

## Research Article

# Extraction, characterisation, and application of palm kernel cake (*Elaeis guineensis* Jacq) fibre

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## Abstract

Palm kernel cake (PKC), a by-product of the palm oil industry, is a promising ingredient due to its high fibre content. This study investigated the physicochemical properties and functional characteristics of PKC fibres extracted using water (W), acid (AC), and alkaline (AL) treatments. Fourier Transform Infrared Spectroscopy (FTIR) analysis confirmed the presence of hydroxy groups and aliphatic chains in cellulose, hemicellulose, and lignin, which contribute to water affinity and gel formation in all treated groups. The total dietary fibre content obtained from the three extraction methods ranged from 92.19% to 97.69% with insoluble fibre comprising 87.15% to 95.58% and soluble fibre ranging from 1.11% to 5.04%. Acid-extracted fibre exhibited superior oil-holding capacity and enhanced glucose and cholesterol absorption, while no significant differences were observed in swelling and water-holding capacity. Overall, acid-extracted PKC fibre demonstrated the best functional properties in glycemic control and lipid metabolism through its glucose and cholesterol absorption capacities, making it a potential ingredient with physiological benefits.

**Keywords:** palm kernel cake, valorisation, by-product, functional ingredients, functional properties

## Introduction

Palm kernel cake (PKC) is a by-product of palm oil production, derived from the pressing of palm kernels to extract oil. It is produced primarily in palm oil-producing countries, with Malaysia being one of the largest producers worldwide. In 2020, Malaysia's palm oil (*Elaeis guineensis* Jacq.) production reached approximately 19.5 million tons, resulting in the production of over 4.5 million tons of PKC [1]. Traditionally, PKC has found its primary application in animal feed, particularly in poultry, ruminants, and aquaculture, due to its high fibre and moderate protein content [2, 3].

PKC is rich in nutrients, including crude protein (16-18%), crude fat (20-25%), and dietary fibre (30-35%) [4]. These nutrients make PKC an excellent source of energy and protein for livestock, while its high fibre content aids in the digestion process of animals. Studies have documented its benefits as a feed

ingredient, particularly for poultry and ruminants, where its fibre content and protein quality are well-suited [5]. Despite its nutritional benefits, PKC contains anti-nutritional factors such as phenolic compounds, which limit its direct application in human food [6]. Nevertheless, the potential uses of its fibre are extensive, especially when its characteristics and behaviour are well understood.

Dietary fibre is a crucial component of a balanced diet, playing a vital role in maintaining digestive health, preventing constipation, and reducing the risk of chronic diseases like heart disease and diabetes. Unfortunately, the worldwide community often fails to meet the recommended daily intake of fibre. The average fibre intake in Malaysia is only 15 grams per day, which is far below the recommended 25-30 grams per day for adults [7]. This fibre deficit is a significant public health concern, as inadequate fibre intake has been associated with numerous health problems. PKC,

with its high content of cellulose, hemicellulose, and lignin, may offer a solution by potentially supplementing human diets with an affordable and sustainable source of dietary fibre.

Several extraction techniques have been explored to isolate fibre from PKC. Liquid phase oxidation (LPO), which involves hot water treatment followed by hydrogen peroxide oxidation, has shown high cellulose yield and purity [8,9]. When combined with alkali treatment, it effectively removes hemicellulose and produces cleaner fibre [8]. Hot water extraction at 100–120°C for one hour has also been reported to increase the total sugar content of PKC [10]. Each extraction method offers distinct advantages depending on its intended application in the industry.

The underutilisation of PKC provides an opportunity to explore its functionality as food ingredient, especially in fibre characteristics. Understanding its properties and behaviour is important to increase its possible applications in food products. Therefore, this study compares the physicochemical and functional properties of PKC fibres extracted using water, acid, and alkali treatments.

## Materials and Methods

### Chemicals, materials and instrumentations

Palm kernel cake (PKC) was sourced from Lee Oilmills Sdn. Bhd. (Seberang Prai, Penang, Malaysia). Analytical-grade hydrochloric acid (HCl), sodium hydroxide (NaOH), ethanol (95% and 100%), and D-glucose were obtained from Merck (Darmstadt, Germany). Corn oil and fresh egg yolk were used as food-grade materials for oil and cholesterol adsorption analyses. Distilled water was used for all solution preparations. The extraction and analytical procedures utilised a water bath (Mettler, Germany), centrifuge (Thermo Fisher Scientific, Waltham, MA, USA), and oven dryer (Binder, Germany). Spectrophotometric measurements were conducted using a UV-Vis spectrophotometer (Shimadzu, Japan), while structural characterisation of dietary fibre samples was performed with a Fourier Transform Infrared (FT-IR) spectrometer (Thermo Scientific Nicolet iS50, USA).

### Sample preparation

The collected palm kernel cake (PKC) was dried at room temperature (25 °C) to remove residual moisture, finely ground to ensure uniform particle size, and sieved to obtain particles  $\leq 0.5$  mm for sample standardisation. The processed PKC was then packed in sealed plastic bags (14 cm  $\times$  20 cm) and stored at room temperature until further use.

## Extraction methods

### Water extraction

The water extraction method, based on the modified approach by [11], was employed to obtain water-extracted insoluble dietary fibre (W-IDF) and water-extracted soluble dietary fibre (W-SDF) from palm kernel cake powder. In this procedure, 100 grams of the powder underwent two extraction cycles using 500 mL of distilled water, each heated to 90 °C in a water bath for 3 hours. Suction filtration was used to collect both the filtrate and filter residues. The filter residue was thoroughly washed with distilled water, dried in an oven, and characterised as W-IDF. Meanwhile, the filtrate was subjected to precipitation by adding 500 mL of 95% ethanol, resulting in the precipitation of W-SDF. After a 24-hour incubation period at room temperature, the precipitate was harvested via centrifugation at 4930 rpm for 10 minutes, washed twice with 100% ethanol, and dried in an oven at 45 °C.

### Extraction by hydrochloric acid solution

Acid-extracted dietary fibre (DF) was prepared using a 1% HCl extraction method adapted from [12], with a modification in the ethanol precipitation ratio. The procedure involved soaking 100 grams of palm kernel cake powder twice for 3 hours in 500 mL of 1% HCl at room temperature. Suction filtration was employed to collect both the filtrate and filter residues. The filter residue was meticulously rinsed with distilled water until neutral and later dried to yield the acid-extracted insoluble dietary fibre (AC-IDF). Meanwhile, the filtrate (AC-SDF) underwent neutralisation with 500 mL of 1% (w/v) NaOH. Subsequently, it was subjected to precipitation by adding 500 mL of 95% ethanol. After a 24-hour incubation period at room temperature, the precipitate was isolated via centrifugation at 4930 rpm for 10 minutes, followed by two washes with 100% ethanol and dried in an oven at 45 °C.

### Extraction by sodium hydroxide

The alkali-extracted dietary fibre (DF) was prepared using a 4% NaOH extraction method adapted from [13], with modifications in NaOH concentration, soaking duration, and ethanol precipitation ratio. A total of 100 g of palm kernel cake powder was soaked twice for 3 hours in 500 mL of 4% NaOH at 4°C. Filtration and rinsing were conducted following the same procedure as in the acid extraction method to obtain the alkali-extracted insoluble dietary fibre (AL-IDF). The filtrate was neutralised with 4% (w/v) HCl and subjected to ethanol precipitation and centrifugation, as described for the acid extraction, to yield the alkali-extracted soluble dietary fibre (AL-SDF).

**Percentage of yield**

The yields of soluble and insoluble dietary fibres extracted using the water, acid, and alkali methods were calculated by dividing the weight of soluble or insoluble dietary fibre by the weight of PKC and multiplying it by 100.

**Physiochemical analysis****Water holding capacity (WHC)**

The WHC of the samples was measured according to the method described by [14], with modifications in the sample-to-water ratio, incubation time, centrifugal speed and duration. Approximately 0.5 g of the sample (W1) was accurately weighed and added to 5 mL of distilled water. The mixture was gently homogenised by manual stirring to ensure uniform dispersion of the sample. The mixture was incubated for 2 hours at room temperature (25 °C) and centrifuged at 101 rpm for 20 minutes. The sediment was collected and weighed at once (W2). The WHC was calculated as follows:

$$\text{WHC} = (W2 - W1) / W1 \quad (1)$$

**Oil holding capacity (OHC)**

The OHC of the DF samples was determined based on the method described by [14], with modifications with modifications in the sample-to-water ratio, incubation time, centrifugal speed and duration. Around 1 g of the DF sample (O1) was accurately weighed and added to 5 mL of corn oil with sufficient mixing, followed by 2 hours of incubation at room temperature (25 °C). After centrifugation at 101 rpm for 20 minutes, the residue was separated from the supernatant and weighed at once (O2). The OHC was determined using the following formula:

$$\text{OHC} = (O2 - O1) / O1 \quad (2)$$

**Swelling capacity (SC)**

SC was determined according to [15], with modifications in sample-to-water ratio. Approximately 1 g of dry sample (w) placed in a 10 mL measuring tube and mixed with 5 mL of distilled water. The height before (h1) was measured and maintained at room temperature for 24 hours. Any trapped air bubbles were removed. The height of the hydrated (h2) sample was recorded, and SC was calculated according to the equation below:

$$\text{SC mL/g} = (h2 - h1) / w \quad (3)$$

**Glucose adsorption capacity (GAC)**

The glucose absorption capacity (GAC) of the extracted fiber was determined in-vitro following the method of [16]. Each sample (0.1 g) was mixed with 20 mL of glucose solution (50 mmol/L) and

mechanically shaken at 37 °C and 120 rpm for 2 hours, before centrifuged at 4000 rpm for 15 minutes. A 1.0 mL aliquot of the supernatant was transferred into a graduated test tube, followed by the addition of 3 mL of DNS reagent. The mixture was heated in boiling water for 5 minutes, cooled to room temperature, and the volume was adjusted with distilled water. Absorbance was measured at 550 nm using a spectrophotometer. The glucose concentration was determined by comparison with a standard calibration curve prepared using glucose solutions at 5, 10, 15, 20, and 25 mmol/L.

**Cholesterol absorption capacity (CAC)**

The cholesterol adsorption capacity (CAC) of the samples was determined in triplicate according to the method described by [17], with slight modifications in sample weight, pH, and incubation conditions. A standard cholesterol calibration curve was prepared by diluting egg yolk to 2%, 4%, 6%, 8%, and 10% concentrations using distilled water, ensuring thorough mixing and proper labelling. For CAC measurement, fresh egg yolk was fully emulsified with nine times its weight of distilled water, and 1.5 g of the sample was gradually mixed with 25 g of the emulsion at pH 2 and 7. The mixture was incubated at 37 °C for 2 hours and centrifuged at 6000 rpm for 15 minutes. The supernatant was collected, and the cholesterol content was quantified using a colorimetric method. The cholesterol adsorption capacity was calculated using the following equation:

$$\text{CAC g/g} = \frac{(\text{Amount of cholesterol before adsorption} - \text{Amount of cholesterol after adsorption})}{(\text{weight of sample})} \quad (4)$$

**Fourier transform infrared (FT-IR)**

Thermo Scientific Nicolet iS50 FT-IR spectrometer was used to measure the FT-IR spectra of the DF samples. The dried DF samples were ground with potassium bromide (KBr) powder before being pressed into pellets (0.2 g of DF sample/2 g of KBr) for FT-IR scanning in the frequency range of 4000–400 cm<sup>-1</sup>.

**Statistical analysis**

All data are expressed as mean ± standard deviation (SD) of triplicate measurements. The experimental data were subjected to one-way analyses of variance (ANOVA), followed by post-hoc Duncan's multiple comparison test using the GraphPad Prism software. The statistical significance of differences between mean values was determined at p < 0.05.

**Results and Discussion****Yield of fibre extracted from palm kernel cake**

The yields of soluble dietary fibre (SDF) and insoluble

dietary fibre (IDF) were obtained through three distinct extraction methods (**Table 1**), with IDF percentages ranging from 87.145% to 96.581%. Among these methods, the alkali-insoluble dietary fibre AL-IDF extraction resulted in the lowest IDF yield at 87.145%, followed by acid extraction at  $92.753 \pm 0.110$  and water extraction at  $96.581 \pm 0.511$ . Correspondingly, the yield of alkali-soluble dietary fibre (AL-SDF) ranked highest at 5.0448%, followed by acid-soluble dietary fibre (AC-SDF) at 1.246% and water-soluble dietary fibre (W-SDF) at 1.108%. The lowest SDF yield was observed for water extraction with 1.108%. The alkaline extraction process utilised a concentrated alkali solution to disrupt the cell wall and partially dissolve hemicellulose in IDF. As demonstrated by [18], alkali solutions, such as sodium hydroxide, induce hydrolysis of hemicellulose, saponification of lipids, and reactions with cellulose and lignin, collectively breaking down cell wall integrity and increasing susceptibility to extraction.

However, despite the effectiveness of these treatments, achieving a complete (100%) recovery of total dietary fibre when combining insoluble and soluble fractions remains challenging. This limitation occurs because not all fibre components are equally susceptible to extraction under the applied conditions; some may remain bound within the matrix or resist solubilisation. Additionally, certain thermolabile or chemically sensitive fibre constituents can degrade or be lost during extraction, leading to incomplete recovery. Variations in extraction efficiency and analytical methodology therefore contribute to inconsistencies between the theoretical and actual total dietary fibre yields [19].

#### Dietary fibre extracted prediction by FTIR

**Figure 1** presents the combined FTIR spectra of PKC soluble (SDF) and insoluble (IDF) dietary fibres extracted under different conditions. The observed variations in peak intensity and position reflect hydrogen bonding and structural changes, confirming the polysaccharide and cellulosic nature of PKC fibres [20]. Several distinct absorption bands were identified and assigned to specific functional groups related to cellulose, hemicellulose, and lignin. All extracted fibres exhibited a broad absorption band between  $3400\text{--}3470\text{ cm}^{-1}$ , corresponding to O–H stretching vibrations in hydroxyl groups present in cellulose, hemicellulose, and lignin. This band indicates extensive hydrogen bonding within the polysaccharide matrix, reflecting strong hydrophilic

interactions that contribute to the fibre's water-holding and gel-forming capacities [9]. A distinct peak near  $2921\text{ cm}^{-1}$ , attributed to C–H asymmetric stretching of  $-\text{CH}_2$  and  $-\text{CH}_3$  groups, indicates aliphatic chains in lignin and carbohydrates. These chains strengthen the lignocellulosic matrix and maintain the structural integrity of PKC fibres [20]. A weak absorption band around  $1730\text{ cm}^{-1}$  was assigned to C=O stretching vibrations of acetyl and uronic ester groups in hemicellulose and pectin-like substances [20] suggesting partial esterification of hemicellulose components, which can influence fibre solubility and chemical reactivity.

Furthermore, peaks observed at  $1600\text{--}1630\text{ cm}^{-1}$ , corresponding to C=C stretching of aromatic rings in lignin, confirm the presence of aromatic compounds typical of lignocellulosic materials. These compounds contribute to the antioxidant and structural-stabilising properties of PKC fibres [9]. Additional peaks near  $1420\text{--}1460\text{ cm}^{-1}$  represent  $\text{CH}_2$  bending vibrations in crystalline cellulose, while those within  $1030\text{--}1060\text{ cm}^{-1}$  are associated with C–O–C and C–O stretching vibrations in glycosidic linkages of polysaccharides, confirming the carbohydrate backbone of the extracted fibres [20]. During water extraction, notable peaks were recorded at  $3435.52\text{ cm}^{-1}$  and  $2924.18\text{ cm}^{-1}$  for soluble and insoluble fibres, respectively. Similarly, in acid extraction, peaks appeared at  $3434.42\text{ cm}^{-1}$  and  $3400.90\text{ cm}^{-1}$ . These minor shifts in wavenumber reflect variations in hydrogen bonding strength and aliphatic chain interactions, indicating subtle chemical modifications to lignin and polysaccharide components during extraction [20].

#### Physicochemical properties of extracted palm kernel cake fibre

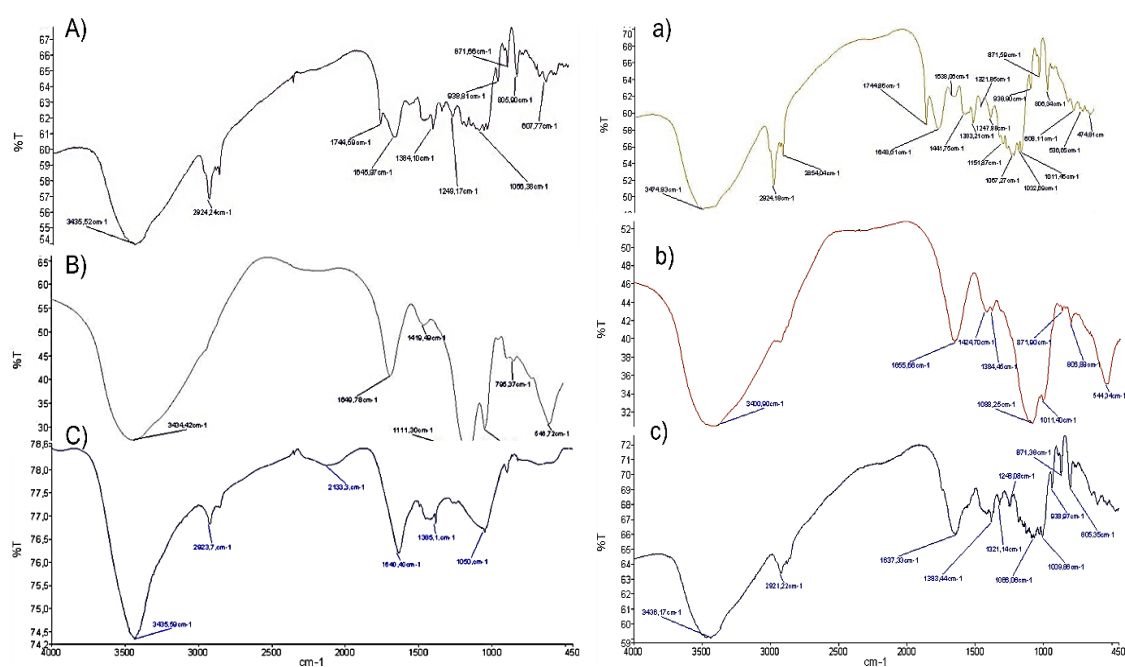
##### Swelling capacity

The swelling capacity of PKC fibres extracted using water, acid, and alkali treatments showed no significant differences (**Figure 3(a)**). This consistency is attributed to the preservation of hydrophilic components, such as cellulose and hemicellulose, which are responsible for water absorption and retention. For instance, [21] reported that PKC fibres showed comparable swelling capacities regardless of particle size, indicating that the extraction method did not significantly impact this property. This uniformity in swelling capacity is crucial for applications in both food and non-food industries, where maintaining the functional properties of dietary fibres is essential.

**Table 1.** The yield of extracted dietary fibre from palm kernel

|    | IDF Yield (%)               | SDF Yield (%)              | Total Dietary Fibre (%)      |
|----|-----------------------------|----------------------------|------------------------------|
| W  | 96.581 ± 0.511 <sup>a</sup> | 1.108 ± 0.003 <sup>a</sup> | 97.688 ± 0.201 <sup>a</sup>  |
| AC | 92.753 ± 0.110 <sup>b</sup> | 1.246 ± 0.032 <sup>a</sup> | 93.999 ± 0.204 <sup>ab</sup> |
| AL | 87.145 ± 0.103 <sup>c</sup> | 5.045 ± 0.064 <sup>b</sup> | 92.190 ± 0.122 <sup>b</sup>  |

Note: All data are presented in the manner of means ± standard deviations (SD) of triplicate measurements. Different superscript letters indicate significant difference ( $p < 0.05$ )



**Figure 1.** Fourier transform infrared (FT-IR) spectra of soluble and insoluble dietary fibres extracted from palm kernel cake using different extraction methods: (A) soluble dietary fibre (SDF) extracted by water, (B) SDF extracted by acid, (C) SDF extracted by alkali, (a) insoluble dietary fibre (IDF) extracted by water, (b) IDF extracted by acid, and (c) IDF extracted by alkali.

### Water holding capacity and oil holding capacity

The water holding capacity (WHC) and oil holding capacity (OHC) of PKC fibres extracted using water, acid, and alkali treatments (**Figures 3(b)** and **3(c)**) demonstrate distinct functional properties based on their ability to retain water and oil. The WHC results indicate that all extraction methods yielded fibres with comparable capacities, suggesting that the treatments did not significantly alter the structural integrity of PKC fibres concerning water retention. WHC is influenced by the fibre's structure, composition, and porosity, which determine its ability to trap and retain water under external forces. In contrast, the results showed that fibres extracted using alkali exhibited a significantly lower OHC compared to those extracted with acid and water. OHC is crucial in human health, as it influences oil absorption during processing and contributes to cholesterol-lowering effects by binding lipids in the digestive system [22]. This suggests that alkali treatment may have altered the fibre matrix, possibly by reducing hydrophobic sites or modifying

the lignocellulosic structure, thereby reducing oil retention. Similar findings have been reported in previous studies where the degradation of polysaccharides and lignin during alkali extraction resulted in reduced oil-binding properties [20]. These variations in WHC and OHC highlight the importance of selecting appropriate extraction methods based on the desired functional properties for industrial applications.

### Glucose adsorption capacity

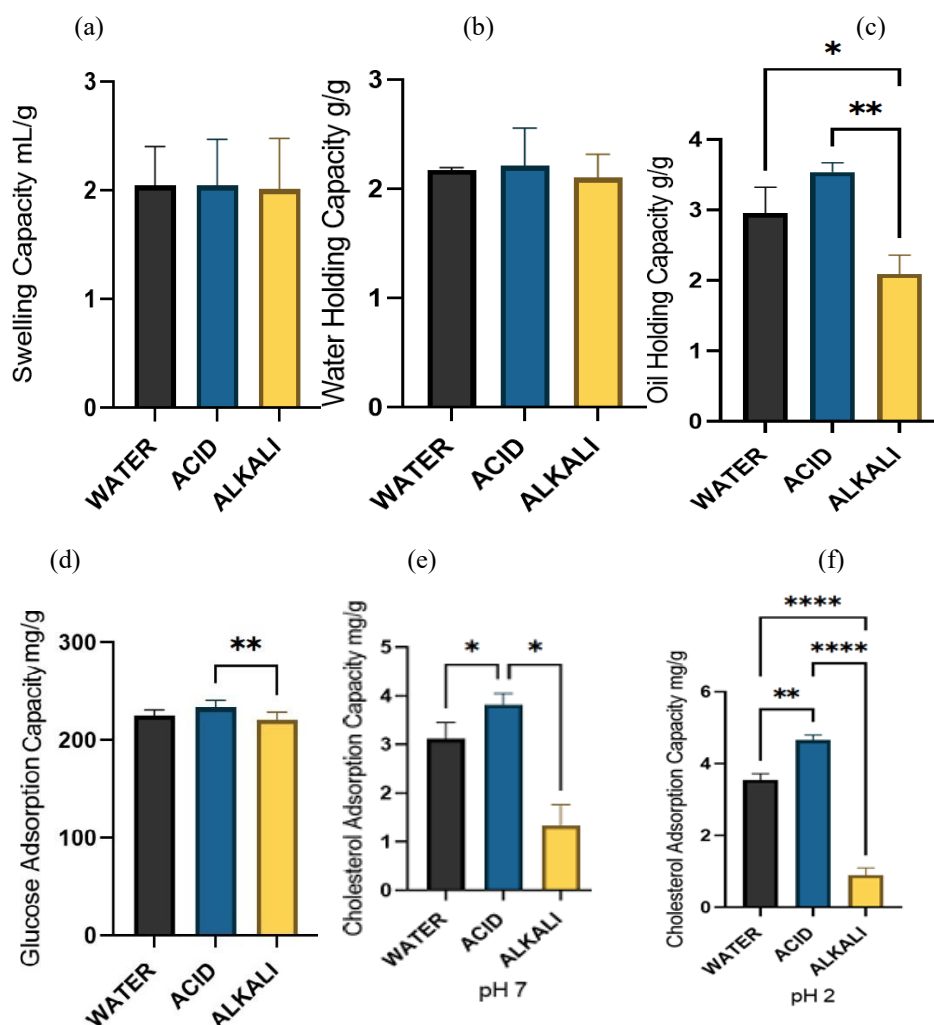
The glucose adsorption capacity (GAC) of PKC fibre is an essential property that influences its potential role in controlling postprandial blood glucose levels. In **Figure 3(d)**, the PKC fibre extracted using acid treatment exhibited the highest GAC, while the alkali-treated fibre showed a slight reduction. This suggests that acid treatment might enhance the fibre's surface properties, increasing the availability of binding sites for glucose molecules. Fibre's ability to adsorb glucose is influenced by its porosity and functional

groups, which may be altered depending on the extraction method. Higher glucose adsorption capacity is beneficial for moderating glucose release into the bloodstream, which is particularly relevant in dietary applications aimed at managing diabetes [23]. Moreover, studies have demonstrated that dietary fibres with high glucose adsorption potential can contribute to lowering the glycemic index and improving insulin sensitivity [24].

### Cholesterol adsorption capacity

Figures 3(e) and 3(f) simulate the small intestinal environment and human gastric juice in neutral (pH 7) and acidic conditions (pH 2), respectively. The cholesterol adsorption capacities of PKC fibres extracted using water, acid, and alkali varied significantly under different pH conditions, reflecting differences in their functional properties. At neutral

pH (pH 7), which simulated the small intestinal environment, the acid-extracted PKC fibre exhibited the highest cholesterol adsorption capacity, followed by the water-extracted fibre, while the alkali-extracted fibre showed the lowest capacity. Under acidic conditions (pH 2), mimicking the gastric environment, a similar trend was observed, with acid-extracted fibre maintaining the best cholesterol-binding ability, significantly higher than both water- and alkali-extracted fibres. This suggests that acidic treatment enhances the structural properties of the fibre and increases its affinity for cholesterol, likely due to increased porosity or surface charge modifications that improve binding efficiency [25]. In contrast, alkali treatment may degrade structural components responsible for cholesterol binding, resulting in reduced adsorption capacity.



**Figure 3.** Functional properties of extracted total dietary fibre a: swelling capacity, b: water holding capacity, c: oil holding capacity, d: glucose adsorption capacity, e, f: cholesterol absorption capacity at different pH values. Different letters above the bars in each panel indicate significant differences ( $p < 0.05$ )

## Conclusion

This study highlights the potential of palm kernel cake (PKC) as a valuable source of fibre for industrial applications. The findings demonstrate that different extraction methods significantly influence the physicochemical and functional properties of PKC fibre, with alkali extraction yielding the highest soluble dietary fibre content. Water-extracted fibres exhibited superior water-holding and oil-holding capacities, making them suitable for improving the texture. Meanwhile, acid-extracted fibres showed enhanced glucose and cholesterol adsorption capacities, indicating potential health benefits in glycaemic control and lipid metabolism. The FTIR analysis confirmed the presence of hydroxyl and aliphatic groups, contributing to the fibre's structural stability and functionality. Overall, the utilisation of PKC as a functional ingredient supports sustainable manufacturing and waste minimisation, aligning with the growing demand for dietary fibre-enriched products. Further optimisation of processing parameters is recommended to enhance the functional properties of PKC fibre for broader applications.

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