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Utilization of the supercritical carbon dioxide extraction technology for the production of deoiled palm kernel cake

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ABSTRACT

The main focus of the present study is to produce deoiled palm kernel cake from palm kernel using the supercritical carbon dioxide ($SC—CO_2$) extraction method. Response surface methodology (RSM) was used to optimize the process parameters of $SC—CO_2$ extraction of oil from palm kernels. The influences of pressure, temperature and extraction time on the yield were investigated. Results showed that the experimental data were fitted into the second order polynomial model. The linear terms of $SC—CO_2$ pressure, temperature and extraction time had the significant effect on the yield of the oil extraction from the palm kernel. The optimum $SC—CO_2$ extraction process parameters were pressure 44.6 MPa, temperature 60 °C and extraction time 50 min. Under these experimental conditions, the oil yield was about 49.2%. The presence of nutrient and anti-nutrient compositions in deoiled PKC subjected to $SC—CO_2$ (PKC_{sc}) was also investigated and compared with the nutrient and anti-nutrient compositions of PKC collected from palm oil mill (PKC_M). Determination of the nutrient compositions in deoiled PKC_{sc} and PKC_M revealed that $SC—CO_2$ maintained the nutrient compositions in deoiled PKC_{sc} during extraction of palm kernel oil. Determination of the anti-nutrients compositions in deoiled PKC_{sc} and PKC_M showed that $SC—CO_2$ effectively influenced the anti-nutrients in deoiled PKC_{sc}. The findings of the present study suggest that $SC—CO_2$ extraction is an effective technique to produce deoiled PKC_{sc}, which can be used as a cheap source of protein and fiber for human and animal food consumption.

1. Introduction

Palm kernel cake (PKC) is a major byproduct of the Palm oil industry [1]. Palm kernels contain about 45–50% of plam kernel oil (PKO) on a wet basis [2]. Palm kernel cake contain about 18.6% crude protein, 37% dietary fiber, and 4.5% crude fiber and ash [3]. Several methods have been utilized worldwide to extract the PKO from palm kernels such as screw pressing, direct solvent extraction and pre-pressing followed by solvent extraction [3–6]. The major disadvantages of these conventional methods of palm kernel oil extraction are environmental pollution, high energy consumption, time-consuming, costly, require organic solvent and intensive separation technology [5,7].

Foods are in high fiber content prevent constipation, lower cholesterol, facilitate weight loss, and have many more benefits [8,9]. This higher fiber content of PKC can be an attractive potential ingredient in the food industry. Fiber-rich foods start to gain much attention in the industrial world due to its human health benefits including lowering the cancer risk, blood sugar, and cholesterol levels; aids in weight loss management, prevention of constipation and much more [9,10]. The palm kernel cake can be considered an attractive food ingredient due to its high content of dietary fiber. It can be explored as a potential source of plant protein and energy source for human food consumption and animal nutrition. The main problem with utilizing PKC for human food consumption is the presence of residual oil remaining in its matrix [11]. The residual oil in PKC gives it a rancid taste after a period of storage, which reduces its potential as a food additive for human food and animal feed consumption.

The conventional palm oil extraction methods are not effective enough to completely extract the oil, and thus leaves an average residual oil content about 6–10 wt% [6]. Supercritical carbon

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dioxide ($SC—CO_2$) offers an effective and cleaner mode of removing oil from palm kernel to produce deoiled PKC_{sc} [5,7]. $SC—CO_2$ has been employed successfully as a solvent to replace other traditional solvents in food industries owing to its non-toxicity, non-flammability, reasonably low cost and environmental friendliness [7–9]. Numerous studies have been conducted to extract PKO from palm kernel using $SC—CO_2$, and it's quantitative and qualitative analysis [5,7,10,11]. Studies reported that $SC—CO_2$ extraction is an effective method to extract oil from the palm kernel [10,11]. However, there is rare studies have been considered the qualitative analyzes of produced deoiled palm kernel cake using $SC—CO_2$ extraction for the possible use of the deoiled PKC_{sc} as fiber and nutrient source for human food and animal feed consumption. It is therefore in the present study, $SC—CO_2$ was utilized to produce deoiled PKC_{sc} from palm kernel. Wherein, Response surface method was applied to determine the optimal experimental conditions with gaining maximum PKO extraction. Subsequently, the optimal experimental conditions were applied to produce deoiled PKC_{sc}. Several analytical methods were utilized to analyzes nutrient and anti-nutrient compositions of the deoiled PKC_{sc}. The nutrient and anti-nutrient compositions of deoiled PKC_{sc} was compared with the palm kernel cake collected from palm oil mill (PKC_M).

In the extraction process, there are multiple independent variables affecting the responding factor. Hence, it is likely to utilize an optimization method that can determine the effect of the variables with gaining maximum yield. Also, the interaction possibility between the independent variables should be considered to determine optimum experimental conditions [12]. In the present study, the optimum experimental conditions of the $SC—CO_2$ extraction of PKO from palm kernel were ascertained using response surface methodology (RSM). RSM is a collection of mathematical and statistical techniques used for the modeling and analysis of problems in which a response of interest is influenced by several input variables with the objective of optimizing the response [13]. Central composite design (CCD) was applied to investigate the effect of $SC—CO_2$ pressure, temperature and extraction time on the oil extraction from palm kernel.

2. Materials and methods

2.1. Samples collection and preparation

Palm kernel (PK) and PKC_M were collected from Fleet Palm Sdn Bhd, Seberang Prai, Penang, Malaysia. The collected PK was washed with water and dried at room temperature. Subsequently, it was ground using analytical mill model IKA(R) A11 from Retsch. Preliminary studies showed that the particle sizes of ≤ 0.5 mm greatly influenced by the palm oil extraction [7]. It is, therefore, the ground PK was sieved using electrical shaker into the particle sizes of ≤ 0.5 mm. The samples were then packed into polyethylene zipped bags and stored in a refrigerator at a temperature of 4 ± 1 °C throughout the experimental period.

2.2. Supercritical carbon dioxide extraction

The experimental setup for the $SC—CO_2$ extraction of oil yield has been discussed elsewhere [7]. In details, Commercial liquefied carbon dioxide gas with a purity of 99%, was purchased locally from Malaysia Oxygen Penang. The liquid carbon dioxide was pumped into the cylindrical extraction vessel (2.5 ml) loaded with 1.6 g of palm kernel. Subsequently, the extraction vessel was placed in the oven and was allowed to equilibrate the preset temperature, after which the extraction vessel was pressurized. The CO_2 was mixed with the palm kernel and extract the oil. Whereby the oil mixture was pressed out of the extraction cell through the outlet valve and the oil was collected in glass vials. Extraction was performed with varying pressures, temperatures and extraction time at flow rates 2 ml/min. The deoiled PKC_{sc} was stored at −20 °C for further analysis. The percentage extracted oil yield was determined using the following equation:

$$\%\,\text{Extraction yield(g)} = \frac{\text{Mass of extraction oil(g)}}{\text{Mass of sample (g)}} \times 100 \qquad (1)$$

2.3. Experimental design and statistical analysis

A 2^3 factorial central composite design (CCD) combined with response surface methodology (RSM) was used to optimize the effects of the independent variables, such as pressure (X_1), temperature (X_2), and extraction time (X_3). In the CCD test, 14 experiments and six replicates at the center point were employed to fit the full quadratic equation model. The general equation can be express as follow:

$$Y = \beta_o + \sum_{j=1}^{k} \beta_j X_j + \sum_{j=1}^{k} \beta_{jj} X_j^2 + \sum \sum_{j=1} \beta_{ij} X_i X_j \quad (k = 3) \qquad (2)$$

where, Y is the predicted response. β_0, β_j, β_{ij} and β_{jj} are constant coefficients of intercept, linear, interaction, and quadratic terms, respectively. While, X_i and X_j are coded variables, and k is the number of coded variables. The $SC—CO_2$ pressure (X_1), temperature (X_2), and extraction time (X_3) were coded according to the following equation:

$$X = \frac{x - [x_{\max} + x_{\min}]/2}{[x_{\max} - x_{\min}]/2}$$

where x is the natural variable, X is the coded variable, $x_{\max}$ is the high level of the natural variable, and $x_{\min}$ is the low level of the variable. The low, intermediate, and high levels of each variable were designated as −1, 0, and +1, respectively, as shown in Table 1. During the entire experimental process, the CO_2 flow rate, the mass of the sample and particle size were kept constant to 2 ml/min, 1.6 g and ≤ 0.5 mm, respectively. The data obtained from $SC—CO_2$ extraction of PKO from palm kernel was analyzed using MINITAB software (ver. 16.2) and fitted with the second-order response surface model equations to the design. The fit of the regression model was checked by the adjusted coefficient of determination (R^2_{adj}). The three-dimensional graphical representation of the system behavior, called the response surface, was used to describe the interaction effects of the variables on the percentage oil extraction.

2.4. Determination of the nutrient and anti-nutrient composition

The optimized experimental condition of $SC—CO_2$ extraction was applied to remove palm kernel oil from the palm kernel to produce deoiled PKC_{sc}. The deoiled PKC_{sc} was then dried in open air to reduce the moisture content up to 5%. Several analytical methods were utilized to determine nutrient compositions (Protein, fiber, fat, carbohydrate and minerals vitamin, cholesterol),

Table 1
The coded and uncoded levels of the independent variables.

Factor	Symbol	Level		
		Low (−1)	Intermediate (0)	High (+1)
Pressure (MPa)	X_1	20	30	40
Temperature (°C)	X_2	40	60	80
Time (min)	X_3	30	45	60