Optimization of Oil Yield from Groundnut Kernel (*Arachis hypogeae*) in an Hydraulic Press Using Response Surface Methodology

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Authors' contributions

This work was carried out in collaboration between all authors. Author JOO designed the study and the laboratory experiments. Authors TJA and JOO managed the literature searches, carried out the analyses of the study and performed the experiments. Author JAA carried out the statistical analysis and interpreted the results. All authors wrote, read and approved the final manuscript.

Original Research Article

ABSTRACT

Aim: The present study investigated the effect of operating parameters on the mechanical extraction of oil from groundnut kernel using hydraulic press

Methodology: A five factor, five levels central composite design (CCD) was applied to determine the effects of five independent variables (moisture content, heating temperature, heating time, applied pressure and pressing time) on oil yield. Response surface analysis method was employed to optimize the parameters in the experiment.

Results: Data analysis shows that all the variables significantly affected the oil yield at 95% confidence level. Optimum oil yield of 32.36 % was obtained when the moisture content, heating temperature, heating time, applied pressure and pressing time were 8.13%, 81.93ºC, 7.03 minutes, 15.77 Mpa and 6.69 minutes, respectively. The experimental values were very close to the predicted values and were not statistically different at p<0.05.

Conclusion: The regression model obtained has provided a basis for selecting optimum process parameters for the recovery of oil using mechanical press.

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1. INTRODUCTION

Groundnut otherwise known as *Arachis hypogeae* is regarded as the fifth most important protein –rich oil seed crop globally grown after soybean, cotton seed, rape seed and sun flower seed [1]. It is regarded as one of the world's most cultivated crops as it is native in the tropical and sub-tropical regions as an oil seed crop [2]. Nigeria has been ranked as the third major producer of groundnut in the world after China and India [3]. Commercial production of oil from oil seeds like groundnut is usually based on mechanical pressing and extraction [4,5]. Mechanical pressing is preffered to other conventional methods because it is impossible to obtain a solvent-free products from the solvent extraction process and also there is chemical modification of oil produced steam distillation and hydrodistillation are used [6-8]. Oil produced from groundnut kernels are used in the production of wide range of products. Process parameters have been found to have effects on the extraction of oil from groundnut kernel [9]. In order to obtain optimum yield, it is imperative to investigate the best processing conditions for the extraction of oil from the kernel.

Response surface methodology (RSM) is a useful mathematical approach that is widely usedto investigate and optimize the combinatorial effects of several process variables influencing response(s) with a reduced number of experimental runs while varying the variables silmultaneously. Central composite design (CCD) is an ideal effective design that allows for sequential experimentation with a reasonable reduced number of design points [10]. It is a powerful tool for understanding complex processes and the detailed mechanisms of which are not known and for describing factor interactions in multifactor systems [11]. CCD is a well suited design that fits quadratic responses well and are suitable for process optimization when used with RSM [12].

RSM has been used to evaluate the effective factors and build regression models to study the interaction and select the optimum operating variables in oil extraction studies [13]. Karazhiyan et al. [14] investigated the extraction conditions for maximum values of yield, viscosity and minimum protein content of hydrocolloid extract from Lepidium sativum seed using response surface methodology. Their results showed that extraction conditions significantly affected the yield with moisture content and pH being the most important variables. Rezzoug et al. [7] employed RSM to evaluate the effects of processing parameters of a recent extraction process: The fast controlled pressure drop (DIC, ''De´tente Instantanee Controlee'') on the extraction yield of rosemary essential oil. The results showed that the processing pressure and processing time were the most significant parameters both on global extraction yield and the extraction yield of the different essential oil compounds investigated.

The study of Li et al. [15] employed RSM to study the ultrasonic – assisted enzymatic exraction of oil from peanut. Their results indicated that enzyme additive amount, hydrolysis time, hydrolysis temperature, materials to water rate, pH and total protein extraction rate were the major parameters that had influence on oil extraction.

The present study investigated the interaction effects of the moisture content, heating temperature, heating time, applied pressure and pressing time on groundnut oil recovery and used RSM for further optimization to enhance the yield using the influential process variables.

2. METHODOLOGY

The groundnut kernel used in this study were purchased from local markets of Ogbomoso, southwestern Nigeria. They were harvested 30 days before procurement and cleaned manually by hand removal of foreign materials. The moisture content was determined according to ASAE standard S410.1. Experimental methods adopted are as described in Olajide [4]. The sample (100 g) were weighted into sample containers and oven dried at 130^oC for 6hrs. The samples were cooled in a dessicator and weighed to determine moisture loss.

The moisture content of kernels in percent wet basis (D) is calculated as:

$$M = \frac{100(loss\,in\,mass\,of\,kernels)}{Initial\,mass\,of\,Kernels} \tag{1}$$

In determining the oil content, the direct gravimetric method of solvent extraction was used. The method involved using normal Hexane of boiling point 80^oC. Grounded samples (50 g) were weighedinto the thimble of the Soxhlet extractor. Reflux condenser was attached and the extraction was carried out for nine(9) hours after which the solvent was distilled off. The traces of solvent was removed by heating the flask containing the oil by using an air-oven method. The oil extracted was weighed while the defatted cake was kept.

The percentage of oil was calculated as follow

$$\% \, Oil = \frac{A-B}{W} * 100 \tag{2}$$

where, A= Weight of flask +oil; B= Weight of flask only; W= Weight of sample taken.

A central composite design (CCD) was adopted to studythe interaction effects of five factors namely: moisture content, heating temperature, heating time, applied pressure and pressing time which are denoted asX_i(i=1, 2, 3, 4, 5), respectively (Table 1). The literature Indicates that the most important process parameters during oil expression are the moisture content of the feed materials, temperature, pressing time, applied pressure and the heating time [16-18]. The factors and their levels were chosen based on the recommendation of Olajide et al. [4]. These parameters were selected and response surface methodology (RSM) was used to determine the effect of independent variableson product qualities. A second degree polynomial equation was fitted in each response to study the effect of variables and to describe the process mathematically.

Table 1. Factors and levels for central composite design

Variable	Symbol	Coded Levels				
		-2	-1	0	1	2
Moisture Content(%wb)	X_1	4.6	6.6	8.6	10.6	12.6
Heating Temperature (℃)	X_2	65	75	85	95	105
Heating Time(min)	X_3	20	30	40	50	60
Applied Pressure (MPa)	X_4	5	10	15	20	25
Pressing Time(min)	X_5	3	4	5	6	7

The data obtained in the experiments (Table 2) were analyzed using response surface methodology so as to fit the quadratic polynomial equation generated by the Design-Expert software version 9.0.2 (Stat-Ease Inc., Minneapolis, MN, USA). The quality of the fit of the model was evaluated using analysis of variance (ANOVA). The fitted quadratic response model is as described in Equation 3.

$$Y = b_0 + \sum_{i=1}^{k} b_i X_i + \sum_{i=1}^{k} b_{ij} X_i^2 + \sum_{i \ 1<j}^{k} \sum_{j}^{k} b_i X_i X_j + e \qquad (3)$$

where Y is response factor (% Oil yield), and i and j denote linear and quadratic coefficients, respectively. bo is the intercept, bi is the first order model coefficient, k is the number of factors, and e is a random number.

3. RESULTS AND DISCUSSION

The experimental results, the predicted values and the residuals are presented in Table 2. The final equation in terms of the coded factors for the central composite response surface quadratic model is as shown in Equation 4. The results of theANalysis Of VAriance (ANOVA) analysis for the response surface model (Equation 4) are shown in Table 3. The model's F-value of 6966.44 implies that the model is significant. The p values <0.05 indicate that the model terms are significant. In this case, X_1, X_2, X_3, X_4 and X_5; the cross products, $X_1 X_2, X_1 X_3$, $X_1 X_4$, $X_1 X_5$, $X_2 X_4$, $X_3 X_4, X_3 X_5$, and $X_4 X_5$; and the quadratic coefficients X_1^2, X_2^2, X_3^2, X_4^2 and X_5^2 are the significant model terms.

$$Y = 29.06 - 4.52X_1 + 5.31X_2 - 0.55X_3 + 1.43X_4 + 0.68X_5 - 3.95X_1 X_2 + 0.12X_1 X_3 - 6.12X_1 X_4 - 2.86 X_1 X_5 - 1.20X_2 X_3 - 1.32X_2 X_4 - 4.11 X_2 X_5 - 0.31X_3 X_4 - 0.85X_3 X_5 - 0.66X_4 X_5 - 7.26X_1^2 + 2.17 X_2^2 + 0.03 X_3^2 - 9.64 X_4^2 + 2.77X_5^2$$

$$(4)$$

The effects of the factors considered: The moisture content, heating temperature, heating time, applied pressure and pressing time were shown in Figs. 1a – j. Heating temperature had the highest effect on oil yield followed by moisture content and applied pressure. The ANOVA analysis (F- values) also indicated the order of significance of the input variables giving temperature as the most important variable that affected the oil yield followed by moisure content and applied pressure.This order of the effect of the factors on the percentage oil yield agrees with that in the work of Olajide et al.[4] which showed that temperature had the highest effect on oil yield.

In addition, a low lack of fit was noted according to ANOVA table (Table 3). This indicates that the model represents the actual relationship of all the parameters, which are well within the selected ranges (Table 2). In actual fact, the Prob > F value of <0.0001 and F- value of 6966.44 for the model are indications of the significance of the model.The regression model obtained could be used to adequately predict the oil yield within the design space as the R^2 value obtained was 0.99. Also, the predicted R^2 of 0.9982 is in reasonable agreement with the adjusted R^2 of 0.9998 as the difference is less than 0.02. This indicates that the model can be used to navigate within the design space.

Table 2. Experimental design matrix and results for oil yield

Run	Variables					Oil yield		
	X_1	X_2	X_3	X_4	X_5	Actual	Predicted	Residual
1	6.6	75	30	10	6	23.57	23.59	-0.020
2	10.6	75	30	10	4	22.45	22.43	0.024
3	6.6	95	30	10	4	27.36	27.34	0.022
4	10.6	95	30	10	6	23.12	23.10	0.020
5	6.6	75	50	10	4	21.01	20.99	0.025
6	10.6	75	50	10	6	26.05	26.03	0.023
7	6.6	95	50	10	6	24.92	24.90	0.021
8	10.6	95	50	10	4	25.94	25.87	0.065
9	6.6	75	30	20	4	23.98	24.00	-0.020
10	10.6	75	30	20	6	23.71	23.73	-0.021
11	6.6	95	30	20	6	30.36	30.38	-0.023
12	10.6	95	30	20	4	23.98	23.96	0.021
13	6.6	75	50	20	6	28.93	28.95	-0.020
14	10.6	75	50	20	4	24.28	24.26	0.024
15	6.6	95	50	20	4	30.13	30.11	0.022
16	10.6	95	50	20	6	17.64	17.62	0.020
17	4.6	85	40	15	5	23.03	23.01	0.020
18	12.6	85	40	15	5	17.13	17.20	-0.065
19	8.6	65	40	15	5	30.08	30.06	0.016
20	8.6	105	40	15	5	32.33	32.39	-0.062
21	8.6	85	20	15	5	27.49	27.47	0.021
22	8.6	85	60	15	5	27.45	27.52	-0.067
23	8.6	85	40	5	5	16.56	16.63	-0.067
24	8.6	85	40	25	5	18.84	18.82	0.021
25	8.6	85	40	15	3	30.14	30.21	-0.069
26	8.6	85	40	15	7	30.07	30.05	0.023
27	8.6	85	40	15	5	27.37	27.36	0.008
28	8.6	85	40	15	5	27.38	27.36	0.018
29	8.6	85	40	15	5	27.33	27.36	-0.032
30	8.6	85	40	15	5	27.41	27.36	0.048
31	8.6	85	40	15	5	27.39	27.36	0.028
32	8.6	85	40	15	5	27.34	27.36	-0.022

Fig. 1a shows the interaction effects of moisture content (X_1) and heating temperature (X_2) on groundnut oil yield keeping all other factors constant. Highest oil yields were obtained at high heating temperature of about 105 ℃ and lower oil yields were obtained at lower heating temperature (75⁰C). Heating temperature have been found to have significant infruence on oil yield [19-21]. At higher temperature, oil yield decreases as the moisture content increases while at lower heating temperature of 75⁰C oil yield increases as moisture content was increased from 4.6 - 8.6% and decreases as moisture content increased from 8.6 – 12.6 %. This indicates that higher oil yield would be obtained at moisture content of 8.6 % while extracting at lower heating temperature.

The interaction effects of moisture content and heating time on oil yield is shown in Fig. 1b. At constant heating temperature, applied pressure and pressing time, oil yield increased slightly as moisture content increased from 4.60 – 7.00% and decreased as the moisture content increased from 7.00 – 12.60%. This conforms with the assertion of previous works

that oil recovery increases as the seed moisture content increases [17,19,22]. The most common trend is that oil yield increases as moisture content and pressure increase[23]. The results also indicate that moisture content is of higher significance to oil yield more than the heatiing time. The interaction effects of applied pressure and moisture content keeping all other factors constant is as shown in Fig. 1c. At the lowest applied pressure (5 MPa), oil yield increased as moisture content increased while at the highest applied pressure (25 MPa), oil yield decreased as moisture content was increased.

As indicated in Fig. 1d, higher oil yield were obtained at higher pressing time and lowest moisture content (4.60%). Moreover, for the range of pressing time investigated (2 – 7 minutes), oil yield decreases as the moisture content was increased when the other variables were kept constant.This is in tandem with the work of Mpagalile and Clarke [24] that suggested that the moisture contents in the range of 10–13% had good oil extraction efficiency. From Fig. 1e, it was observed that increase in heating temperature from 75 – 105ºC has positive effect on oil yield for the range of heating time investigated (3 – 25 min). However, the combination of lower heating time and higher heating temperature favoured oil yield. Interaction effects of heating temperature and applied pressure on groundnut oil yield is as shown in Fig 1f. Oil yield increases as the heating temperature was increased. Applied pressure of 25 Mpa favoured oil yield than the lowest one (5 MPa).

At the highest pressing time (7 min), slight increase in oil yield was observed as the heating temperature was increased from 75 – 105ºC (Fig. 1g) However, at lower pressing time (3 min), significant oil yield increase was observed as the heating temperature was increased from 75 – 105ºC. This further indicates that heating temperature is significant in the recovery of oil from groudnut kernels using mechanical press.

As presented in Fig. 1h, increase in applied pressure caused slight decrease in oil yield as the heating time was increased from 5 – 25 minutes. This is in agreement with the study of Rezzoug et al. [7] that showed that the processing pressure and processing time were the most significant parameters both on global extraction yield and the extraction yield of the different essential oil compounds. However, slight decrease in oil yield was obtained at higher heating time. This indicates that lower heating time and and higher applied pressure would favour oil yield more than higher heating time and lower applied pressure.

Fig. 1i shows the combined effect of pressing time and heating time on the oil yield when all other factors remained constant. Increase in heating time brought about decrease in oil yield for both extremes of pressing time (3 – 7 minutes). This is in tandem with the previous finding that suggests that oil yield increased with increase in applied pressure and pressing time [25-27]. The effect of pressing time on oil yield is not as significant as the heating time. In Fig. 1i, optimum oil recovery was obtained when the applied pressure was 15 Mpa. Extremes of applied presure do not favour oil recovery. However,Pressing time had little impact on oil yield as the efffect were negligible as compared to the applied pressure.Optimum oil yield of 32.36 % was obtained when the moisture content, Heating temperature ,Heating time, applied pressure and pressing time were 8.13%, 81.93ºC, 7.03 minutes, 15.77 Mpa and 6.69 minutes, respectively as shown in Fig. 2.
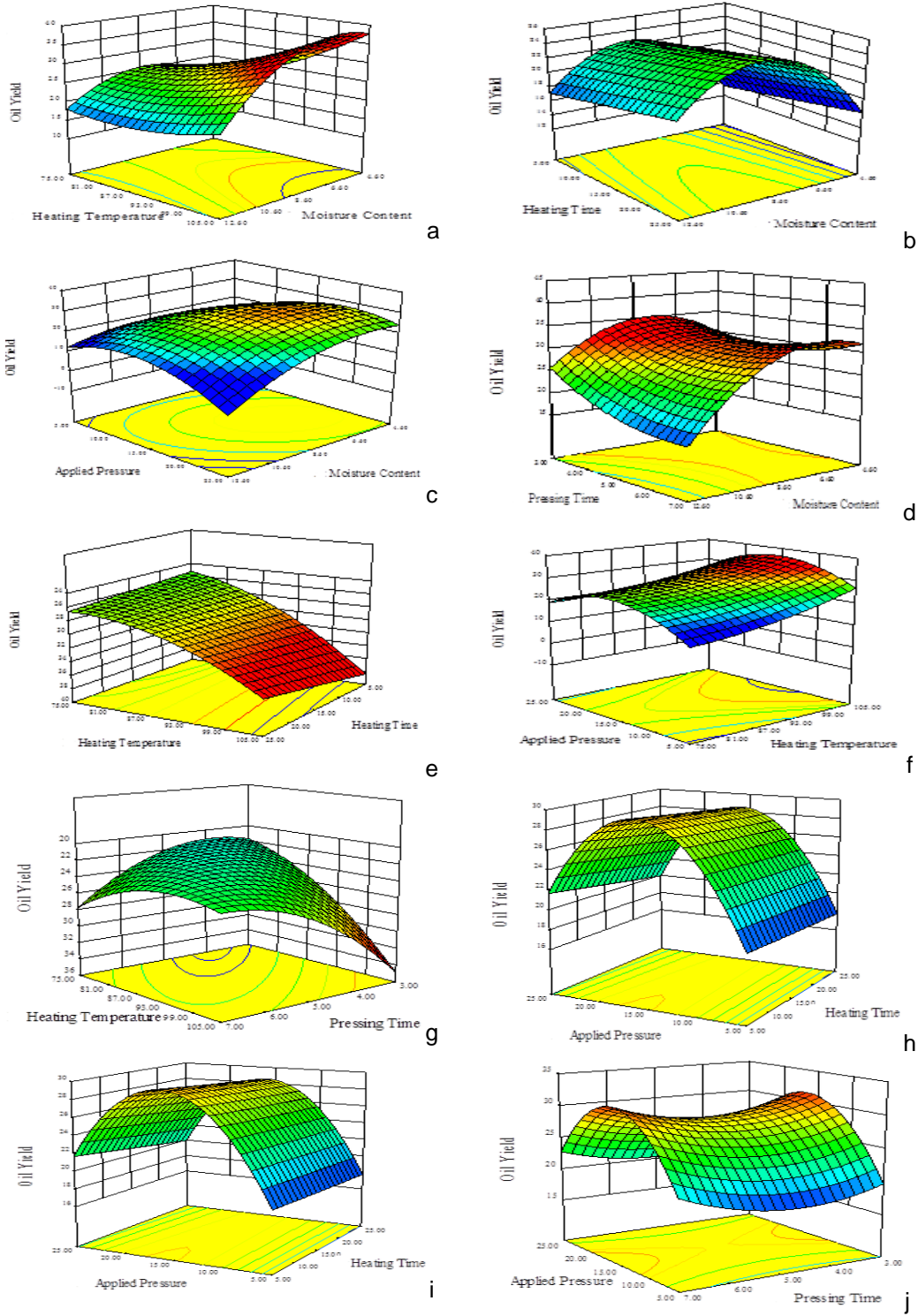
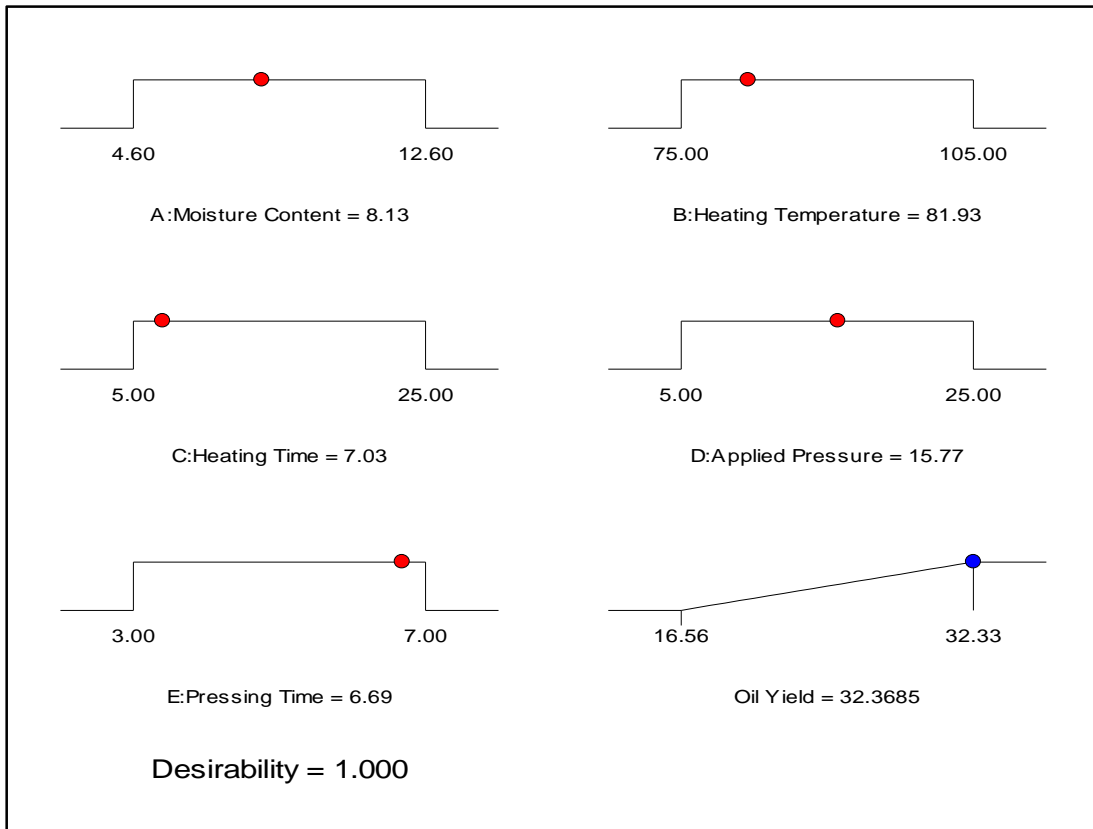**Fig. 1. Response surface plots of the effects of input variables on oil yield**

Table 3 Continued……

X_2^2	27.39	27.39	7480.99	< 0.0001
X_3^2	0.03	0.03	8.52	0.0140
X_4^2	170.35	170.35	46523.33	< 0.0001
X_5^2	14.02	14.02	3829.05	< 0.0001
Residual	0.04	0.00		
Lack of Fit	0.04	0.01	6.46	0.0293
Pure Error	0.00	0.00		
Cor Total	510.24			

4. CONCLUSION

Central composite design and response surface methodology were used to study the interaction of extraction parameters and optimize oil yield during the extraction of oil from groundnut kernels. Results of optimisation by RSM shows that extraction conditions influenced the extraction of oil from groundnut kernels. The most important variables were moisture content and heating temperature. Heating temperature had the most influence while pressing time had the least. The correlation coefficient (R-squared) of the model analysis was found to be 0.99. Numerical optimization determined the optimum parameters for extraction to be when the moisture content, heating temperature, heating time, applied pressure and pressing time were 8.13%, 81.93ºC, 7.03 minutes, 15.77 Mpa and 6.69 minutes, respectively.The regression model obtained has provided a basis for selecting optimum process parameters for the recovery of oil using mechanical press.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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