hortic. Bras.*, vol. 41, pp. 1–5, 2023, doi: 10.1590/s0102-0536-2023-e2572.

[10] G. Chen *et al.*, "Tocotrienol-rich vitamin E improves diabetic nephropathy and persists 6 – 9 months after washout : a phase IIa randomized controlled trial," pp. 1–16, 2019, doi: 10.1177/2042018819895462.

[11] O. Asbaghi, B. Nazarian, M. Yousefi, J. A. Shoae, and H. Rasekhi, "Effect of vitamin E intake on glycemic control and insulin resistance in diabetic patients : an updated systematic review and meta - analysis of randomized controlled trials," *Nutr. J.*, vol. 22, no. 10, pp. 1–22, 2023, doi: 10.1186/s12937-023-00840-1.

[12] R. Loganathan, A. H. A. Tarmizi, S. R. Vethakkan, and K. T. Teng, "Retention of carotenes and vitamin e, and physicochemical changes occurring upon heating red palm olein using deep-fat fryer, microwave oven and conventional oven," *J. Oleo Sci.*, vol. 69, no. 3, pp. 167–183, 2020, doi: 10.5650/jos.ess19209.

[13] B. T. Y. Ping, C. A. C. Idris, and Z. A. Maurad, "Oxidative stability of refined red palm olein under two Malaysian storage conditions," *J. Oleo Sci.*, vol. 69, no. 10, pp. 1209–1218, 2020, doi: 10.5650/jos.ess20045.

[14] Z. Gao, Y. Zhu, J. Jin, Q. Jin, and X. Wang, "Chemical–Physical Properties of Red Palm Oils and Their Application in the Manufacture of Aerated Emulsions with Improved Whipping Capabilities," *Foods*, vol. 12, no. 21, 2023, doi: 10.3390/foods12213933.

[15] L. Agustina, B. Budiyanto, and T. Tutuarima, "Subtitusion of Rpo To Seasoning Oil and Acceptability and Fortification Potency of Vitamin a Trough Chicken Noodle," *J. Agroindustri*, vol. 8, no. 2, pp. 150–158, 2019, doi: 10.31186/j.agroind.8.2.150-158.

[16] M. E. Mulyono, M. E. S. Lubis, B. G. Yudanto, and F. R. Panjaitan, "Original article Application of dry fractional crystallisation on High-Oleic Low-Palmitic red palm super olein production," *Int. J. Food Sci. Technol.*, vol. 58, pp. 3402–3409, 2023, doi: 10.1111/ijfs.16353.

[17] Y. Kurniati and W. H. Susanto, "Pengaruh Basa NaOH dan Kandungan ALB CPO terhadap Kualitas Minyak Kelapa Sawit Pasca Netralisasi," *J. Pangan dan Agroindustri*, vol. 3, no. 1, pp. 193–202, 2015.

[18] D. A. Setyawardhani and T. H. Satiawardana, "Innovative approach to vegetable oil production and refining technology in Indonesia : a review," *Discov. Chem. Eng.*, vol. 4, pp. 1–23, 2025.

[19] I. A. Saputra, B. Budiyanto, and D. Silsia, "The Effect of The Addition of NaOH in Water Degumming and Alkali Refining Process The Quality of Red Palm Oil Olein (RPOO)," *J. Agroindustri*, vol. 13, no. 1, pp. 85–94, 2023, doi: 10.31186/j.agroind.13.1.85-94.

[20] S. Pootao and K. Kanjanapongkul, "Effects of ohmic pretreatment on crude palm oil yield and key qualities," *J. Food Eng.*, vol. 190, pp. 94–100, 2016, doi: 10.1016/j.jfoodeng.2016.06.021.

[21] I. Nor Shafizah, R. Irmawati, H. Omar, M. Yahaya, and A. Alia Aina, "Removal of free fatty acid (FFA) in crude palm oil (CPO) using potassium oxide/dolomite as an adsorbent: Optimization by Taguchi method," *Food Chem.*, vol. 373, no. PB, p. 131668, 2022, doi: 10.1016/j.foodchem.2021.131668.

[22] L. Ifa *et al.*, "Heliyon Analysis of bentonite performance on the quality of re fi ned crude palm oil ' s color , free fatty acid and carotene : the effect of bentonite concentration and contact time," *Heliyon*, vol. 7, no. March, pp. 1–9, 2021, doi: 10.1016/j.heliyon.2021.e07230.

[23] Otuaga, E. Juliana, Okpoghono, Geoarge, and B. Omenebelle, "Proximate Composition, Phytochemicals and Antioxidant Status of Banga Soup (Elaeis guineensis extract)," *J. Sci. Ind. Res. (India).*, vol. 4, no. 2, pp. 63–74, 2020.

[24] T. C. Shekhar and G. Anju, "Antioxidant Activity by DPPH Radical Scavenging Method of Ageratum conyzoides," *Am. J. Ethnomedicine*, vol. 1, no. 4, pp. 244–249, 2015.

[25] A. Windarsih, Suratno, H. D. Warmiko, A. W. Indrianingsih, A. Rohman, and Y. I. Ulumuddin, "Untargeted metabolomics and proteomics approach using liquid chromatography-Orbitrap high resolution mass spectrometry to detect pork adulteration in

Pangasius hypopthalmus meat," *Food Chem.*, vol. 386, no. July 2021, p. 132856, 2022, doi: 10.1016/j.foodchem.2022.132856.

[26] S. Deeto, S. Thepa, V. Monyakul, and R. Songprakorp, "The experimental new hybrid solar dryer and hot water storage system of thin layer coffee bean dehumidification," *Renew. Energy*, vol. 115, pp. 954–968, 2018, doi: 10.1016/j.renene.2017.09.009.

[27] AOAC, *Official Methods Of Analysis*. Washington, DC: Arlington, 2005.

[28] D. Setyaningsih, A. Apriyantono, and M. P. Sari, *Analisis Sensori untuk Industri Pangan dan Agro*. Bogor: IPB Press, 2010.

[29] E. Menalla, J. G. Serna, D. Cantero, and M. J. Cocero, "Hydrothermal hydrolysis of triglycerides: Tunable and intensified production of diglycerides, monoglycerides, and fatty acids," *Chem. Eng. J.*, vol. 493, no. April, 2024, doi: 10.1016/j.cej.2024.152391.

[30] M. Lertcanawanichakul, T. Sahabuddeen, H. Madoromae, and S. Jankhlay, "Red Palm Oil as a Bioactive Ingredient for Cosmeceutical Applications : Antioxidant , Antimicrobial , and Skin- Protective Properties Red Palm Oil as a Bioactive Ingredient for Cosmeceutical Applications : Antioxidant ," pp. 0–6, 2025, doi: 10.20944/preprints202509.1633.v1.

[31] F. Morcillo, V. Vaissayre, J. Serret, S. Avallone, H. Domonh, and F. Jacob, "Natural diversity in the carotene , tocochromanol and fatty acid composition of crude palm oil," *Food Chem.*, vol. 365, pp. 1–10, 2021, doi: 10.1016/j.foodchem.2021.130638.

[32] R. Loganathan, K. M. Subramaniam, A. K. Radhakrishnan, Y. M. Choo, and K. T. Teng, "Health-promoting effects of red palm oil: evidence from animal and human studies," *Nutr. Rev.*, vol. 75, no. 2, pp. 98–113, 2017, doi: 10.1093/nutrit/nuw054.

[33] D. R. Wickramasinghe Mudiyanselage and I. Wickramasinghe, "Comparison of physicochemical characteristics of virgin coconut oils from traditional and hybrid coconut varieties," *J. Agric. Food Res.*, vol. 12, no. December 2022, p. 100554, 2023, doi: 10.1016/j.jafr.2023.100554.

[34] C. H. Tan *et al.*, "Red Palm Oil : A Review on Processing , Health Benefits and Its Application in Red Palm Oil : A Review on Processing , Health Benefits and Its Application in Food," no. August 2021, 2022, doi: 10.5650/jos.ess21108.

[35] C. Robichon *et al.*, "Unveiling synergistic antioxidant combinations for α-tocopherol in emulsions: A spectrophotometric-mathematical approach," *Curr. Res. Food Sci.*, vol. 11, no. July, 2025, doi: 10.1016/j.crfs.2025.101134.

[36] C. K. Sen, S. Khanna, and S. Roy, "Tocotrienols: Vitamin E beyond tocopherols," *Life Sci.*, vol. 78, no. 18, pp. 2088–2098, 2006, doi: 10.1016/j.lfs.2005.12.001.

[37] W. T. Chong *et al.*, "Optimization of process parameters in preparation of tocotrienol-rich red palm oil-based nanoemulsion stabilized by Tween80-Span 80 using response surface methodology," *PLoS One*, vol. 13, no. 8, pp. 1–22, 2018, doi: 10.1371/journal.pone.0202771.

[38] H. Delisle, "The nutritional value of red palm oil," no. October, pp. 217–232, 2018, doi: 10.19103/as.2017.0018.33.

[39] M. Podda, C. Weber, M. G. Traber, and L. Packer, "Simultaneous determination of tissue tocopherols, tocotrienols, ubiquinols, and ubiquinones," *J. Lipid Res.*, vol. 37, no. 4, pp. 893–901, 1996, doi: 10.1016/s0022-2275(20)37587-8.

[40] M. G. Traber and J. Atkinson, "Vitamin E, antioxidant and nothing more," *Free Radic. Biol. Med.*, vol. 43, no. 1, pp. 4–15, 2007, doi: 10.1016/j.freeradbiomed.2007.03.024.

[41] A. Kamal-Eldin and L. Å. Appelqvist, "The chemistry and antioxidant properties of tocopherols and tocotrienols," *Lipids*, vol. 31, no. 7, pp. 671–701, 1996, doi: 10.1007/BF02522884.

[42] M. Shafras, R. Sabaragamuwa, and M. Suwair, "Role of dietary antioxidants in diabetes: An overview," *Food Chem. Adv.*, vol. 4, no. June 2023, p. 100666, 2024, doi: 10.1016/j.focha.2024.100666.

[43] M. T. Fatima, A. A. Bhat, S. Nisar, K. A. Fakhro, and A. S. Al-Shabeeb Akil, "The role of dietary antioxidants in type 2 diabetes and neurodegenerative disorders: An assessment of the benefit profile," *Heliyon*, vol. 9, no. 1, p. e12698, 2023, doi: 10.1016/j.heliyon.2022.e12698.

[44] S. Mariyam, S. Jose, S. Kumar, and M. . Parmar, "Super power of antioxidant in oxidative stress and Diabetes Mellitus," *Diabetes Updat.*, vol. 6, no. 2, pp. 1–4, 2020, doi: 10.15761/du.1000144.

[45] M. Z. Sadikan, N. A. A. Nasir, R. Agarwal, and N. M. Ismail, "Protective effect of palm oil-derived tocotrienol-rich fraction against retinal neurodegenerative changes in rats with streptozotocin-induced diabetic retinopathy," *Biomolecules*, vol. 10, no. 4, 2020, doi: 10.3390/biom10040556.

[46] S. B. Budin, F. Othman, S. R. Louis, M. A. Bakar, S. Das, and J. Mohamed, "The effects of palm oil tocotrienol-rich fraction supplementation on biochemical parameters, oxidative stress and the vascular wall of streptozotocin-induced diabetic rats.," *Clinics (Sao Paulo).*, vol. 64, no. 3, pp. 235–244, 2009, doi: 10.1590/s1807-59322009000300015.

[47] E. Said, S. Mousa, M. Fawzi, N. A. Sabry, and S. Farid, "Combined effect of high-dose vitamin A, vitamin E supplementation, and zinc on adult patients with diabetes: A randomized trial," *J. Adv. Res.*, vol. 28, pp. 27–33, 2021, doi: 10.1016/j.jare.2020.06.013.

[48] M. Yupita, B. Budiyanto, and H. Koto, "Substitution of Red Palm Oil Olein (RPOO) as a Source of Provitamin E in Grilled Meatball Sauce," *AGRITROPICA J. Agric.*

Sci., vol. 5, no. 1, pp. 13–21, 2022, doi: 10.31186/j.agritropica.5.1.13-21.

[49] M. Yupita, B. Budiyanto, and H. Koto, "Substitution of Red Palm Oil Olein (RPOO) as a Source of Provitamin E in Grilled Meatball Sauce," *AGRITROPICA J. Agric. Sci.*, vol. 5, no. 1, pp. 13–21, 2022, doi: https://doi.org/10.31186/J.agritropica.5.1.13-21.

[50] F. A. Matough, S. B. Budin, Z. A. Hamid, M. Abdul-Rahman, N. Al-Wahaibi, and J. Mohammed, "Tocotrienol-rich fraction from palm oil prevents oxidative damage in diabetic rats," *Sultan Qaboos Univ. Med. J.*, vol. 14, no. 1, pp. 95–103, 2014, doi: 10.12816/0003342.

[51] R. Feng, X. Liu, R. Xu, B. Xu, H. Tao, and B. Zhang, "Konjac Glucomannan Acts as the Skeleton of Emulsion Gel Exhibiting Stable Water Retention by Promoting the Structure Density of Gel Network," *J. Food Sci.*, vol. 90, no. 9, 2025, doi: https://doi.org/10.1111/1750-3841.70533.

[52] H. N. Jang, T. R. Kumayas, and A. Romulo, "Physicochemical and sensory evaluation of shirataki noodles prepared from porang and tapioca flours," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1169, no. 1, 2023, doi: 10.1088/1755-1315/1169/1/012101.

[53] W. Iftari, R. Amalia, A. N. Savitri, and G. Saragih, "Study of The Addition of Red Palm Oil (RPO) to The Sensory and Chemical Characteristics of Beef Sausage," *J. Pangan dan Agroindustri*, vol. 10, no. 4, pp. 194–203, 2022.

[54] H.-J. Kim, J. Jin, and K.-T. Lee, "Studies on the Fat Content and Fatty Acid Composition of the Black-bean-sauce Noodles in the Chinese Restaurants," *J. Agric. Sci.*, vol. 37, no. 2, pp. 261–266, 2010.

[55] S. Zhu *et al.*, "Effects of konjac glucomannan intake patterns on glucose and lipid metabolism of obese mice induced by a high fat diet," *Food Funct.*, vol. 15, pp. 9116–9135, 2024, doi: http://doi.org/10.1039/D4FO02442G.