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Influence of palm kernel variables on the yield and quality of oil expressed using an expeller

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Abstract: The objectives of this study were to establish the impact order of the oil-palm kernel processing variables, namely: kernel moisture content (KMC), kernel heating temperature (KHT), kernel heating duration (KHD), and kernel particle size (KPS) on the palm kernel oil (PKO) yield; to develop an empirical model for the PKO yield as influenced by the KMC, KHT and KHD; to investigate the effect of the KMC, KHT and KHD on the PKO quality; and to specify levels of the kernel variables for the maximum PKO yield with minimum variability. The study was undertaken using oil-palm kernels of unidentified variety from Nsukka, Nigeria. The statistical analysis of data was performed with Design-Expert 8P and Minitab 19 Software at $P = 0.05$. The impact order of the studied kernel variables on the PKO yield, using an expeller (MS-100), was found to be the KPS, KMC, KHD, and KHT. For the maximum PKO yield with minimum variability in the PKO yield, a KMC of 5% (wb), a KHT of 80 °C, a KHD of 10 min, and a KPS of 11 mm and above is recommended.

Keywords: oilseed variables; screw press; screening experiment; empirical modelling; PKO yield

The oil-palm kernel is the source of the palm kernel oil (PKO) and palm kernel cake (PKC). The PKO is edible and has industrial applications while the PKC is a useful component of livestock feeds (Akubuo and Eje 2002). The expression of the oil from the oilseeds is an important industrial operation. The method employed affects both the quantity and quality of the oil expressed. Two methods are basically used commercially to express the oil from the oilseeds. One is the solvent extraction method, in which a solvent is used to dissolve the oil present in the oilseed and the resultant mixture is later heated to evaporate the solvent and collect the oil. The other is the screw press method that is widely used for the commercial expression of the oil from the oilseeds, especially for high oil-content seeds like palm kernels, groundnuts, sunflowers, etc. (Sayasoonthorn et al. 2012). The efficient expression of the oil from the oilseeds using a screw press involves the careful establishment of the optimal pressing conditions for different oilseeds as the best process parameters are somewhat different for each oil-bearing seed and nut (Deli et al. 2011).

Oilseed variables include the pre-heating moisture content, roasting or heating temperature, particle size, age, variety, maturity, cleanliness, and pre-treatments (Bargale 1997). Orhevba et al. (2013) obtained a maximum yield of the neem seed oil at a moisture content of 8.1% wb. Aremu and Ogunlade (2016) recorded the maximum yield of the oil from the African oil bean at an 8% dry basis (db). Studies on the PKO expression using a screw press (expeller) are very limited. Only two published studies have investigated the effect of palm kernel variables on the PKO yield (Akinoso et al. 2006a; Ezeoha et al. 2020). Again, only one study, Akinoso and Igbeka (2007) published a study of the effect of palm kernel variables on the PKO quality. No study has

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investigated how sensitive the variability in the PKO yield is to the different levels of the major kernel variables. The essence of the present study was, therefore, to confront the few previous studies and to fill the above knowledge gap.

The specific objectives of this work were to: establish the order of the influence of the KMC, KHT, KHD and KPS on the PKO yield using an MS-100 screw press (producer, country); develop an empirical model for the PKO yield as a function of the kernel variables; investigate the effect of the kernel variables on the PKO quality; and identify and specify levels of the kernel variables to achieve the maximum PKO yield with minimum variability.

MATERIAL AND METHODS

Material. The study was undertaken using an unidentified variety of oil-palm kernels obtained from a local market in Nsukka, Enugu State, Nigeria and a Magnus (Nigeria) fabricated palm kernel screw press with an oil extraction efficiency of 73%, a capacity of 100 $kg \cdot h^{-1}$, a speed of 56 rpm and a choke gap of 1.85 mm.

Preparation of the material. The four batches of oil-palm kernels used in the study were sorted to remove un-cracked and partially-cracked nuts and unwholesome kernels; after which they were sieved to remove dust, debris, and other foreign material. The initial moisture content of the kernels was determined in accordance with ASAE S410.2. (2010) Sun-drying was used to lower the moisture content of the kernels as required. The rewetting formula [Equation (1)] given by Coskun et al. (2005), Ozumba and Obiakor (2007) and Karimi et al. (2009) was used to raise the kernels to the required higher moisture content.

$$Q = \frac{A(b-a)}{(100-b)} \qquad (1)$$

where: Q – the quantity of the distilled water to be added to the seed sample (g); A – the initial mass of the seed sample (g); a – initial moisture content of the seed sample (%); b – desired moisture content of the seed sample (%).

Methodology. The experimental design is the process of planning, designing, and analysing an experiment so that valid and objective conclusions can be drawn from it. A fractional factorial design is a type of an orthogonal array design which allows experimenters to study the main effects and desired interaction effects in a minimum number of trials. A 2^{4-1} fractional factorial design enables one to study 4 factors at 2-levels with only 8 experiments ($2^{4-1} = 2^3 = 2 \times 2 \times 2 = 8$) instead of 16 ($2^4 = 2 \times 2 \times 2 \times 2 = 16$) experiments without replications. A full factorial design consists of all the possible combinations of the levels for all the factors. The total number of experiments for studying k factors at 2-levels is, therefore, 2^k without replications (e.g., $2^3 = 2 \times 2 \times 2 = 8$).

A 2^{4-1} fractional factorial experimental design (Table 1) with 2 replications was used to screen the batch A kernel factors in order to establish their impact order on the *PKO* yield.

A 2^3 full factorial central composite design (CCD) with 6 centre points and 6 axial star points without replication (Table 2) was used to generate the data for the empirical model using the batch B kernels. For empirical modelling studies, the influence of the kernel size (*KPS*) was eliminated by using the whole and large broken (≥ 11mm) kernels only. This strategy was adopted because the 4-factor screening experiments showed that the MS-100 screw press used in this study was designed for processing whole and large broken (≥ 11mm) kernels only; as feeding the MS-100 press, using, for example, pulverised kernels (especially sizes less than or equal to 3 mm) caused poor material flow, excess heat build-up in the press, the burning of the kernels, and a low *PKO* yield.

A one-factor at a time (OFAT) experimental design with 2 replications (Table 3) was used to assess the effect of the kernel factors on the PKO quality, using the batch C kernels. Each oil sample was examined for the quality based on the colour, free fatty acid, and oil moisture content using AOCS Method C13b-45, AOAC Method 940.28, and AOCS Method Ca 2c-25 (AOCS, 2013a, b; AOAC 2012), respectively. For the colour determination, the diameter of the glass tubes used was 12.7 mm.

Table 1. 2^{4-1} Fractional factorial experimental design (screening experiment)

Factors	Low level	High level
KMC (% wb)	3	7
KHT (°C)	30	130
KHD (min)	5	15
KPS (mm)	3	≥ 11

KMC – kernel moisture content; *KHT* – kernel heating temperature; *KHD* – kernel heating duration; *KPS* – kernel particle size

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Table 2. 2^3 full factorial experimental design with 6 centre points and 6 axial star points

Run	Type	Kernel factors		
		KMC (% wb)	*KHT* (°C)	*KHD* (min)
1	factorial	5	60	17
2	factorial	9	60	7
3	factorial	5	60	7
4	factorial	9	120	17
5	factorial	5	120	17
6	centre	7	90	12
7	centre	7	90	12
8	factorial	9	120	7
9	factorial	5	120	7
10	factorial	9	60	17
11	centre	7	90	12
12	centre	7	90	12
13	axial	7	141	12
14	axial	4	90	12
15	centre	7	90	12
16	axial	7	40	12
17	axial	11	90	12
18	centre	7	90	12
19	axial	7	90	6
20	axial	7	90	21

KMC – kernel moisture content; *KHT* – kernel heating temperature; *KHD* – kernel heating duration

Table 3. One-factor at a time experimental design with 2 replications

Sample No.	Factors		
	KMC (% wb)	*KHT* (°C)	*KHD* (min)
1	7	130	15
2	7	30	15
3	7	130	15
4	3	130	15
5	7	130	5
6	7	130	15
7	3	30	5
8	3	130	5

KMC – kernel moisture content; *KHT* – kernel heating temperature; *KHD* – kernel heating duration

A 2^3 full factorial experimental design (Table 4) with four centre points and 2 replications was used for the variability study using the batch D kernels. A matrix with a natural log of the standard deviation [ln (SD)] of two replicate yields as the response was computed from the experimental results and used to assess how the *KMC*, *KHT*, and *KHD* and their interactions affected the variability of the *PKO* yield (Jiju 2008). This was performed by plotting the Pareto plot of the effects, the main and interactions plots.

Table 4. 2^3 full factorial experimental design with centre points

Factors	Low level	Centre	High level
KMC (wb; %)	3	5	7
KHT (°C)	30	80	130
KHD (min)	5	10	15

KMC – kernel moisture content; *KHT* – kernel heating temperature; *KHD* – kernel heating duration

The screw press was test run for about 2 min before processing the kernel samples. The expressed oil per sample size of 500 g was collected in a 3 L transparent plastic bucket over a muslin cloth filter. The collected oil was clarified by allowing it to stand for 48 hours. The volume of the pure oil was measured with a 500 mL graduated transparent plastic beaker. The data were analysed using the Design-Expert (version 8.0) and Minitab (version 17) statistical software packages.

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RESULTS AND DISCUSSION

Results of kernel variables screening experiment. The ANOVA showed that the *KPS* (3 mm versus ≥ 11 mm), *KMC-KPS*, and *KPS-KHD* interactions had a significant ($P < 0.05$) positive effect on the *PKO* yield using the MS-100 screw press. However, the *KMC* (3 and 7% wb), *KHT* (30 and 130 °C), *KHD* (5 and 15 min), and *KHT-KPS* interaction had effects, but the effects were not significant at a 5% level of significance. This non-significant effect of the *KMC*, *KHT*, and *KHD* on the oil yield was reported by Ezeoha et al. (2020) for the factor levels of 3–10% *KMC*, 50–130 °C *KHT*, and 5–20 min *KHD*. The cube plot of the results of the screening experiment (Figure 1) showed that the best condition for the maximum *PKO* yield by the batch A kernels used for the screening experiment was: KPS of ≥ 11 mm, *KHD* of 5 min, *KHT* of 30 °C, and *KMC* of 3% wb with a *PKO* yield of 242 mL/500 g-kernels; equivalent to 93.1% of the total kernel oil content (using the MS-100 screw press). Ezeoha et al. (2020) reported a 6.6% *KMC*, 80 °C *KHT*, and 10 min *KHD* for the maximum oil yield of 205 mL/500 g-kernels. It has been stated that at a moisture content (MC) level above the optimum pre-heating MC, there is swelling of the mucilage which produces a cushioning effect on the seed; the swelling impedes the oil flow and the cushioning impedes the rupturing of the seed's particles and internal tissue during the oil expression (Fasina and Ajibola 1989). Also, an adequate heating duration (HD) is required for the protein coagulation, cell breakdown, reduction in the oil viscosity, and adjustment of the MC to the optimum level to improve the oil yield (Fasina and Ajibola 1989).

The *KPS* size was a very critical factor for the MS-100 screw press used in this study. A *KPS* of ≥ 11 mm (whole kernels and large-sized broken kernels) gave a higher *PKO* yield than a kernel size of 3 mm (already crushed kernels) and this difference was significant at a 5% level. Feeding the MS-100 press, for example, with pulverised or crushed kernels (especially sizes less than or equal to 3 mm) caused a poor material flow, excess heat build-up in the press, the burning of kernels, and a low *PKO* yield; suggesting that it was designed to handle whole and/or large-sized broken kernels. Hamzat and Clarke (1993) reported that coarsely ground samples of groundnut yielded more oil than finely ground samples.

A *KHT* of 30 °C gave a higher *PKO* yield (242 mL/500 g-kernels) than a KHT of 130 °C (233 mL). This situation was probably because at the 130 °C temperature conditioning in the oven prior to the oil extraction, the oil losses were noticed as was earlier observed by Ezeoha et al. (2020), especially when the *KMC* was below 5%. The oil yield of sunflower seeds increased with a heating temperature at a higher seed moisture content only (Singh 1984). The temperature was an important factor in the PKO extraction from oil-palm kernels. *KHT*s of 80 to 130 °C were optimal. However, the higher the heating temperature adopted, the lower the heating duration should be selected to prevent any possible PKO losses in the heating vessel. Fasina and Ajibola (1989) observed that a high heating temperature and long heating duration could

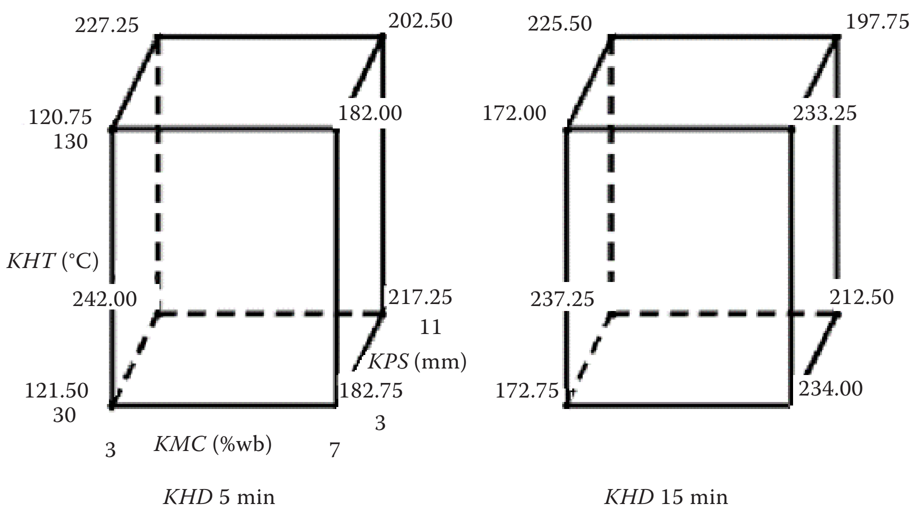

Figure 1. Cube plot of the mean PKO yield versus the *KMC*, *KHT*, *KPS*, and *KHD* (Minitab 19) (screening experiment)

KMC – kernel moisture content; *KHT* – kernel heating temperature; *KHD* – kernel heating duration; *KPS* – kernel particle size

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have a negative effect on the quantity of the expressed seed oil. Ozumba et al. (2017) also observed that the processed oil loss increased significantly as the heating temperature of the oil palm kernel increased from 70 to 130 °C. The heat treatment of the oilseeds increases the oil yield due to the breakdown of the oil cells, the coagulation of the protein in the cells which makes the oil easily separable, and the decreased viscosity which makes the oil flow more readily (Fasina and Ajibola 1989). Heating the oilseed also adjusts its MC to an optimum level for the maximum expression (Adeeko and Ajibola 1990).

Based on the reported cases of oil losses when kernels with a moisture content of ≤ 5% have been preheated before the oil extraction using a screw press, very dry kernels (3%) might not even need to be heated before processing to avoid any oil losses in the toaster or oven. Kernels with a 3% moisture content (wb) could be more economically processed without preheating the kernels. The heat generated in the action zone of the screw press when the press was charged is considered enough for the efficient extraction of the PKO. Kernels with a moisture content higher than 3% (wb), but less than or equal to 10% (wb) should be preheated at a temperature of 80 to 130 °C for a duration of 10 to 17 min depending on the heating temperature adopted. Pre-heating the kernels is costly whether undertaken with solar energy or electrical heating energy in an oven or toaster. In the tropics where sunlight is in abundance, especially in the dry season, it might be considered cheaper to toast the kernels by spreading them under the sun with intermittent stirring. From experience, adequate toasting is achieved when the kernel's body begins to exhibit a shiny appearance, and this usually happens at a *KMC* of about 3% wb.

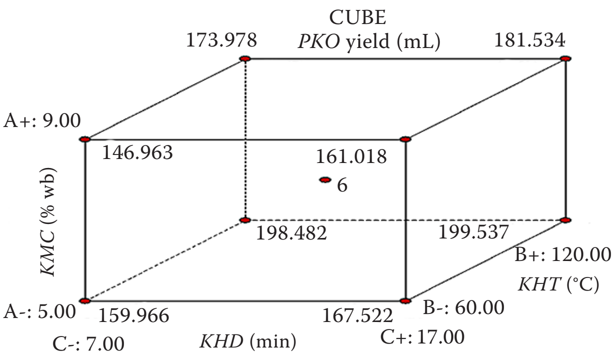

Figure 2. Cube plot of mean palm kernel oil (PKO) yield versus *KMC*, *KHT*, and *KHD* (Design-Expert) (modelling experiment)

KMC – kernel moisture content; *KHT* – kernel heating temperature; *KHD* – kernel heating duration; A – lower value of *KMC*; B – lower value of *KHT*; C – lower value of *KHD;* +stands for higher values

Results of the empirical modelling experiment. The main effect plots of the kernel factors showed that the *PKO* yield increased as the *KMC* decreased with a peak at a *KMC* of 5% or less. Also, the *PKO* yield increased as the *KHT* increased from 60 to 120 °C or above. Again, the *PKO* yield increased slightly as the *KHD* was increased from 7 to 17 minutes. The interaction plots of the kernel factors' effects showed that the maximum *PKO* yield (210.8 mL) was obtained at 120 °C *KHT* and 5% *KMC* or less.

The cube plot of the results of the modelling experiment (Figure 2) showed that the best condition for the maximum *PKO* yield only using the whole and large broken (≥ 11 mm) kernels of the batch B kernels was: *KHD* of 17 min, *KHT* of 120 °C, and *KMC* of 5% wb which gave a *PKO* yield of 200 mL/500 g-kernels. Akinoso et al. (2006a) reported a 4.5% *KMC*, 130 °C *KHT*, and 5 min *KHD* for the maximum oil yield. The difference in the optimal condition is attributed to the varietal and factor level differences.

The prediction model, in terms of the actual factors, was given by Equation (2):

$$PKO \text{ yield} = 147.42 - 3.88KMC + 0.49KHT + 0.76KHD \quad (2)$$

where: *PKO* – palm kernel oil yield (predicted); *KMC* – kernel moisture content; *KHT* – kernel heating temperature; *KHD* – kernel heating duration

The above linear model was significant ($P < 0.0001$), with an R-squared value of 76%. The model shows that the *KMC* had the greatest influence on the *PKO* yield with a coefficient of 3.88. The MC had highest influence on the palm kernel and sesame seed oil yield followed by the heating duration and then the heating temperature (Akinoso et al. 2006b). The results of the model's confirmation experiment are presented in Table 5 with the standard error (SE) calculation. The SE was 2.22, which was less than the *PKO* yield (predicted) ± 3, showing that the model was satisfactory (Jiju 2008). The *PKO* yield (predicted) was 199.89 mL/500 g-kernels (Figure 2) compared to the actual oil yield of 194.8 mL/500 g-kernels (Table 5). Akinoso et al. (2006a) earlier suggested a quadratic model with an R-squared value of 86%.

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Table 5. Results of the model confirmation experiments

Sample No. *PKO* yield	(mL/500 g)
1	189
2	198
3	190
4	197
5	200
Average	194.8
Standard error	± 2.22

PKO – palm kernel oil

Results of the experiment to assess the effects of the *KMC*, *KHT*, and *KHD* on the PKO Quality. Table 6 shows the results of the experiment to determine the effect of the *KHT*, *KHD*, and *KMC* on the colour intensity, free fatty acid and moisture content of the expressed PKO. The table shows that the colour intensity of the PKO oil increased with the *KHT* (1.2R/10Y at 130 °C *KHT* > 1R/10Y at 30 °C KHT) at a constant *KMC* of 7% (wb) and a *KHD* of 15 minutes. However, the free fatty acid (FFA) decreased from 3.62% at 30 °C to 2.39% at 130 °C while the moisture content of the oil increased from 0.00% at 30 °C to 1.70% at 130 °C. The colour intensity of the PKO also increased with the *KMC* (1R/10Y at 7% *KMC* compared to 0.4R/7Y at 3% *KMC*); the FFA also increased with the *KMC* (1.76% at 3% *KMC* compared to 2.37% at 7% *KMC*); and the MC of the PKO increased from 0.00% at 3% *KMC* to 1.72% at 7% *KMC*. The colour intensity increased from 0.9R/10Y at 5 min *KHD* to 1.1R/10Y at 15 min *KHD*; the FFA decreased from 3.02% at 5 min to 2.38% at 15 min *KHD*; while the MC of the oil increased from 0.00% at 5 min to 1.72% at 15 min *KHD*. The increase in the colour intensity of the expressed PKO with the increase in the *KHT*, *KMC*, and *KHD* agreed with the findings of Akinoso and Igbeka (2007). Also, Adeeko and Ajibola (1990) reported the same observation for groundnuts. The colour intensity of the PKO increased as the *KMC*, *KHT*, and *KHD* increased because of the moisture loss by the carbohydrates and the oxidation of the carotenoid and fatty acids in the oilseeds during the thermal processing (Olayanju 2002; Akinoso et al. 2006b). The moisture loss and co-oxidation is accelerated by the high *KHT*, *KMC*, and *KHD*, thereby making the oil colour intensity to increase. The observed decrease in the FFA with the increase in the *KHT* and *KHD* and its increase with the increase in the *KMC* was also reported by Olayanju (2002) and Fakayode et al. (2016) in beniseed and moringa seed oils, respectively. The explanation was that during the oil extraction from the oilseeds, the water inside the seeds moves out with the oil and reacts with the triglycerides to form FFA and glycerin (Olayanju 2002). Thus, with an increase in the *KHT* and *KHD*, the oilseeds' moisture content decreases leading to a reduction in the FFA.

Orhevba et al. (2013) reported that the moisture content of the neem seed kernel had a fluctuating effect on the values of the free fatty acid of the expelled neem seed oil. They also observed that the moisture content at higher levels affected the colour of the oil, which changed from brown to dark brown.

Results of the test of the effect of the *KMC*, *KHT* and *KHD* levels on the variability in the *PKO* yield.

The Pareto plot of the results of the test of the effect of the levels of the kernel variables on the variability

Table 6. Results of the one-factor at a time experiments on the effect of the *KMC*, *KHT*, and *KHD* on the PKO quality

Sample No.	Kernel factors			Quality indices*		
	KHT (°C)	*KHD* (min)	*KMC* (%wb)	colour (12.7 mm)$^+$	FFA (%)	MC (% wb)
1	130	15	7	1.2R/10Y	2.39	1.71
2	30	15	7	1R/10Y	3.62	0.00
3	130	15	7	1R/10Y	2.37	1.70
4	130	15	3	0.4R/7Y	1.76	0.00
5	130	5	7	0.9R/10Y	3.02	0.00
6	130	15	7	1.1R/10Y	2.38	1.72
7	30	5	3	0.9R/10Y	2.54	2.00
8	130	5	3	0.8R/8Y	2.77	0.00

*Values are the means of 2 replicates; (12.7 mm)$^+$ – the cell path length or diameter of the sample glass tube used; R – red colour range (0.1–20); Y – yellow colour range (1 – 70); *KHT* – kernel heating temperature; *KMC* – kernel moisture content; *KHD* – kernel heating duration; FFA – free fatty acid; MC – moisture content; PKO – palm kernel oil

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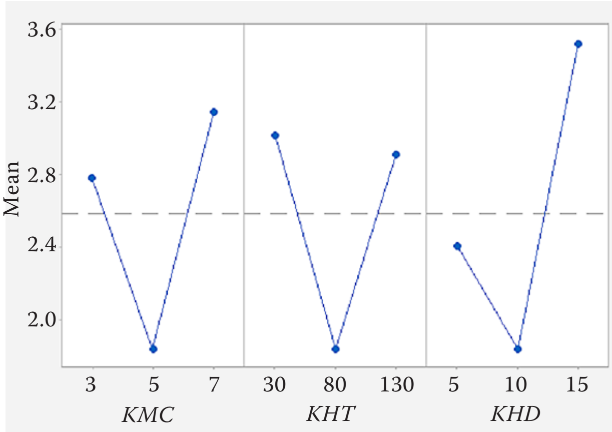

Figure 3. Main plots of the ln SD of the palm kernel oil yield versus the *KMC*, *KHT*, and *KHD* (Minitab)

KMC – kernel moisture content; *KHT* – kernel heating temperature; *KHD* – kernel heating duration

in the *PKO* yield showed that none of the levels of the studied variables had a significant effect on the variability of the *PKO* yield at a 5% significant level. However, the *KHD* had the largest effect followed by the *KMC–KHD* interaction, *KMC-KHT-KHD* interaction, *KMC*, *KHT-KHD* interaction, *KHT*, and *KMC-KHT* interaction in that order. The main plot indicated that the lowest variability in the *PKO* yield occurred at a *KMC* of 5% (wb), a *KHT* of 80 °C, and a *KHD* of 10 min as shown in Figure 3.

CONCLUSION

The following conclusions were drawn from the results of this study:

The influence order of the major oil-palm kernel variables on the *PKO* yield using an MS-100 screw press was first, the KPS (crushed versus whole and large broken (≥ 11 mm) kernels), second, the *KMC* (3 to 7% wb), third, the *KHD* (5 to 15 min), and fourth, the *KHT* (30 to 130 °C).

A linear empirical relationship given as: *PKO* yield (pred.) = 147.42 – 3.88*KMC* + 0.49*KHT* + 0.76*KHD* was developed for the *PKO* yield as a function of the three major kernel variables namely, kernel moisture content (3–10% wb), kernel heating temperature (60–130 °C), and kernel heating duration (5–17 minutes). The model had an *R*-Squared value of 75%.

The *KMC* had effect on PKO quality, especially on the colour and FFA; with very dry kernels (3%) yielding lighter-coloured oils with a lower FFA percent than the less dry kernels with a 7% moisture content (wb) and above. The *KHT* had an effect on the PKO quality, especially on the FFA and colour; with the high KHTs yielding more coloured PKO with a lower FFA percent than the low *KHT*s.

The factor levels of the studied *KMC*, *KHT*, and *KHD* had a non-significant ($P > 0.05$) effect on the variability of the *PKO* yield, but the *KHD* had the largest effect, followed by the *KHD-KMC* interaction; the lowest variability in the *PKO* yield occurred at a *KMC* of 5% (wb), a *KHT* of 80 °C, and a *KHD* of 10 minutes.

The optimal values of the studied kernel variables for maximising the *PKO* yield, obtaining a lighter-coloured oil with a low FFA, and ensuring the minimum variability in the *PKO* yield were: kernel preheating moisture content of 5% (wb); kernel heating temperature of 80 °C; kernel heating duration of 10 min; and whole kernels or a kernel particle size of 11 mm and above when using the MS-100 screw press or any other press designed for whole kernels.

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