Chapter 5
Prediction of Oil Yield from Oil Palm Mesocarp Using Thermally Assisted Mechanical Dewatering (TAMD)

Hasmiera Hashim, Suzana Yusup and Patricia Arlabosse

Abstract Thermally assisted mechanical dewatering (TAMD) is a new technology for the separation of solid/liquid. When applied to "nature-wet" biomass, the TAMD process significantly enhances the separation yield. In the present study, TAMD was used to extract the crude palm oil (CPO) from mesocarp. The CPO yield of 70.77 wt% was achieved at optimum parameters of 73.0 °C, 6.7 bar and 60 min of extraction time. This CPO yield was comparable with previous works on the enzymatic extraction and hot compressed water extraction (HCWE) with CPO yield of 71.0 and 70.50 wt% respectively. Apart from that, this value was higher for about 13.80% compared to commercial CPO extracted using screw press which obtained the oil yield of 61.0 wt%. Based on the literatures, the highest CPO yield was obtained from supercritical CO_2 extraction at 77.0 wt% whereas the lowest CPO yield was extracted using subcritical R134a which gave 66.0 wt% of oil yield. Nevertheless, the operational conditions of supercritical CO_2 were 300 bar and 80 °C which were higher than that of TAMD. In conclusion, TAMD extraction has a potential to be an alternative method to extract CPO by producing higher oil yield.

Keywords Crude palm oil · Oil yield · Thermally assisted mechanical dewatering · Response surface methodology

5.1 Introduction

Oil palm (Elaeis quineensis Jacq.) is known as the highest yielding crops for edible oil in the world. It made up 31.7% of global production followed by 25.3% of soybean,

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12.2% of rapeseed and 8.0% of sunflower oil (Hammond et al. 2005). Palm oil is an essential source of food and lipid that used in many consumer products such as cooking oil, cosmetic and dairy products. Palm trees are able to produce 4–10 times more oil per hectare than other oil crops (Barcelos et al. 2015). Comparing to soybean oil, palm oil only requires one-tenths of land, one-seventh of fertilizer, one-fourteenth of pesticide, and one-sixth of energy to produce the same amount of oil (de Vries et al. 2010). Cheap production of palm oil has increased the global demand significantly for last decades and it is expected to grow more in the future (Abdullah and Wahid 2010).

Despite of high global demand, the disadvantages come along with the production of palm oil. Palm oil is frequently associated with deforestation for the expansion of plantation to meet the global demand (Aikanathan 2013). The deforestation causes the loss of natural habitat for species such as tigers, elephants and orangutans (Sayer et al. 2012). However, this conflict can be prevented through another means such as enhancing the extraction process of palm oil to increase the oil yield. In typical palm mill in Malaysia, mechanical screw press is utilized to extract crude palm oil (CPO) production (Che Yunus 2015). The conventional process involves sterilization of fruit bunches, stripping, digestion of fruit and mechanical pressing. Various researches have been conducted to mitigate this drawback through alternative methods such as aqueous enzymatic, hot compressed, supercritical extraction using carbon dioxide (CO_2) and subcritical of 1,1,1,2-tetrafluoroethane (R134a) (Sarip et al. 2016). The use of these alternative methods showed significant improvement in the oil yield up to 0.77 g oil/g dried mesocarp (Berger 1983; George and Arumughan 1992). Nevertheless, most of these methods remained at research scale due to economic constraints, impracticality and environmental sustainability. Therefore, it is important to explore thermally assisted mechanical dewatering (TAMD) as a possible alternative method for the improvement of oil yield.

5.2 Methodology

The methodology involved sample preparation, extraction process using thermally assisted mechanical dewatering and oil yield calculation.

5.2.1 Sample Preparation

Oil palm fresh fruits were collected from Felda Seroja Palm Mill in Jengka 18, Pahang, Malaysia. The feedstocks were treated using sterilization process. The fruitlets were sterilized at 130 °C for 1 h using a steam sterilizer. Mesocarps were obtained by shredding the softened pulp into 3–5 mm of particle sizes and sealed in the plastic container before being stored in a freezer at −5 °C for further experimental use.

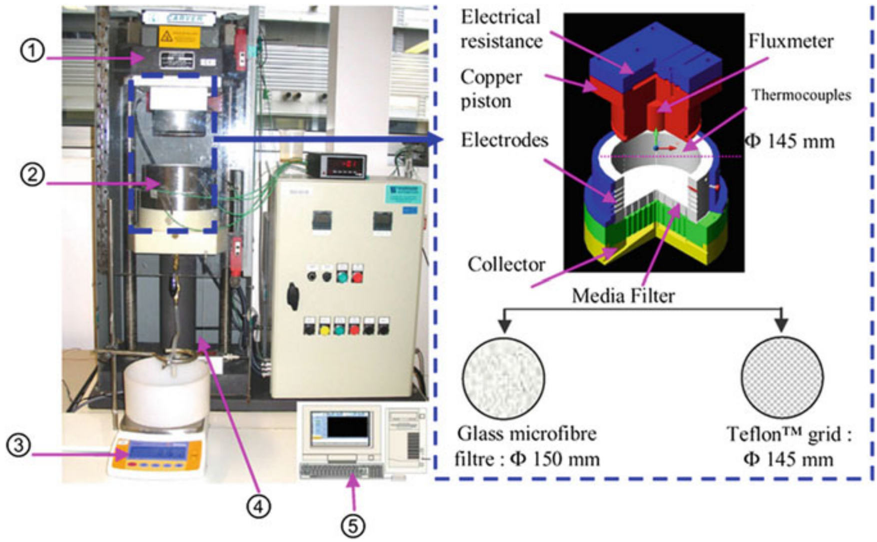

Fig. 5.1 Detail of experimental set up. (1) CARVER hydraulic press; (2) filtration/compression cell; (3) electronic scale; (4) movement sensor; (5) computer and data acquisition

5.2.2 Extraction Process

The extraction process was conducted using thermally assisted mechanical dewatering (TAMD). The TAMD experimental set up was equipped with hydraulic press, filtration/compression cell, electronic scale, movement sensor and computer and data acquisition as shown in Fig. 5.1. The maximum capacity of temperature and pressure are 105 °C and 15 bar respectively in TAMD. Prior to the extraction process, the desired temperature (24–103 °C) was computed into the system to achieve the operating temperature for the sample. Three electrical resistances were inserted at the compressive piston to investigate the temperature impact and control the temperature with minimum error at ±0.1 °C. The sample was loaded into filtration/compression cell. The sample was weighed for 80.0 g using an electronic mass balance. The sample was pressed by the hydraulic press at desired temperatures (24–103 °C) and pressures (2.5–12 bar) for different extraction times (40–65 min). The sample was progressively separated into filtrate and pressed cake. The filtrate was filtered using the media filter to remove the impurities.

5.2.3 Calculation on Oil Yield

The wet weight and dry weight were 80 g of shredded pulp and de-oiled pressed cake respectively. The extracted CPO yield was calculated using Eq. (5.1):

$$Y_{oil} = \frac{W_W - W_d}{W_w} \times 100 \tag{5.1}$$

where Y_{oil} is the oil yield (g-oil/g-sample), W_w is the wet weight (g) and W_d is the dry weight (g).

5.3 Result and Discussions

TAMD extraction was conducted to extract CPO from mesocarp. The operating parameters used were temperature, pressure and extraction time. Total of 20 runs were conducted to determine the optimum parameters. Each run was conducted for three replicates and the average oil yield was taken.

5.3.1 Determination of Optimum Parameters

The analysis of variance (ANOVA) was used to analyse the fitness of TAMD extraction, the adequacy of model, parameter studied, interaction between parameters as well as coefficient of variance (CV) and standard deviation (SD) by using Design Expert version 10.0 of Response Surface Methodology (RSM) model. The ANOVA for extraction of CPO was shown in Table 5.1.

Table 5.1 Analysis of variance (ANOVA) for TAMD extraction of mesocarp

Source	Sum of squares	DoF	Mean square	F value	*p*-value
Model	828.78	9	92.09	84.24	<0.0001
A-temperature (°C)	232.87	1	232.87	213.04	<0.0001
B-pressure (bar)	4.44	1	4.44	0.86	0.3757
C-time (min)	70.76	1	70.76	64.73	<0.0001
AB	30.92	1	30.92	28.29	0.0003
AC	0.081	1	0.081	0.074	0.7912
BC	0.38	1	0.38	0.35	0.5667
A^2	419.68	1	419.68	383.94	<0.0001
B^2	111.52	1	111.52	102.02	<0.0001
C^2	4.49	1	4.49	4.10	0.0703
Residual	10.93	10	1.09		
Lack of fit	5.14	5	1.03	0.89	0.6506
Pure error	5.79	5	1.16		
R^2	0.9870		Standard deviation	1.05	
Adequate precision	33.084		C.V. (%)	1.68	

The model f-value of 84.24 implied the model was significant. There was only a 0.01% chance that an f-value became large due to noise. The probability (*p*) value of the quadratic model was below 0.0001 which indicated that the model was well fitted to the actual values. The extraction of crude palm oil (CPO) from the mesocarp was accurately described by a quadratic polynomial model. The maximum oil yield (Y) as a function of independent factors was shown in Eq. (5.2). The coded factors of Y, A, B and C represented the oil yield, temperature, pressure and extraction time respectively.

$$\begin{aligned} \mathrm{Y(coded)} &= 68.28 + 4.13\mathrm{A} + 0.12\mathrm{B} + 2.28\mathrm{C} - 1.97\mathrm{AB} + 0.10\mathrm{AC} \\ &\quad - 0.22\mathrm{BC} - 5.40\mathrm{A}^2 - 2.78\mathrm{B}^2 - 0.56\mathrm{C}^2 \end{aligned} \tag{5.2}$$

The accuracy of the model was evaluated using lack of fit to assess its significance. In this model, the insignificant lack of fit with *p*-value of 0.5506 was higher than 0.05 which concluded that second order polynomial equation provided good prediction of the CPO yield. According to Cameron and Windmeijer (Colin Cameron and Windmeijer 1997), R-squared should be at least 0.80 for good fit of the model. The R-squared of the model of 0.9870 indicated the regression model explained the experimental data well. The predicted R-Squared of 0.9414 was in reasonable agreement with the Adjusted R-Squared of 0.9753 where the difference was less than 0.2. Adequacy precision measures the signal to noise ratio and the ratio greater than 4 is desirable. The noise ratio was 33.084 which indicated a satisfactory signal. A low value of standard deviation of 1.05 demonstrated the closeness of data to the average value whereas the low coefficient of variation of 1.68 represented high precision to the estimated values. The predicted yield of CPO was 70.77 wt% at the optimum parameters of 73.0 °C, 6.7 bar and 60 min. The CPO yield extracted from TAMD was comparable with previous works on extraction of CPO using enzymatic extraction and hot compressed water extraction (HCWE) with CPO yield of 71.0 and 70.50 wt% respectively (Sarip et al. 2016; Berger 1983; George and Arumughan 1992; Mahmoud et al. 2008; Colin Cameron and Windmeijer 1997; Teixeira et al. 2013).

Although the obtained yield was comparable, TAMD was conducted at lower temperature of 73.0 °C compared to hot compressed water at 160 °C and enzymatic extraction at 90 °C. Apart from that, the CPO yield of 70.77 wt% was higher about 13.80% compared to commercial CPO extracted using screw press which obtained the oil yield of 61.0 wt% (Nagendran et al. 2000). Based on the literatures, the highest CPO yield of 77.0 wt% was extracted using supercritical CO_2 extraction followed by Soxhlet (Hexane) extraction with 75.7 wt% of oil yield (Lau et al. 2008). The lowest CPO yield was extracted using subcritical R134a which gave 66.0 wt% of oil yield (Mustapa et al. 2009). Nevertheless, the operational conditions of supercritical CO_2 were 300 bar and 80 °C which were higher than TAMD. Nevertheless, the alternative extraction methods produced higher oil yield compared to conventional method. The comparison between oil extracted using TAMD and other extraction methods was tabulated in Table 5.2.

Table 5.2 Comparison of CPO extraction using TAMD and other extraction methods

Extraction method	Operating condition	CPO yield (wt%)	Reference
Supercritical fluid CO_2 extraction	80 °C, 300 bar	77.0	Lau et al. (2008)
Soxhlet (hexane) extraction	65 °C	75.7 ± 0.5	Sarip et al. (2016)
Aqueous enzymatic extraction	90 °C	71.0	Teixeira et al. (2013)
Hot compressed water (HCW)	160 °C, 50 bar	70.0 ± 0.5	Sarip et al. (2016)
Subcritical R134a extraction	80 °C, 100 bar	66.0	Mustapa et al. (2009)
Commercial CPO	40 bar	61.0	Nagendran et al. (2000)
TAMD	73 °C, 6.7 bar	70.77	This work

5.3.2 *Effect of Independent Operating Parameters*

The effect of independent operating parameters on the CPO yield was shown in Fig. 5.3. Based on Fig. 5.3a, temperature demonstrated significant influence on crude palm oil (CPO) yield with p-value <0.0001. This positive result was in agreement with previous works related to the effect of temperature on the oil recovery from the oilseeds (Willems et al. 2008; Ebewele et al. 2010). CPO yield improved significantly with increasing temperature especially when the pressing temperature increased from 40 to 70 °C. In fresh mesocarp, the lipid and protein constituent were enclosed within the cell wall and intercellular voids (Silvamany and Jahim 2015). Introduction of temperature helped to rupture the cell wall and intercellular void which was subsequently increased the mass transfer rate (Burubai 2007). The broken cell wall led to protein denaturation and coagulation which reduced the oil viscosity. It facilitated the flow of oil from the cell into the inter matrix of mesocarp (Willems et al. 2008). Overall, the influence of pressing temperature caused change of solid structure and reduced the viscosity of the oil. However, further increasing temperature from 75 to 90 °C started to reduce the CPO yield moderately. At these temperatures, the colour of CPO became darker and the pressed cake was dried and hard compared to at low pressing temperature. The comparison of pressed cake condition at high temperature and low temperature was observed in Fig. 5.2. This phenomenon was contributed by the effect of water vaporization.

Water evaporated faster than oil at higher temperature which caused significant amount of moisture loss. The pressed cake became hard and dried thus reducing the oil flow through the cell matrices.

Applied pressure demonstrated the weak influence on the CPO yield. CPO yield increased slowly with increasing pressure from 4.5 to 7.00 bar. The CPO yield started to level off at pressure between 7.0 to 7.5 as shown in Fig. 5.3b. Beyond these applied pressure, the CPO yield reduced moderately as pressure was approaching 10 bar.

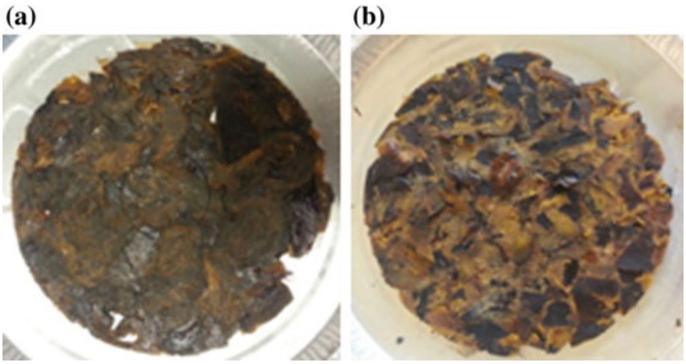

Fig. 5.2 Pressed cake condition at temperature of **a** 87 °C and **b** 63 °C using TAMD

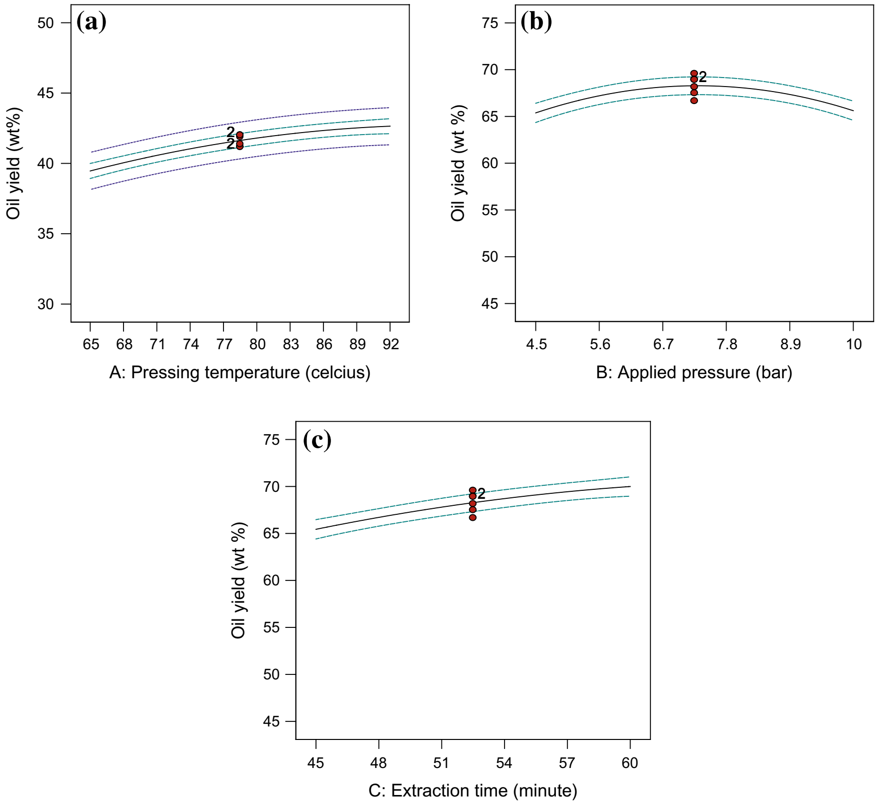

Fig. 5.3 The effect of **a** temperature **b** pressure and **c** extraction time on the CPO extraction

This result was opposite with result in earlier work where a higher oil yield would be extracted at a higher applied pressure (Ebewele et al. 2010). At higher pressure, the cake slowly deformed and compacted. As the intercellular voids became smaller, the oil flow became restricted and subsequently reduced the oil yield. This condition indicated that the excessive pressure did not really give a positive impact on the oil yield. A similar result was observed in the extraction of oil from *Jatropha curcas L.* kernel. (Willems et al. 2008; Ebewele et al. 2010; Silvamany and Jahim 2015; Burubai 2007; Subroto 2015).

The effect of pressing time on the oil yields from mesocarp was shown in Fig. 5.3c. The oil yield was directly proportional to pressing time. The oil yield continued to increase as the pressing time increased. These results were in close agreement with the previous work reported by Acheheb et al. (2012) in the extraction of oil from *Pistacia atlantica* using hydraulic press machine. The pressing time showed moderate effect on the oil yield where the yield increments were approximately 5 wt%. It was concluded that the pressing time was within the optimum values. Longer extraction time than this range was not feasible as it added to operation cost for big scale production.

5.3.3 Effect of Interactive Parameters

The effect of interaction between the parameters was shown in Fig. 5.4. Based on Fig. 5.4a, the effect of pressing temperature was more significant at lower pressure compared to higher pressure to achieve maximum crude palm oil (CPO) yield. For instance, the temperature of 87 °C produced 68.15 wt% and 61.13 wt% of CPO at pressure of 7.25 bar and 10 bar respectively. The result indicated that lower pressure produced more CPO than higher pressure at constant pressing temperature and extraction time. A similar effect was also reported in previous works by Mpagalile and Clarke (2005) and Subroto et al. (2015). The oil yield started to be reduced at higher temperature and pressure. The interaction between these parameters became counteractive at higher values and this effect was explained by Bargale et al. (1999) in his previous work. Increasing temperature decreased the viscosity of oil thus facilitated the oil flow through the compressed cake. Conversely increasing pressure caused the cake to become harder and limited the oil flow from the intercellular voids (Bargale et al. 1999). In general, the oil yield increased with extraction time for all pressing temperature. Based on Fig. 5.4b, CPO yield increased progressively from 40 to 55 min when pressing temperature was conducted from 40 to 80 °C. This condition was contributed by coagulation of protein and reduction in oil viscosity which allowed the oil to flow easily.

A similar condition was observed by several researchers that the pressing temperature and extraction time showed significant effect on the oil yield (Pominski et al. 1970; Bongirwar et al. 1977). There was a significant reduction in oil yield at lower and higher range of temperature for longer extraction time. Extending the extraction time at high temperature led to substantial moisture loss and hardened the

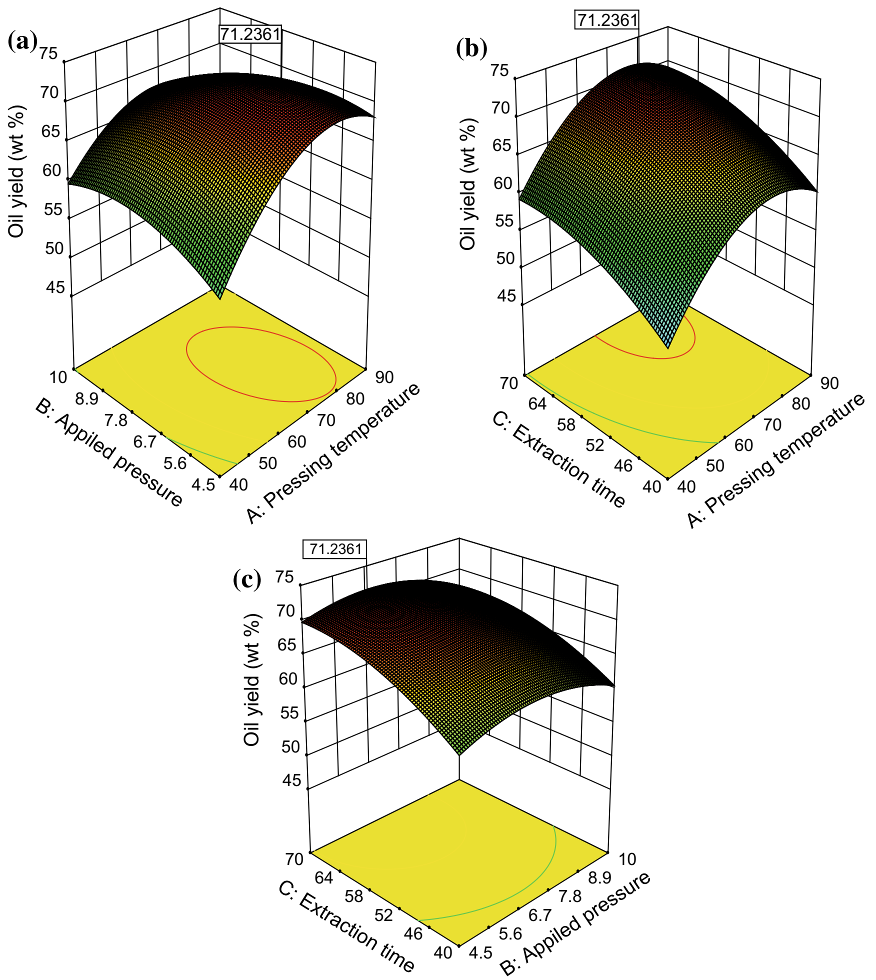

Fig. 5.4 Oil yield as a function of interactive parameters

cake. This phenomenon was known as the effect of moisture content in the oil. Water acted as an interfacial agent between the protein-rich cake and oil. At higher pressing temperature, the adhesion became thicker and formed a paste-like plastized material (Subroto 2015). Furthermore, high temperature and long extraction time contributed negative influences on the quality of extracted oil and pressed cake (Anjou 1972; Ohlson 1976).

The applied pressure demonstrated minimal influences on the crude palm oil (CPO) yield for all pressing time. Based on Fig. 5.4c, the oil yield increased very slowly at pressure of 5.0 bar and started to level off at 7.0 bar. This condition was likely happened due to maximum consolidation point. Consolidation point is defined as a minimum pressure needed to flow oil out from the intercellular void (Ajibola et al. 2002; Herak 2013). Once the cake deformation reached maximum consolidation point, further increment in pressure and time showed no effect on the oil yield. The oil yield began to drop with pressure above 8.0 bar for longer extraction time. The adverse effect was affected by the closure of intercellular voids. Beyond the optimum pressure, the voids became smaller and restricted the oil flow.

5.4 Conclusion

The optimum parameters of CPO were at 73 °C and 6.7 bar for 60 min to obtain the maximum yield of 70.77 wt%. The obtained yield was in close agreement with the predicted value generated from RSM. Based on the ANOVA, the R-squared of the model and lack of fit were 0.9870 and 0.5506 which indicated that the model was significant. It was observed that the temperature and time were statically important in affecting the CPO yield compared to pressure. In terms of parameter interactions, temperature-pressure and temperature-time displayed significant influence on CPO yield based on their respective *p*-value. The oil yield extracted using TAMD was higher about 13.80% than conventional method, screw press which obtained 61.0 wt% of CPO yield. TAMD also produced comparable oil yield with other alternative methods at optimum parameters. As a conclusion, TAMD extraction has a potential to be an alternative method to extract CPO from mesocarp.

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