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Oil Expelling from Dehulled De-Skinned Groundnut Kernel using Screw Press: Optimization of Process Parameters and Physico-chemical Characteristics

D. Mridula*, Dhritiman Saha, R. K. Gupta, Sheetal Bhadwal, Simran Arora and Sonmati R. Kumar

Food Grains and Oilseeds Processing Division, ICAR-Central Institute of Post-Harvest Engineering & Technology, Ludhiana, Punjab, India

**Corresponding author*

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A B S T R A C T

Screw pressing parameters for oil expelling was optimized with dehulled deskinned groundnut and wheat bran (fibre material) at variable sample moisture and press head temperature in two different sets of experiments. Box-Behnken design of response surface methodology was adopted for the study with dehulled deskinned groundnut (80-95g), wheat bran (8-16g) and sample moisture (8-14%, w.b.) while press head temperature ranged between 50-90 ^{o}C. Oil expelling properties viz. oil recovery, residual oil, press rate, sediment content in oil, oil and meal temperature, free fatty acid (FFA) value were considered as dependent variables. Oil recovery and residual oil in cake was affected due to change in composition of wheat bran, dehulled and deskinned groundnut, sample moisture and press head temperature. The study concluded that 85.6% dehulled deskinned groundnut kernel and 14.4% wheat bran with 8% moisture content could be considered for screw pressing of dehulled deskinned groundnut at 66.5˚C press head temperature.

Introduction

India is the second largest producer of groundnut in the world with a production of 8.94 million tonnes during 2017-18. Groundnut, being the major oilseed crop in India, recorded a production of 1.32 million tonnes oil during 2017-18 (USDA, 2018). The oil content in groundnut may vary from 40 to 54% depending upon type, variety and climatic condition. Groundnut oil contain substantial amount of unsaturated fatty acids namely oleic and linoleic acids accounting for 38-56% and 16-38% each, respectively and low in free fatty acid (FFA). Palmitic acid, saturated fatty acid, is the major fatty acid with about 10-16% (Nagaraj, 2009).

The oil extraction process aims at higher oil recovery with good quality meal suitable for its incorporation in human foods. Generally, the oil is expelled through two main steps:

pressing (solid-liquid expression) and solvent extraction (Savoire *et al.,* 2013). The process of solvent oil extraction encompasses the extraction of vegetable oil from plant material using a volatile solvent like petroleum ether, hexane, benzene (Onwuka, 2013) with maximum extraction of 98% oil. However; the process is costlier and chances for flammability is high. Screw presses are widely used for oil expelling from oilseeds. A screw press comprises of a horizontal screw fixed inside a perforated barrel through which oil is expelled.

The screw and the barrel are gradually tapered at the discharge end to increase the pressure on the oilseeds (Bogaert *et al.,* 2018). Recovery of 86–92 % of oil is obtained through mechanical pressing of oilseeds in two passes. The oil expelling process is dependent on different seed pre-treatment factors viz., cleaning, dehulling, moisture conditioning, flaking, cooking, extruding and drying to optimal moisture content of the oilseeds (Mridula *et al.,* 2015; Singh *et al.,* 2002).

Groundnut pods are surrounded by an outer thick woody shell with two to three kernel or seeds embedded inside. The groundnut hull constitutes about 25% of the total pod. The groundnut hull so produced after dehulling are either burned, dumped, or left to deteriorate naturally. The effective utilization of groundnut hull has been tried in cattle feed and for human consumption for fiber purposes (Kerr *et al.,* 1986). The hull consists of about 60% fiber, and hence amounts to poor digestibility (Singh and Diwakar, 1993). Commercially, groundnut oil is expelled using a mixture of whole and dehulled groundnut resulting in dark and poor quality of groundnut meal (due to presence of groundnut hull) thus making it unsuitable for use in food products. Besides, reddish brown colour of groundnut skin or testa contributes to the darker colour of the meal and may affect the quality characteristics of the food products. Dehulling and de-skinning of groundnut before screw pressing will result in good quality meal with acceptable colour for its utilization in all kind of food products as also observed in other studies (Mridula *et al.,* 2011, 2013, 2014; Pohjanheimo *et al.,* 2006).

However, mechanical oil extraction from dehulled de-skinned groundnut kernel (DDGK) with good oil recovery may not be possible without addition of fibrous portion with the kernel or seed as also seen in the study conducted by Mridula et al (2015), which showed minimum oil recovery from 100% dehulled flaxseed while maximum recovery of oil was found at 70% dehulled with 30% whole flaxseed. Hence, wheat bran, an edible category by-product of wheat milling industry may act as fibrous material for its use during mechanical oil extraction. Keeping in view the above points, optimization of important screw pressing parameters was carried out using DDGK and wheat bran as a source of fibre in a komet screw press to obtain higher oil recovery and edible quality meal/ cake.

Materials and Methods

Raw material preparation

Groundnut pods, procured from a local commercial supplier, were used for the study. Groundnut pods were dehulled using groundnut pod decorticator, followed by de-skinning using a groundnut de-skinner, developed by ICAR-CIPHET, Ludhiana. The groundnut kernels were crushed using a hammer mill (Make: CIAE Bhopal, capacity-20 kg/h) and aspirated using an aspirator to remove the red coloured skin particles from crushed groundnut kernels. The crushed groundnut kernels was then sieved in a perforated round metal screen (BSS: 4; and average particle size: 3.85mm) and packed in plastic pouches, sealed and stored at 10°C for two days before conducting the experiments.

Wheat bran was taken as a prospective source of fibre for screw pressing experiments of dehulled deskinned groundnut kernel. Wheat bran was obtained from M/s Saraswati Rice and General Mills, Jagraon, Ludhiana, Punjab, India. The wheat bran used for the study contained 5.96% (w.b.) moisture, 12.62% protein, 3.78% fat and 6.32 mg/100g iron. The freshly prepared wheat bran was stabilized as per the standard procedure suggested by Vetrimani and Rao (1990). The stabilization of wheat bran restricts the enzymatic activity of lipase (if any), which may lead to development of FFA in meal samples. The wheat bran was treated at 175°C for 40 min in a hot air oven followed by drying at 60°C to lower the moisture content ≤5% (Sudha *et al.,* 2011). The treated bran was properly packed and stored in a plastic container at 5°C for further use in this study.

Moisture conditioning of crushed groundnut kernels

The sample moisture of dehulled deskinned groundnut kernel (DDGK) was determined following standard procedure using hot air oven method (at 105°C) until the sample reached to constant weight (AOAC, 2000). The conditioning of the DDGK samples was carried out for different sample moisture content (8, 11 and 14% w.b.) as per the experimental plan.

The initial moisture content of the groundnut sample was 6% w.b. In order to achieve the higher moisture content, distilled water was added to the sample followed by thorough mixing and storing in sealable pouches in refrigerator (5°C) for 24 h (Mridula *et al.*, 2011, 2017). The amount of distilled water to be added was calculated using the following formula (Chakraverty, 1988):

$$W_m = W_1 \left[\frac{\Delta M}{100 - M_2} \right]$$

where, W_m: moisture to be added/ removed (g), W_1: initial weight of sample at M_1(g), $\Delta M = M_2 - M_1$ ($M_2 > M_1$) and $\Delta M = M_1 - M_2$ ($M_1 > M_2$), M_1: initial moisture content (w.b.); M_2: final moisture content (w.b.).

Oil expression

A Komet screw press (model CA59G, Germany) was used for the screw pressing of groundnut in a single pass. The screw shaft was 140 mm long with 30 mm screw diameter and 15 mm pitch. The inner diameter of the restriction die was 8 mm with a screw speed of 20 rpm. The press head was heated to the temperature of 70±2°C using an electrical resistance heating ring before the initiation of the screw pressing process. The groundnut kernels were initially pressed for 20-30 min to obtain steady flow of oil and meal from the screw press. Screw pressing of groundnut samples with different moisture content was carried out at 70±2°C.

In order to optimize the press head temperatures for enhanced oil recovery from DDGK, another set of experiment was carried out as per the experimental plan at constant 8% sample moisture content. The oil and resultant meal/ cake samples, obtained during the experiments were evaluated for important physico-chemical characteristics.

The oil and meal sample's temperature was determined during the expelling process with a multi-thermometer (least count - 0.1°C, range -50 to +150°C) by inserting the probe of thermometer in the oil exuding out below the barrel. The crude oil and meal obtained from each experimental samples were collected, and the time required for oil expelling was recorded using a stopwatch. The crude oil and meal/ cake samples were weighed using a weighing balance (least count - 0.0001g) and the press rate was calculated as per the following formula:

$$Press\ rate = \frac{crude\ oil\ weight\ + cake\ weight}{time}$$

Residual oil in meal

The residual oil content in the meal samples was determined as per the standard procedure (AOAC, 2000).

Sediment content of crude oil

The sediments in crude oil are the solid weight per unit weight of unfiltered crude oil. The solid particles were filtered from the oil using pre-weighed filter paper (Make: Whatman Ashless Filter paper; Grade: 42) to obtained oil weight. The filtered solid samples were rinsed with petroleum ether and dried at 50^{o}C to evaporate the solvent. Thereafter, filter paper with solids, were weighed and sediment content in oil samples were evaluated.

Oil Recovery

Oil recovery (OR) from DDGK is the ratio of oil in sample to the actual oil present in unpressed raw material sample. The oil recovery was calculated with the following formula (Zheng *et al.,* 2003).

$$OR(\%) = \left(1 - \frac{weight\ of\ meal \times meal\ oil\ content}{weight\ of\ raw\ material \times raw\ material\ oil\ content}\right) \times 100$$

Physico-chemical characteristics of groundnut oil

Free fatty acid (FFA) value in groundnut oil was determined as per the recommended procedure (Ranganna, 1986). FFA content is expressed by acid value as oleic acid (mg KOH/g oil). Colour quality (L, a, b values and yellowness index) of the meal samples was evaluated (Singh *et al.,* 2013) after 12 h of screw pressing experiments using Hunter Colorimeter (model no. 45/0-L, U.S.A).

Statistical Analysis

The design of experimental runs for this study was carried out according to Response surface methodology (RSM). Box-Behnken design of RSM with three independent process parameters were planned using Design Expert 8.0 (version 8.0.2, Stat-Ease Inc, USA) software. Seventeen sets of screw pressing experiments were carried out using three independent variables viz., DDGK (80 to 95g), wheat bran (8 to 16g) and sample moisture content (8 to 14%). Another set of experiment was planned and carried out using Box-Behnken design to optimize the press head temperatures for higher oil recovery from DDGK. Seventeen set of this experiments for oil expelling using screw press were carried out using three independent variables viz., DDGK (80 to 95g), wheat bran (8, to 16g) and press head temperatures (50 to 90 ±2^{o}C). The moisture content of the samples in this experiment was kept constant i.e. 8%**.** The levels of different independent variables and plan of these two set experiments at different sample moisture and press head temperatures are given in Table 1. The responses i.e. dependent variables were oil recovery, residual oil in meal, sediment content, press rate, oil and meal temperature, and free fatty acid content in meal.

The Design Expert software was also considered for analysis of experimental results. Multiple regression analysis was used to fit the model to the experimental data and represented by an equation. The developed model was evaluated using F-ratio, coefficient of correlation (R^2) and lack of fit test. Minimization and maximization of polynomials thus fitted was done by numerical optimization technique of this statistical package. A weight was assigned to each goal to adjust the shape of the desirability function and goals were combined in to an overall desirability function. The numerical optimization technique of Design Expert software was done for optimization of the responses.

Results and Discussion

Effect of process parameters on groundnut oil recovery

The oil recovery indicates the efficiency of the expelling process of oilseeds. The effect of moisture content, level of dehulled deskinned groundnut kernel (DDGK) and wheat bran on oil recovery indicated significant effect on oil recovery (Fig. 1, Table 2). There was an increase in the oil recovery with decrease in sample moisture. This increase in oil recovery might be due to higher frictional resistance at low sample moisture in the barrel during screw pressing. Besides, higher seed moisture acts as a lubricant in the barrel (Singh *et al.*, 2002; Mridula *et al.*, 2019) that might have reduced the oil recovery. Wheat bran in the sample mixture indicated an increase in the oil recovery with increasing proportion in the sample mixture. Wheat bran i.e. fibrous material might enhanced the frictional resistance in the screw barrel may be due to increased fibre content. At a given level of wheat bran (8g), oil recovery increased from 59.73 % at 14% moisture content to 64.63% at 11% moisture content, which further increased to 71.25% at 8% moisture. The oil recovery (78.93%) was found maximum with 8% moisture content, 87.5g DDGK and 16g wheat bran while the minimum oil recovery (57.67%) was observed at 14% moisture content, 12g wheat bran and 80g DDGK. Regression analysis for oil recovery indicated that the model was significant at $p \leq 0.05$ with coefficient of regression (R^2) as 0.992, thus indicating the adequacy of the model to predict the response to interpret the effect of studied independent variables on oil recovery using equations (1):

$$\text{Oil recovery (\%)} = + 67.11 +3.57A +2.99B-5.61C-0.69AB +0.23AC +1.00BC +0.99A^2 -1.02B^2 +0.95C^2 \quad (1)$$

The effect of press head temperature, DDGK and wheat bran on oil recovery has been shown in Fig. 1, Table 3. The oil recovery from DDGK was found to increase with increase in press head temperature up to 70°C, but further increase in temperature reduced the oil recovery as also observed by Mridula et al (2019) for oil expelling from dehulled sunflower. The oil recovery (77.96%) was found maximum at 70°C with 95g DDGK and 16g wheat bran while the minimum oil recovery (58.68%) was observed at 50°C with 87.5g DDGK and 8g wheat bran. At a given level of wheat bran (8g), oil recovery increased from 59.31% at 50°C to 64.31% at 70°C while further increase in temperature from 70 to 90°C showed a marked decreased in oil recovery from 64.31% to 59.35%. This increase in the oil recovery up to 70°C might be due to heating of oilseeds causing the oil to exude out from the seeds (Ward, 1976). The decrease in oil recovery with increase in temperature from 70°C to 90°C may be explained in terms of binding between oil and proteins within the seed structure that restrict the flow of oil from the seeds (Soetaredjo *et al.*, 2008). The regression model indicated significant impact of press head temperature, wheat bran and DDGK on oil recovery with coefficient of determination (R^2) as 0.974 and non-significant lack of fit (Table 3). The relationship between oil recovery and press head temperature may be expressed by the following predictive quadratic regression equations.

$$\text{Oil recovery (\%)} = +69.45+4.74\,A+3.19\,B+0.81\,C+0.33\,AB+0.51\,AC-0.30BC-0.44A^2-0.20\,B^2-5.28C^2 \quad (2)$$

Effect of process parameters on press rate

The press rate of DDGK with wheat bran was ranged from 1.24 to 1.70, 1.16 to 2.08 and 1.88 to 2.21 kg/h (w.b.), respectively at 8, 11 and 14% (w.b.) sample moisture. The press rate was found maximum at 14% sample moisture and 12g wheat bran while minimum was observed at 11% sample moisture and 16g wheat bran in the sample mixture (Table 2). Higher press rate at 14% sample moisture might be attributed to low resistance inside the screw barrel and lower lubricant effect of sample moisture. Singh *et al.,* (2010) observed an increase in press rate with increase in moisture content from 6.5 to 13.8% d.b. of pre-treated whole flaxseed. The increased press rate at higher moisture content was also reported by Mridula *et al.,* (2015) for dehulled and whole flaxseed sample and Mridula *et al.,* (2019) for dehulled sunflower. Similarly, Singh *et al.,* (2002) reported decrease in press rate from 5.8 to 5.2 kg/h and 6.1 to 5.2 kg/h for cooked and uncooked crambe seeds at decreased moisture content from 9.2 to 3.6% d.b. The press rate of different DDGK samples with wheat bran was also influenced by the press head temperature with minimum at 50^{o}C and maximum at 90^{o}C (Table 3). The press rate of DDGK with wheat bran, expelled at 50, 70 and 90^{o}C varied between 1.20 to 1.53, 1.34 to 1.61 and 1.27 to 1.71 kg/h (w.b.), respectively. The relationship between press head temperature, sample moisture and level of DDGK and wheat bran on press rate may be expressed by following predictive quadratic regression equations.

$$\text{Press rate (sample moisture)} = +1.78-0.30A-0.048B+0.21C-0.012AB-0.061AC+0.10BC-0.15A^2+1.523E\text{-}003\,B^2-1.046E\text{-}003C^2 \quad (3)$$

$$\text{Press rate (press head temperature)} = +1.44-0.15A+0.015B+0.057C-7.345E\text{-}003AB-0.026AC+5.605E\text{-}003B\,C+4.193E\text{-}003A^2+0.018B^2-0.016C^2 \quad (4)$$

Effect of process parameters on sediment content

The sediment content of samples with varied level of wheat bran and at moisture content of 8, 11% and 14% (w.b.) varied from 15.58 to 20.13, 10.0 to 22.56 and 16.92 to 21.77%, respectively. The sample moisture as well as wheat bran did not show significant impact on the sediment content in oil samples (Table 2) as also reported by Mridula *et al.,* (2019) in case of dehulled sunflower. Singh *et al.,* (2010) did not observe the significant impact of conditioned whole flaxseed on sediment content in crude oil. However, Mridula *et al.,* (2015) reported low sediments at higher moisture content during expelling of whole and dehulled flaxseed. Sediments in crude oil of de-skinned groundnut sample with wheat bran, expelled at different level of press head temperature ranged from 10.61 to 16.93, 5.94 to 20.73, and 6.033 to 18.07 at 50, 70 and 90^{o}C, respectively. The sediments observed in crude oil samples expelled at different press head temperatures did not show any significant influence (Table 3) as also observed by Mridula *et al.,* (2019). However, Mridula et al (2015) reported significant impact of press head temperature with minimum sediment content at 120°C. This variation in the findings of different studies may be due to the change in the level of studied parameters and the crop properties.

$$\text{Sediment content (sample moisture)} = +14.90-1.93A-0.56\,B+0.70C+3.88AB-0.13AC-0.22BC+0.43\,A^2+1.75B^2+2.38C^2 \quad (5)$$

Sediment content (press head temperature) =+17.74-1.10A-0.80B+0.69C-3.32AB-2.56AC-1.30BC-5.22A^2-1.59 B^2-0.74 C^2 (6)

Effect of process parameters on residual oil

Analysis of variance showed that sample moisture significantly affected the residual oil content in cake that ranged from 11.86 to 21.15% (Table 2). The residual oil in cake varied between 11.86-15.00%, 16.21-18.76% and 17.68-21.15% at 8, 11 and 14% sample moisture (w.b.), respectively. The comparison of the results of oil recovery and residual oil indicated that the increased oil recovery resulted in the decreased residual oil in cake. Residual oil in DDGK cake increased with increasing sample moisture and was maximum at 14% moisture content ($P<0.05$). Studies also indicated the decreased residual oil in cake with decreasing moisture content (Singh *et al.,* 1984; Singh *et al.,* 2002; Mridula *et al.*, 2015, 2019). This trend might be due to higher frictional resistance caused by lower moisture content of seed in the screw barrel during the pressing of de-skinned groundnut. Reuber (1992) and Hoffmann (2013) also indicated that lower seed moisture increases friction, whereas higher moisture content acts as a lubricant during oilseeds pressing. Residual oil content in different cake samples, expelled at 50-90 ^oC press head temperature varied between 14.88 to 22.82%. Residual oil content in cake samples was also influenced by the press head temperature with minimum residual oil at 70^{o}C (Table 3) as also observed in other study (Mridula *et al.*, 2019). Regression analysis for studying the effect of independent parameters on residual oil in cake samples suggested that the model was significant at $p\leq0.05$. Therefore, the second order model was adequate to predict the residual oil in cake and interpret the effect of independent variables on this response using following regression equations:

Residual oil (sample moisture) = +17.59-1.40A+6.375E-003B+2.89C-1.750E-003AB-0.082AC-0.23 BC-0.46A^2+0.36 B^2-0.71C^2 (7)

Residual oil (press head temperature) =+17.55-2.51 A-6.917E-003 B+0.076 C-0.18 A B-0.025 A C+0.19 BC+0.71A^2-0.19 B^2+2.15C^2 (8)

Effect of process parameters on oil and cake temperatures

The temperature of DDGK oil samples obtained by pressing at constant press head temperature (70^{o}C) and variable sample moisture (8 to 14%) ranged from 51.6 to 54.6^{o}C, which was statistically insignificant (Table 2). The temperature of oil obtained at constant moisture (11%) with variable press head temperature (50 to 90^{o}C) ranged between 43.5 to 61.8^{o}C, which was found statistically significant ($p<0.05$) with the variation of press head temperature (Table 3). Oil temperature was found minimum at 50^{o}C with maximum at 90^{o}C press head temperature.

Oil temperature (sample moisture) = + 53.86+0.062A+0.075B-0.46C-0.025AB-0.85AC-0.27BC-0.46A^2-0.58 B^2-0.61 C^2 (9)

Oil temperature (press head temperature) =+51.24+0.50A-0.88B+6.87C+0.45AB-0.60AC+ 2.95BC+0.33A^2+2.18B^2+0.83C^2 (10)

The cake temperature may significantly impact the quality characteristics of the resultant meal. Higher oil expelling temperature can produce cake with dark colour, rendering it unsuitable for utilization in food products. Hence the oilseed should be pressed at desirable temperature and moisture to obtain good quality meal. Both, press head temperature and sample moisture affected the DDGK cake temperature with no significant impact of level of wheat bran in this study (Table 2&3).

DDGK Cake temperature of different samples at variable sample moisture ranged between 46.8 to 52.5^{o}C while at different press head temperature ranged from 40.6 to 58.1^{o}C. Zheng *et al.,* (2005) also observed increased cake temperature with increasing press head temperature at constant moisture content of flaxseed (6.3%). Mridula *et al.,* (2015) also reported the minimum cake temperature at 80^{o}C with maximum at 120^{o}C press head temperature.

Cake temperature (sample moisture) $=+51.28-0.100\ A+0.51\ B+1.21C+0.65\ A\ B-1.55A\ C-0.63BC-0.23A^{2}-0.65B^{2}-1.30\ C^{2}$ (11)

Cake temperature (press head temperature) $=+49.38-0.31\ A+0.088\ B+7.23C+0.93AB-1.55AC+0.35\ B\ C-0.90A^{2}+1.40\ B^{2}-0.53\ C^{2}$ (12)

Table.1 Experimental plan for oil expelling process parameters from dehulled de-skinned groundnut kernel (DDGK)

S. No.	Independent variables at constant temperature			Independent variables at constant moisture		
	Wheat bran (g)	DDGK (g)	Moisture (%)	Wheat bran (g)	DDGK (g)	Press head temperature, °C
1	12.0 (0)	87.5 (0)	11.0 (0)	12.0 (0)	95.0 (+1)	50.0 (-1)
2	12.0 (0)	80.0 (-1)	14.0 (+1)	16.0 (+1)	87.5 (0)	50.0 (-1)
3	8.0 (-1)	87.5 (0)	14.0 (+1)	16.0 (+1)	87.5 (0)	90.0 (+1)
4	8.0 (-1)	80.0 (-1)	11.0 (0)	12.0 (0)	87.5 (0)	70.0 (0)
5	12.0 (0)	87.5 (0)	11.0 (0)	12.0 (0)	80.0 (-1)	50.0 (-1)
6	16.0 (+1)	87.5 (0)	8.0 (-1)	8.0 (-1)	87.5 (0)	90.0 (+1)
7	16.0 (+1)	87.5 (0)	14.0 (+1)	8.0 (-1)	95.0 (+1)	70.0 (0)
8	16.0 (+1)	95.0 (+1)	11.0 (0)	12.0 (0)	87.5 (0)	70.0 (0)
9	12.0 (0)	87.5 (0)	11.0 (0)	12.0 (0)	80.0 (-1)	90.0 (+1)
10	8.0 (-1)	87.5 (0)	8.0 (-1)	16.0 (+1)	80.0 (-1)	70.0 (0)
11	16.0 (+1)	80.0 (-1)	11.0 (0)	12.0 (0)	95.0 (+1)	90.0 (+1)
12	12.0 (0)	95.0 (+1)	8.0 (-1)	12.0 (0)	87.5 (0)	70.0 (0)
13	8.0 (-1)	95.0 (+1)	11.0 (0)	8.0 (-1)	80.0 (-1)	70.0 (0)
14	12.0 (0)	87.5 (0)	11.0 (0)	16.0 (+1)	95.0 (+1)	70.0 (0)
15	12.0 (0)	80.0 (-1)	8.0 (-1)	12.0 (0)	87.5 (0)	70.0 (0)
16	12.0 (0)	95.0 (+1)	14.0 (+1)	8.0 (-1)	87.5 (0)	50.0 (-1)
17	12.0 (0)	87.5 (0)	11.0 (0)	12.0 (0)	87.5 (0)	70.0 (0)

Table.2 ANOVA of dehulled deskinned groundnut oil expelling process variables on responses at different sample moisture content

Term	Oil recovery, %	Press rate, kg/h	Sediment content, %	Residual content, %	Oil temperature, °C	Cake temperature, °C	Free fatty acid, %	L value	a value	b value	Yellowness index
Model	98.94**	5.10*	1.44	55.33**	1.15	6.91**	41.29**	3.92*	3.61	3.14	9.23**
A-Wheat bran, g	204.75**	26.46**	2.80	90.49**	0.035	0.14	1.06	0.27	0.15	1.810E-003	0.58
B-Dehulled deskinned groundnut kernel, g	143.53**	0.67	0.24	1.876E-003	0.050	3.57	1.06	2.36	0.33	1.04	2.48
C-Moisture, %	506.07**	13.20**	0.37	385.91**	1.91	19.98**	343.64**	18.00**	15.88**	15.51**	58.36**
A*B	3.77	0.021	5.68*	7.070E-005	2.794E-003	2.87	0.53	0.43	1.42	0.12	0.10
A*C	0.42	0.55	6.138E-003	0.16	3.23	16.33	4.77	7.47*	0.55	0.47	0.013
B*C	8.01*	1.54	0.017	1.22	0.34	2.65	0.53	0.080	6.34*	4.02	11.56*
A*A	8.22*	3.47	0.072	5.08	0.97	0.37**	5.582E-003	1.01	3.224E-003	0.033	0.42
B*B	8.88*	3.573E-004	1.21	3.15	1.58	3.05	9.38*	4.83	1.47	2.67	1.83
C*C	7.70*	1.685E-004	2.25	12.09*	1.72	12.14*	9.38*	0.87	6.68*	4.74	8.00*
Lack of fit	0.52	1.97	0.38	2.06	2.66	2.51	4.17	0.50	0.35	1.16	1.82
C.V. %	1.04	9.67	19.11	2.42	1.78	1.53	2.62	1.34	4.55	2.36	3.23
R^2	0.992	0.868	0.649	0.986	0.596	0.899	0.982	0.834	0.823	0.801	0.922

* ($p \leq 0.05$), ** ($p \leq 0.01$)

Table.3 ANOVA of dehulled deskinned groundnut oil expelling process variables on responses at different Press head temperature

Term	Oil recovery, %	Press rate, kg/h	Sediment content, %	Residual content, %	Oil temperature, °C	Cake temperature, °C	Free fatty acid value	L value	a value	b value	Yellow ness index
Model	30.01**	10.61**	1.17	15.64**	17.73**	11.56**	116.25**	1.46	1.01	1.75	1.26
A-Wheat bran, g	124.74**	81.10**	0.44	96.97**	0.71	0.18	0.58	1.15	1.376E-003	0.11	0.081
B-Dehulled deskinned groundnut kernel, g	56.64**	0.81	0.24	7.371E-004	2.18	0.014	13.63**	0.33	0.29	0.15*	0.25
C-Press head temperature,°C	3.65	11.21*	0.17	0.088	134.62**	97.81**	887.41	5.89*	5.66*	7.59*	5.77*
A*B	0.30	0.092	2.01	0.24	0.29	0.80	0.20	7.986E-004	0.40	1.03	0.24
A*C	0.72	1.19	1.20	4.814E-003	0.51	2.25	0.090	1.05	1.56	4.33	2.00
B*C	0.25	0.053	0.31	0.27	12.39**	0.11	6.61*	0.045	4.230E-003	0.018	0.015
A*A	0.57	0.031	5.24	4.12	0.16	0.80	2.69	0.45	0.052	0.063	0.10
B*B	0.12	0.59	0.48	0.29	7.12*	1.93	6.70*	0.38	0.41	5.310E-003	0.20
C*C	81.49**	0.46	0.10	37.63**	1.03	0.27	121.90**	3.83	0.78	2.50	2.69
Lack of fit	1.05	5.31	1.53	2.17	1.05	0.39	2.70	1.93	2.03	4.84	2.98
C.V. %	1.80	3.36	32.99	3.83	3.17	4.19	0.97	4.69	12.00	4.52	9.88
R^2	0.975	0.932	0.600	0.953	0.958	0.937	0.993	0.652	0.565	0.692	0.618

* ($p \leq 0.05$), ** ($p \leq 0.01$)

Table.4 Optimized parameters for oil expelling of dehulled deskinned groundnut kernel

Particulars	**Optimum values of process parameters and responses**				**Optimum values of process parameters and responses**				
	Target (importance)	**Experimental range**	**Optimum value**	**Desirability**	**Name**	**Target (Importance)**	**Experimental range**	**Optimum value**	**Desirability**
Independent variables					**Independent variables**				
A: Wheat bran, g	in range (3)	8-16	16.00	0.818	A: Wheat bran, g	in range (3)	8-16	16.00	0.875
B: Dehulled deskinned groundnut kernel, g	in range (3)	80-95	80.00		B: Dehulled deskinned groundnut kernel, g	in range (3)	80-95	95.00	
C: Moisture, %	in range (3)	8-14	8.00		C: Press head temperature, °C	in range (3)	50-90	66.46	
Responses			Predicted value	Experimental value	**Responses**			Predicted value	Experimental value
Press rate, kg/h	in range (3)	1.158-2.207	1.34	1.35	Press rate, kg/h	in range (3)	1.197-1.71	1.31	1.34
Sediment content, %	minimize (5)	10.003-22.563	13.42	13.57	Sediment content, %	minimize (5)	5.94-20.73	6.25	6.52
Residual oil, %	minimize (5)	11.860-21.15	12.34	12.66	Residual oil, %	minimize (5)	14.88-22.82	15.41	15.51
Oil recovery, %	maximize (5)	57.665-78.487	75.68	75.89	Oil recovery, %	maximize (5)	58.68-77.96	76.72	76.52
Oil temperature, °C	minimize (1)	51.60-54.60	53.27	53.14	Oil temperature, °C	minimize (1)	43.50-61.80	52.20	52.07
Cake temperature, °C	minimize (1)	46.80-52.50	47.55	47.66	Cake temperature, °C	minimize (1)	40.60-58.10	49.48	49.53
Free fatty acid value	minimize (1)	0.589-0.898	0.63	0.62	Free fatty acid value	minimize (1)	0.66-0.83	0.70	0.68

Fig.1 Effect of dehulled deskinned groundnut kernel, wheat bran, sample moisture and press head temperature on oil recovery

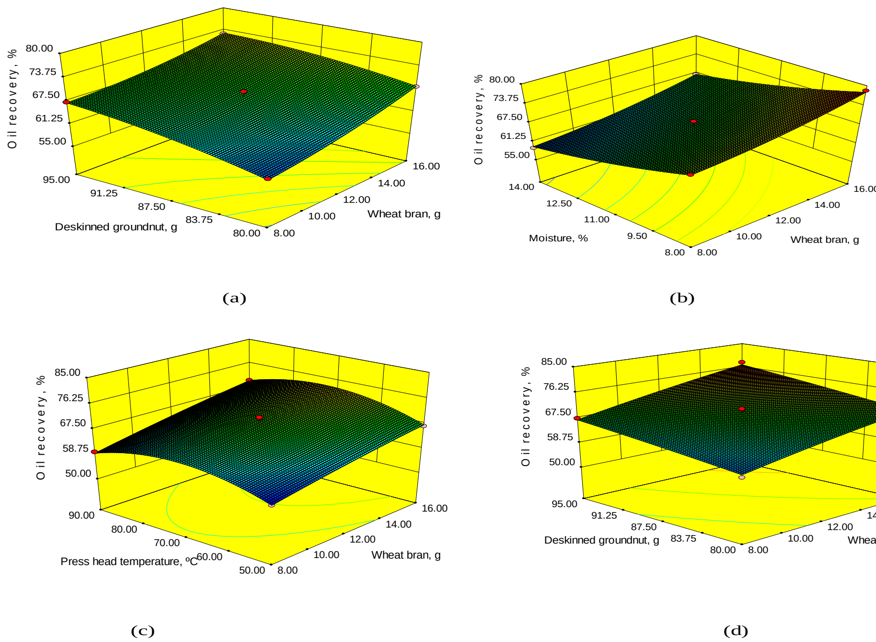
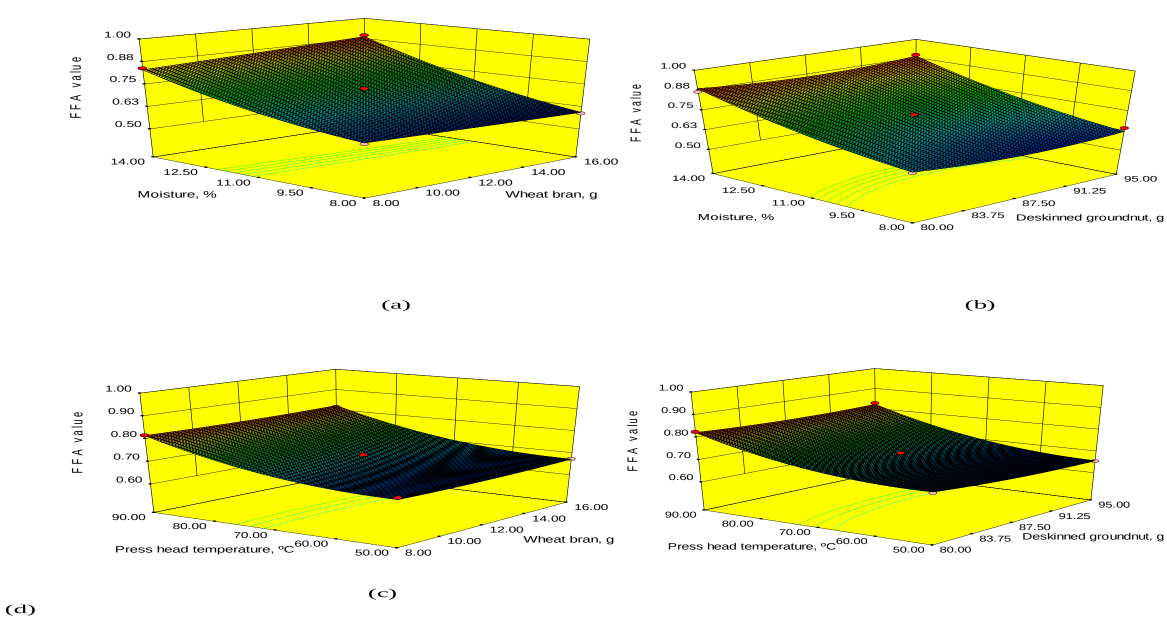


Fig.2 Effect of dehulled deskinned groundnut kernel, wheat bran, sample moisture and press head temperature on free fatty acid (FFA) value of expelled oil



Effect of process parameters on physico-chemical characteristics

The hydrolysis of triglycerides in oil results in the formation of free fatty acid (FFA), which influences the flavour, aroma and other characteristic of oil (O'Brien, 2004). FFA content in the DDGK oil samples obtained with 8 to 14% sample moisture and constant press head temperature (70^oC) ranged from 0.59 to 0.90% with minimum FFA in the oil sample at 8% sample moisture (Fig. 2, Table 2). The DDGK expelled at 50 to 90^oC press head temperature indicated 0.66 to 0.83 FFA value in oil samples with minimum FFA value at 50^oC and maximum at 90^oC press head temperature (Fig. 2, Table 3). Since the FFA content was found to be less than 2% it may be considered for use in food products (Nagaraj, 2009). The increase in FFA in oil samples might be due to decomposition of glycerides at higher press head temperature (Kordylas, 1990; Young, 1996). The level of wheat bran did not bring a significant effect on FFA value of oil samples. The meal obtained from this study from DDGK with wheat bran may be considered for use in food products due to its lower FFA value.

Free fatty acid value (sample moisture) = +0.71+7.012E-003 A-7.013E-003 B+0.13 C+7.012E-003 AB+0.021A C+7.012E-003B C+7.013E-004 A^2+0.029 B^2+0.029C^2 (13)

Free fatty acid value (press head temperature) = +0.70+1.897E-003 A-9.224E-003 B+0.074C-1.584E-003A B+1.060E-003 A C+9.088E-003B C+5.644E-003 A^2+8.914E-003 B^2+0.038C^2 (14)

The colour quality i.e. *L*, *a*, *b* values and yellowness index of the cake obtained by pressing of DDGK and wheat bran sample mixture at different moisture content (8 to 14%) varied between 64.86 to 70.73, 4.58 to 5.91, 12.90 to 14.76 and 40.57 to 54.37, respectively; whereas colour values at different press head temperatures (50 to 90 ^oC) were 66.28 to 78.39, 3.92 to 5.90, 12.18 to 14.36 and 35.6 to 50.28, respectively. Colour quality of cake was significantly affected with sample moisture in this study (Table 2).

Yellowness index (sample moisture) =+48.97-0.42 A+0.87B+4.21 C-0.25AB-0.089AC+ 2.65BC-0.49 A^2+1.03B^2-2.15 C^2 (15)

Yellowness index (press head temperature) = +46.27-0.44A-0.79B+3.75C+1.08AB+3.12AC +0.27BC-0.69A^2+0.96 B^2-3.53C^2 (16)

Optimization and validation of screw pressing parameters

Optimum conditions were determined by maximizing oil recovery while minimizing residual oil in cake, sediment in oil, oil and cake temperature, and FFA with independent parameters in the studied range. On the basis of statistical analysis, 80g DDGK, 16g wheat bran with 8% sample moisture while 95g DDGK, 16g wheat bran with 66.45^oC press head temperature revealed the maximum desirability of 0.818 and 0.875 at studied sample moisture and press head temperature, respectively. The oil expelling of DDGK was carried out using the optimized conditions and analyzed for various responses. The results were statistically analyzed using one sample t-test, which has been presented in Table 4. Non-significant validation results of responses indicated the validity of the optimized parameters.

In conclusion the optimization of screw pressing parameters for DDGK at variable sample moisture and press head temperature was successfully carried out using RSM. Oil recovery was found to be affected due to variability in levels of wheat bran, DDGK, sample moisture as well as press head temperature highlighting the importance of optimizing for expelling of DDGK to achieve higher oil recovery and good quality meal. The study concluded that 85.6% DDGK and 14.4% wheat bran with 8% sample moisture may be considered for screw pressing of DDGK at 66.5˚C press head temperature.

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