



## Removal of Shells in Palm Kernel Cake via Static Cling and Electrostatic Separation

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### ABSTRACT

Palm kernel cake (PKC), a by-product of the palm oil industry is limited in its use as a feed ingredient for poultry due to its high fibre and lignin content. The presence of these anti-nutritive components is the result of shells contaminating the by-product. The nutritive value of PKC has to be improved in order to increase its inclusion rate in poultry diet. In this study, PKC was subjected to a separation method using static cling and electrostatic separation to remove the shells present in PKC. Response surface methodology based on Box-Behnken design was used to optimize the separation method with moisture content (8 to 18%), particle size distribution (0.5 to 2.5 mm) and feed rate (20 to 200 g/min) as the independent variables evaluated. According to the regression coefficients and significance of the quadratic polynomial model, the optimum separation parameters were as follows: 13% PKC moisture content; <1.5 mm PKC particle size and 110 g/min feed rate. Under these conditions, the total lignin content of PKC was reduced to 8.1% PKC and crude fibre to 10.2%.

### INTRODUCTION

In 2013, Malaysia has more than 4.49 million hectares of oil palm plantation, producing more than 2.2 million tonnes of palm kernel cake (PKC) per annum. Palm kernel cake is the residue left from the kernel after oil extraction. The Malaysian Palm Oil Board (MPOB) reported that 2.23 million tonnes of PKC which accounted 93% of PKC produced in 2011 was exported to countries such as the European Union for formulation of ruminant feeds [1]. Successful application of PKC as a concentrate feed for ruminant is well established [2, 3].

The protein content of PKC was about 14 to 21% [4] and metabolisable energy of 9.74 MJ kg<sup>-1</sup> [5]. Due to its relatively high protein content, PKC has been considered as a feed ingredient for poultry [6-8]. Earlier studies by Osei and Amo [9]

showed inclusion rate of up to 10% PKC in broiler diet did not affect the feed conversion efficiency, and later Okeudo et al. [10] reported that inclusion rate of 30% did not significantly affect broilers performance. However, broilers fed with diet containing 45% PKC suffered significant performance reduction even with the supplementation of lysine and methionine. Although these results clearly indicate the potential of PKC as a poultry feed, its utilization is still not widely accepted, due to inconsistency of research findings [4].

Due to the rising cost of imported feed ingredients like corn and soybean, local feed resources has to be seriously considered to sustain the local poultry production. As PKC is available throughout the year, and is non-competitive as human food, its utilization as poultry feed has to be enhanced. The main problem in PKC for it to be considered as an alternative feed ingredient for poultry is the high shell and dirt content of

3.6 to 21.4% [11,12], lignin 15% [13] and fibre 18 to 21% [14-16]. These components greatly reduced nutrient digestibility [17].

The shells in the PKC are indigestible and are generally considered as the main source of lignin [18]. The shells cannot be eliminated from PKC during palm kernel processing prior to oil extraction. It is also difficult to completely remove the shells because they are of various sizes, irregular in shapes and also of similar densities to the kernel residue. Due to these factors, the PKC available in the market is contaminated with broken shells. Sinurat et al. [19] reported the removal of shells in PKC via sieving method, was not successful in removing shells with particle size of lower than the size of sieve pores. Electrostatic separation method based on electromagnetic characteristics has been developed for industries such as agriculture and mineral beneficiation [20]. In agriculture, electrostatic separation was used to separate fiber from the dry-milled corn [21] and fibre-containing oilseeds [22], separate aleurone and pericarp fraction of bran [23] and separate broken and complete wheat seeds [24]. In mineral beneficiation, electrostatic separation was used to separate unburned carbon from coal fly ash [25].

The phenomenon whereby light objects have the tendency to be attracted and stick to other objects owing to static electricity is called static cling. The static cling ability is associated with triboelectric effect whereby different materials can become electrically charged via electron transfer when they come in contact through friction [26]. In the present study, electrostatic separation technique was evaluated to reduce the lignin and fibre content of PKC based on the interaction of three dependent variables (moisture content, PKC particle size distribution and feed rate) using response surface methodology (RSM).

## MATERIALS AND METHODS

### Sample preparation

The PKC (purchased from Ace Edible Oil Industries Sdn. Bhd. from Kapar, Selangor) was milled to obtain <0.5 mm, <1.5 mm and <2.5 mm diameter particle size fractions. The PKC moisture content was adjusted to 8%, 13% and 18% by adding distilled water. The treated PKC samples were sealed in polyethylene bags and stored at -20°C. Palm kernel shells were also collected, ground (1.5 mm sieve) and dried at 60°C.

### Separation technique

An apparatus was designed to remove shells from PKC via static cling and electrostatic separation technique. Different types of polymers (chiffon, acrylic, polyester, jute fiber and acetate fiber) were evaluated as separators. Two hundred gram of PKC were spread on the surface of the separator sheet. Horizontal shaking (reciprocal movement) caused the shell particles to fall off from the separator, leaving the PKC residue sticking on the surface of the separator, which was collected manually using a scraper. The separation process was standardized by maintaining 160 g of PKC collected on the surface of the separator, while the amount of unwanted PKC was set at 40 g from the total 200 g of PKC used for every run.

### Response Surface Methodology (RSM)

The experiment for three independent variables was conducted using Box-Behnken design and RSM [27]. The independent variables were PKC moisture content (8 to 8%), PKC particle size (0.5 to 2.5 mm) and feed rate (20 to 200 g/min). The feed rate was the amount PKC placed on the surface of separator per minute. The experimental design for three independent

variables was investigated using Box-Behnken and RSM. The PKC moisture content ( $Z_1$ , %), particle size distribution ( $Z_2$ , mm), and feed rate ( $Z_3$ , g/min) were taken as independent variables. The coded and actual variable levels of the three independent variables used in this study are presented in Table 1. The total lignin content of the collected PKC and unwanted PKC was used as the dependent variables of the samples. The experimental design, which resulted in 17 runs was developed using Design Expert 7.0.0 (2005). Regression analysis was performed for the results of dependent variables and fitted to the empirical second-order polynomial model.

### Chemical Analyses

Crude fibre and protein were measured according to standard AOAC procedures [28]. The insoluble or klason lignin content was measured based on the modified standardized method of American Society for Testing and Materials (ASTM) D-1106 [29]. Three millilitres of 72% sulphuric acid were added to 150 mg of sample. The sample was placed in water bath at 30 °C for one hour. Eighty four millilitres of de-ionized water were added, and the sample mixture was placed in an autoclave at temperature of 125 °C for one hour. The sample was cooled into room temperature and filtered using a crucible filter. The insoluble lignin was washed using 50 ml of deionized water. The sample was dried in an oven at temperature of 103 °C until constant weight. The insoluble lignin content was calculated by the formula below:

$$IL = \frac{W_{lignin}}{W_{PKC}} \times 100$$

Where,

$IL$  = insoluble lignin content (%)

$W_{lignin}$  = Weight of dry insoluble lignin or Klason lignin (g)

$W_{PKC}$  = Weight of dry matter of PKC (g)

The soluble lignin content was determined via spectrophotometric method using the filtrate obtained above. Five millilitres of 3% sulphuric acid were added to 5 ml of the filtrate. The absorbance was taken at 205 nm using a UV spectrophotometer. The soluble lignin content was calculated by the formula below:

$$SL = \frac{CV}{1000 \times W_{PKC}} \times 100$$

Where,

$SL$  = soluble lignin content (%)

$V$  = total volume of the filtrate (ml)

$W_{PKC}$  = Weight of dry matter of PKC (g)

$C$  = concentration of soluble lignin in the filtrate (g/l),

The concentration of soluble lignin in the filtrate ( $C$ ) is given by:

$$C = \left( \frac{A}{110} \right) \left( \frac{V_{final}}{V_{initial}} \right)$$

Where,

$A$  =  $Abs_{205nm}$

$V_{final}$  = final volume of the solution (ml)

$V_{initial}$  = initial volume of the solution (ml)

The total lignin content was obtained as shown below:

Total lignin ( $TL$ ) = Insoluble lignin ( $SL$ ) + Soluble lignin ( $IL$ )

### Statistical Analysis

All experiments were carried out in three replicates. Design-Expert 7.0.0 software (2005) was used for the analysis of variance (ANOVA) of the experimental results. Minitab software version 16.2.4 (2013, Minitab Pty Ltd, Sydney

Australia) were used for t-test and ANOVA analysis. All significant differences were considered at significant level of  $p < 0.05$ .

**RESULTS AND DISCUSSION**

**Selection of separator**

Contact electrification is a process whereby two dissimilar objects produces surface charges when they are come into contact by rubbing or frictional contact [30]. In textile, contact electrification is the most important source of electrostatic charge [31]. The development of electrostatic charge on fibres, fabrics and other textile assemblies can cause many serious problems. For example, the formation of electrostatic attraction due to contact charging can cause fabric cling that impede the opening of parachutes [31]. The lunar dust that cling to the astronaut’s spacesuit can reduced the external visibility on landing [32]. Instead of considering the contact electrification and static cling of textiles as a problem, the phenomenon could be applied for the separation of shells from PKC since PKC was accidentally observed to adhere on the surface of textiles, while the shells showed less ability to cling on the surface of textiles.

In the present study, five different types of polymers (chiffon, acrylic, polyester, jute fiber and acetate fiber) were evaluated as separators. The results clearly showed that the separation was dependant on the types of separator used. Table 1 shows that polyester gave the highest separation efficiency to produce collected PKC with the lowest total lignin content. It is probably because polyester has higher static electrification compared to other materials used in the present study. The chiffon made up from synthetic fiber showed the lowest separation efficiency as PKC particles could not adhere to the material surface.

**Table 1.** The effect of the types of separator on the removal of lignin from PKC.

| Types of separator | Total lignin (%)        |                         |                         |
|--------------------|-------------------------|-------------------------|-------------------------|
|                    | Untreated PKC           | Collected PKC           | Unwanted PKC            |
| Control            | 15.80±0.49 <sup>a</sup> |                         |                         |
| Chiffon            |                         | 14.39±0.26 <sup>b</sup> | 18.33±0.58 <sup>c</sup> |
| Polyester          |                         | 7.64±0.45 <sup>b</sup>  | 42.22±0.60 <sup>c</sup> |
| Acrylic            |                         | 8.81±0.31 <sup>b</sup>  | 40.82±0.52 <sup>c</sup> |
| Jute fiber         |                         | 12.39±0.64 <sup>b</sup> | 26.75±0.93 <sup>c</sup> |
| Acetate fiber      |                         | 13.18±0.31 <sup>b</sup> | 22.54±0.26 <sup>c</sup> |

Note:  
(PKC moisture content, 8 %; particle size, <2.5 mm; and feed rate, 100 g/min)  
Means ± standard deviation (n=3) with different superscripts within a row are significantly different (p<0.05)

**Lignin content based on RSM**

Table 2 show the experimental and predicted results of 17 separation runs on the content of total lignin of collected and unwanted PKC. The amount of total lignin of collected and unwanted PKC changed significantly in the range of 5.2% to 13.2% and 13.1% to 54.0%, respectively, under different experimental conditions. The analysis of variance for the predictive models developed for the total lignin of collected PKC and total lignin of unwanted PKC is shown in Table 3. The analysis showed that both models are acceptable (P<0.05) and has insignificant lack of fit which indicates the models could be used to predict values for the total lignin of collected and unwanted PKC. The coefficient of determination (R<sup>2</sup>) shows that only 3.3% and 2.0% of total variation for total lignin models of collected and unwanted PKC are not explainable.

For the predictive model of total lignin of collected PKC, the linear coefficients (Z<sub>1</sub>, Z<sub>3</sub>) and quadratic coefficients (Z<sup>2</sup><sub>2</sub>,

Z<sup>2</sup><sub>3</sub>) were found to be significant, indicated by the small P-value (P<0.05). The other term coefficients (Z<sub>2</sub>, Z<sub>1</sub>Z<sub>2</sub>, Z<sub>1</sub>Z<sub>3</sub>, Z<sub>2</sub>Z<sub>3</sub>, Z<sup>2</sup><sub>1</sub>) were not significant with large P-values (P>0.05).

For the predictive model of total lignin of unwanted PKC, the linear coefficients (Z<sub>1</sub>, Z<sub>3</sub>), cross product coefficients (Z<sub>1</sub>Z<sub>2</sub>) and quadratic coefficients (Z<sup>2</sup><sub>2</sub>, Z<sup>2</sup><sub>3</sub>) were found to be significant, indicated by the small P-value (P<0.05). The other term coefficients (Z<sub>2</sub>, Z<sub>1</sub>Z<sub>3</sub>, Z<sub>2</sub>Z<sub>3</sub>, Z<sup>2</sup><sub>1</sub>) were not significant with large P-values (P>0.05). The following second-order polynomial equations showed the relationship of the independent and dependent variables of the separation method experiments:

$$\text{Total lignin of collected PKC, \%} = 7.66+3.17Z_1+0.32Z_2+0.62Z_3 -0.72 Z_1 Z_2-5E^{-3} Z_1 Z_3-0.47 Z_2 Z_3+0.40Z_1^2+1.87 Z_2^2 +1.15 Z_3^2 \text{ (Eq. 1)}$$

$$\text{Total lignin of unwanted PKC, \%} = 44.13-13.92Z_1+0.39 Z_2-2.52 Z_3 +5.21 Z_1 Z_2 -0.34 Z_1 Z_3+1.94Z_2 Z_3-2.48 Z_1^2-8.44 Z_2^2-3.53 Z_3^2 \text{ (Eq. 2)}$$

**Table 2.** Experimental design for PKC and shell separation method with respective uncoded factors and response functions for total lignin of collected and unwanted PKC.

| Run | Coded variables |                |                | Uncoded variables                     |                                     |                                    | Responses                        |       |                                 |       |
|-----|-----------------|----------------|----------------|---------------------------------------|-------------------------------------|------------------------------------|----------------------------------|-------|---------------------------------|-------|
|     | Z <sub>1</sub>  | Z <sub>2</sub> | Z <sub>3</sub> | Moisture content (Z <sub>1</sub> , %) | Particle size (Z <sub>2</sub> , mm) | Feed rate (Z <sub>3</sub> , g/min) | Total lignin of collected PKC, % |       | Total lignin of unwanted PKC, % |       |
|     |                 |                |                |                                       |                                     |                                    | Exp.                             | Pred. | Exp.                            | Pred. |
| 1   | 0               | 1              | 1              | 13                                    | 2.5                                 | 200                                | 11.12                            | 11.16 | 31.2                            | 31.97 |
| 2   | -1              | 1              | 0              | 8                                     | 2.5                                 | 110                                | 8.21                             | 7.82  | 42.9                            | 42.31 |
| 3   | -1              | -1             | 0              | 8                                     | 0.5                                 | 110                                | 5.21                             | 5.72  | 53.98                           | 51.97 |
| 4   | 0               | -1             | -1             | 13                                    | 0.5                                 | 20                                 | 9.31                             | 9.27  | 37.01                           | 36.24 |
| 5   | 1               | 0              | -1             | 18                                    | 1.5                                 | 20                                 | 12.12                            | 11.77 | 26.88                           | 27.06 |
| 6   | 0               | 0              | 0              | 13                                    | 1.5                                 | 110                                | 8.02                             | 7.66  | 43.21                           | 44.13 |
| 7   | 1               | 1              | 0              | 18                                    | 2.5                                 | 110                                | 13.22                            | 12.71 | 22.88                           | 24.90 |
| 8   | 0               | 0              | 0              | 13                                    | 1.5                                 | 110                                | 7.45                             | 7.66  | 44.67                           | 44.13 |
| 9   | 1               | 0              | 1              | 18                                    | 1.5                                 | 200                                | 12.53                            | 13.00 | 24.12                           | 21.34 |
| 10  | 0               | 0              | 0              | 13                                    | 1.5                                 | 110                                | 7.62                             | 7.66  | 44.89                           | 44.13 |
| 11  | 0               | -1             | 1              | 13                                    | 0.5                                 | 200                                | 12.32                            | 11.45 | 25.11                           | 27.31 |
| 12  | -1              | 0              | 1              | 8                                     | 1.5                                 | 200                                | 6.32                             | 6.67  | 50.04                           | 49.86 |
| 13  | 0               | 1              | -1             | 13                                    | 2.5                                 | 20                                 | 9.99                             | 10.86 | 35.32                           | 33.12 |
| 14  | 0               | 0              | 0              | 13                                    | 1.5                                 | 110                                | 8.11                             | 7.66  | 42.02                           | 44.13 |
| 15  | 0               | 0              | 0              | 13                                    | 1.5                                 | 110                                | 7.12                             | 7.66  | 45.87                           | 44.13 |
| 16  | -1              | 0              | -1             | 8                                     | 1.5                                 | 20                                 | 5.89                             | 11.77 | 51.44                           | 54.22 |
| 17  | 1               | -1             | 0              | 18                                    | 0.5                                 | 110                                | 13.11                            | 13.51 | 13.11                           | 13.70 |

Note:  
Exp. Experimental  
Pred. Predicted

**Table 3.** Analysis of variance (ANOVA) for optimization of lignin reduction in PKC by static cling and electrostatic separation technique.

| Source                        | df                            |                              | F-value                       |                              | Prob > F                      |                              |
|-------------------------------|-------------------------------|------------------------------|-------------------------------|------------------------------|-------------------------------|------------------------------|
|                               | Total lignin of collected PKC | Total lignin of unwanted PKC | Total lignin of collected PKC | Total lignin of unwanted PKC | Total lignin of collected PKC | Total lignin of unwanted PKC |
| Model                         | 9                             | 9                            | 23.08                         | 37.40                        | 0.0002                        | < 0.0001                     |
| Z <sub>1</sub>                | 1                             | 1                            | 151.75                        | 244.44                       | < 0.0001                      | < 0.0001                     |
| Z <sub>2</sub>                | 1                             | 1                            | 1.58                          | 0.19                         | 0.2485                        | 0.6775                       |
| Z <sub>3</sub>                | 1                             | 1                            | 5.86                          | 8.03                         | 0.0461                        | 0.0253                       |
| Z <sub>1</sub> Z <sub>2</sub> | 1                             | 1                            | 3.94                          | 17.13                        | 0.0874                        | 0.0044                       |
| Z <sub>1</sub> Z <sub>3</sub> | 1                             | 1                            | 0.00                          | 0.07                         | 0.9894                        | 0.7949                       |
| Z <sub>2</sub> Z <sub>3</sub> | 1                             | 1                            | 1.67                          | 2.39                         | 0.2374                        | 0.1664                       |
| Z <sup>2</sup> <sub>1</sub>   | 1                             | 1                            | 1.28                          | 4.07                         | 0.2945                        | 0.0833                       |
| Z <sup>2</sup> <sub>2</sub>   | 1                             | 1                            | 27.87                         | 47.26                        | 0.0011                        | 0.0002                       |
| Z <sup>2</sup> <sub>3</sub>   | 1                             | 1                            | 10.51                         | 8.29                         | 0.0142                        | 0.0237                       |
| Residual                      | 7                             | 7                            |                               |                              |                               |                              |
| Lack of Fit                   | 3                             | 3                            | 6.05                          | 5.10                         | 0.0574                        | 0.0746                       |
| Pure Error                    | 4                             | 4                            |                               |                              |                               |                              |
| Cor Total                     | 16                            | 16                           |                               |                              |                               |                              |
| R <sup>2</sup>                | 0.9674                        | 0.9796                       |                               |                              |                               |                              |
| Adj R <sup>2</sup>            | 0.9255                        | 0.9534                       |                               |                              |                               |                              |
| C.V.%                         | 7.84                          | 6.75                         |                               |                              |                               |                              |

**Effects of static cling and electrostatic separation technique on lignin content**

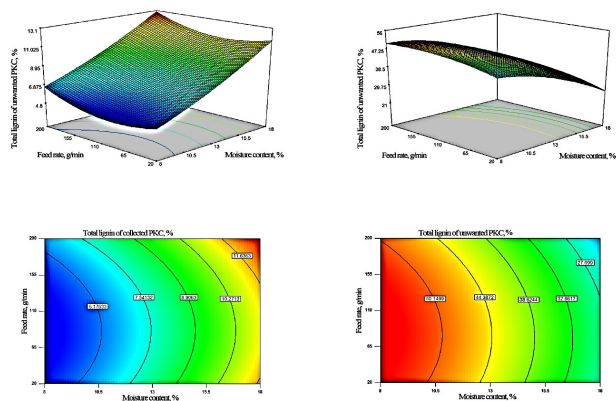
The separation method evaluated significantly reduced ( $P < 0.05$ ) lignin in PKC by 50%. The response surface plots as shown in Fig. 1 to Fig. 3 illustrate the conditions for optimum reduction of lignin in PKC. The lowest value of lignin content was obtained when the moisture content was low, with moderate PKC particle size and feed rate.

During the separation process, contact electrification occurred when different materials contacted each other. In this case, the contact of the separator with the PKC contaminated with shells. During the separation process, the PKC particles and shells behaved differently. Most PKC remain attached to the separator and adhered to the separator surface. The PKC was detached from the surface of the separator by using a scrapper. On the other hand, most of the shells and some the PKC fell off during the shaking process. The amount of PKC attached to the surface of separator increased as the separator shaking cycles and speed increased. This was possibly due to the increased of static charge as the rubbing cycle, strength and speed increased [33,34].

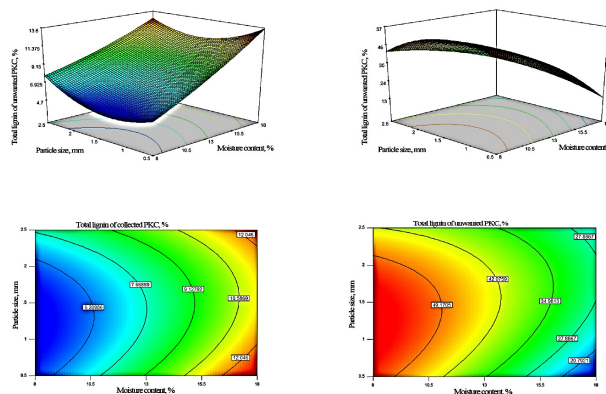
As shown in Fig. 1, when the moisture content of PKC decreased, the efficiency of separation process was increased. This was indicated by the decrease and increase of the total lignin of collected and unwanted PKC respectively. The efficiency of separation was reduced with humidity, possibly due to the reduction of charge when the relative humidity is high [30,35,36].

Fig. 2 shows the total lignin content of collected PKC decreased as particle size increased up to <1.3 mm. This can be explained by the increase of particle electrification (eg. PKC and polyester in this case) with particle size that resulting in stronger particle-wall adhesion [36,37]. However, larger particle size could result in reduced adhesion on the surface [38]. For example, the use of PKC with higher particle size (>1.3 mm) showed reduction of separation efficiency probably because of low surface charge-to-mass ratio that reduce the static cling strength of PKC to the separator.

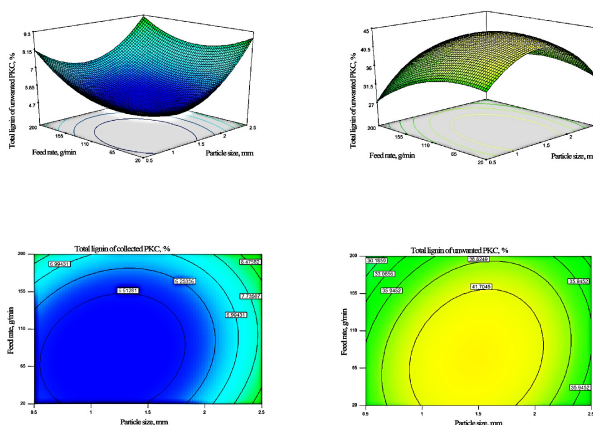
As shown in Fig. 3, the increased of feed rate up to 110 g/min increased the separation efficiency, but higher feed rate caused a reduction in separation efficiency. This is because the amount of PKC spread on the surface of separator was overloaded. Hence, the amount of PKC that come in contact with the surface of separator was reduced.



**Fig. 1.** The effect of moisture content and feed rate on total lignin of collected and unwanted PKC (particle size <1.5 mm).



**Fig. 2.** The effect of moisture content and particle size on total lignin of collected and unwanted PKC (feed rate 110 g/min).



**Fig. 3.** The effect of particle size and feed rate on total lignin of collected and unwanted PKC (moisture content 13%).

**Optimization and Model Verification Performance**

The amount of total lignin in collected PKC would influence the nutritive value of PKC. Therefore, the conditions of separation method evaluated were set to produce low amount of lignin in the collected PKC. Numerical RSM optimization methods were used in the study by selecting the desired goals for each independent and dependent variables.

The predictive models for the optimal separation conditions were verified by repeating the separation experiment under the following conditions: particle size <1.5 mm; moisture content 13%; feed rate 110 g/min; type of separator, polyester. The confirmation was done to ensure that the predicted results by the predictive models were not biased towards the experimental results. The data presented in Table 5 showed that the predicted values for lignin content were close to the experimental values obtained. The amount of lignin in collected PKC was reduced by nearly 50%. The results also showed the other parameters measured including crude fibre, protein and energy content of treated PKC. The crude fibre was reduced by 40%, while the protein content increased to 18.5%. The separation process as compared to the untreated PKC did not significantly affect the gross energy of both collected and unwanted PKC. This was due to the similarity of the gross

energy between the shells and the PKC. Therefore, the gross energy is not affected after removal of shells from PKC. It is anticipated that further reduction in lignin and crude fibre present in PKC could be achieved by increasing the frictional contact time, different separator materials and adjusting the speed rate.

**Table 5.** Chemical composition of untreated PKC, treated PKC and shells.

| Sample              | Untreated PKC            | Collected PKC (Exp.)     | Collected PKC (Pred.) | Unwanted PKC (Exp.)      | Unwanted PKC (Pred.) | Shells                   |
|---------------------|--------------------------|--------------------------|-----------------------|--------------------------|----------------------|--------------------------|
| Total lignin, %     | 15.8 ± 0.49 <sup>a</sup> | 8.1 ± 0.57 <sup>b</sup>  | 7.7                   | 42.4 ± 0.82 <sup>c</sup> | 44.1                 | 49.6 ± 1.05 <sup>d</sup> |
| Crude fibre, %      | 17.1 ± 0.81 <sup>a</sup> | 10.2 ± 0.98 <sup>b</sup> | -                     | 30.4 ± 0.85 <sup>c</sup> | -                    | 55.3 ± 1.05 <sup>d</sup> |
| Crude protein, %    | 16.2 ± 0.90 <sup>a</sup> | 18.5 ± 0.64 <sup>b</sup> | -                     | 8.7 ± 0.45 <sup>c</sup>  | -                    | 1.7 ± 0.03 <sup>d</sup>  |
| Gross energy, MJ/kg | 17.7 ± 0.28 <sup>a</sup> | 17.6 ± 0.29 <sup>a</sup> | -                     | 17.8 ± 0.16 <sup>a</sup> | -                    | 17.5 ± 0.27 <sup>a</sup> |

Note:

Exp. Experimental

Pred. Predicted

Mean ± standard deviation (n=3) with different superscripts within rows are significantly different (P<0.05).

## CONCLUSIONS

The present study demonstrated that removal of shells via static cling and electrostatic separation technique has the potential to reduce the lignin and fibre content of PKC. Under the experimental conditions conducted, the level of lignin was reduced to 8.1%, while that of crude fibre to 10.2%.

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