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Oil expelling from whole and dehulled sunflower seeds: Optimization of screw pressing parameters and physico-chemical quality

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Abstract
The important oil expelling parameters was optimized using dehulled and whole sunflower seeds at variable sample moisture and press head temperature in two different experiments. Box-Behnken design of response surface methodology was used to plan the study considering 60-80g dehulled sunflower, 20-40g whole sunflower and 6-10% (w.b.) sample moisture while press head temperature was 50-90ºC. The oil expelling parameters such as oil recovery, residual oil in meal, press rate, sediment content in oil, oil and meal temperature, free fatty acid (FFA) were taken as dependent variables. This study indicated that 68.64% dehulled sunflower with 31.36% whole sunflower having 6% sample moisture may be considered for oil expelling of sunflower at 71.5˚C press head temperature.

Keywords: sunflower, oil expelling, press head temperature, sample moisture, oil recovery

Introduction
Sunflower (*Helianthus annuus* L.) is one of the important oilseeds with a production of about 47.40 million metric tons worldwide in 2017-18 (USDA, 2017-18). The production of sunflower in India was 0.21 million metric tonnes during 2017-18 (4th Advance Estimate, Ministry of Agriculture& Farmers' Welfare, Govt. of. India). The oil content in sunflower kernel varies from 48 to 53% depending upon type, variety and climatic condition. Sunflower oil contains unsaturated fatty acids namely oleic and linoleic acids accounting for 42-57% and 33-48% each, respectively. In general, sunflower oil contained 2.3% stearic acids, 4.6% palmitic (saturated fatty acids) and 41% oleic and 52% linoleic acid (unsaturated fatty acids) (Nagaraj, 2009) [11].

The purpose of oil expelling process involves higher oil recovery with good quality meal suitable for its utilization in foods. The common oil extraction processes employed are solvent extraction and mechanical pressing. Solvent oil extraction process is the most effective method and can extract over 98% oil. However; this process is costlier and also dangerous due to flammable nature of the solvent. The mechanical pressing involves the use of hydraulic press, screw press and rolling press to recover maximum oil before extraction of residual oil from meal through solvent extraction. The mechanical pressing of oilseeds can recover around 86-92 % of oil in two passes. The oil recovery using mechanical method is influenced by numerous factors such as oilseed moisture, cracking, dehulling, etc. (Mridula *et al.*, 2015) [7].

Sunflower kernel constitutes about 60-70% of the total seed while hull accounts about 30-40% of the total sunflower seed (Nagaraj, 2009) [11]. Traditionally, sunflower oil is expelled utilizing the whole sunflower seeds, which results in darker and poor quality of meal due to presence of excess amount of fibre (hull), making it unsuitable for food purposes (Nagaraj, 2009) [11]. Studies indicated that dehulling of oilseeds is important for getting good quality edible oil, better flavour and protein content in the meal suitable for food purposes (Mridula *et al.*, 2017, 2014, 2011, 2013; Pohjanheimo *et al.*, 2006) [6, 8, 10, 9, 13]. However, some amount of fibre is important for enhancing oil recovery from dehulled flaxseed (Mridula *et al.*, 2015) [7]. Hence, a combination of whole and dehulled sunflower can also result in good oil recovery with acceptable quality meal for its further utilization in foods for human consumption. In view of this, optimization of important oil expelling parameters was carried out using dehulled and whole sunflower in komet screw press for achieving higher oil recovery and better-quality meal.

Material and Methods

The design of experimental combinations for this study was done according to Response surface methodology (RSM). Box-Behnken design of RSM with three independent process parameters and experimental runs were planned using Design Expert 8.0 software. Seventeen sets of oil expelling experiments were carried out using three independent variables viz., dehulled sunflower (60, 70, 80g), whole sunflower (20, 30, 40g) and sample moisture content (6, 8, 10%). The press head temperature of all experimental samples during oil expelling was kept at 70 ºC.

In order to optimize the press head temperatures for higher oil recovery from sunflower, another set of experiment was planned using Box-Behnken design. Seventeen sets of oil expelling experiments were carried out using three independent variables viz., dehulled sunflower (60, 70, 80g), whole sunflower (20, 30, 40g) and press head temperatures (50, 70, 90 ±2ºC). The moisture content of all experimental samples was kept at 6%. The levels of independent variables and experimental plan with different oilseed/ kernel moisture content and press head temperatures is given in Table 1. The response variables were oil recovery, residual oil in meal, sediment content, press rate, oil and meal temperature and free fatty acid content in meal.

Raw material preparation

Whole sunflower seeds were procured from the local supplier and used for the study. Sunflower seed sample was dehulled using sunflower dehuller developed by ICAR-CIPHET, Ludhiana. The dehulled sunflower seeds were packaged in plastic bags, sealed and stored at 10ºC for conducting the experiments of this study.

Table 1: Experimental plan for oil expelling from whole and dehulled sunflower seed () The values in brackets indicate the coded values of the experiment

S. No.	Independent variables at constant temperature			Independent variables at constant moisture		
	Whole sunflower (g)	Dehulled sunflower (g)	Moisture (%)	Whole sunflower (g)	Dehulled sunflower (g)	Press head temperature, °C
1	30 (0)	70 (0)	8 (0)	30 (0)	70 (0)	70 (0)
2	20 (-1)	60 (-1)	8 (0)	30 (0)	70 (0)	70 (0)
3	30 (0)	70 (0)	8 (0)	40 (+1)	70 (0)	90 (+1)
4	30 (0)	60 (-1)	6 (-1)	30 (0)	80 (+1)	50 (-1)
5	20 (-1)	70 (0)	10 (+1)	30 (0)	60 (-1)	50 (-1)
6	30 (0)	70 (0)	8 (0)	20 (-1)	70 (0)	50 (-1)
7	40 (+1)	70 (0)	6 (-1)	30 (0)	60 (-1)	90 (+1)
8	40 (+1)	80 (+1)	8 (0)	40 (+1)	80 (+1)	70 (0)
9	40 (+1)	70 (0)	10 (+1)	30 (0)	70 (0)	70 (0)
10	20 (-1)	80 (+1)	8 (0)	30 (0)	70 (0)	70 (0)
11	30 (0)	80 (+1)	6 (-1)	30 (0)	80 (+1)	90 (+1)
12	30 (0)	70 (0)	8 (0)	20 (-1)	80 (+1)	70 (0)
13	30 (0)	70 (0)	8 (0)	30 (0)	70 (0)	70 (0)
14	30 (0)	80 (+1)	10 (+1)	40 (+1)	60 (-1)	70 (0)
15	40 (+1)	60 (-1)	8 (0)	20 (-1)	60 (-1)	70 (0)
16	20 (-1)	70 (0)	6 (-1)	20 (-1)	70 (0)	90 (+1)
17	30 (0)	60 (-1)	10 (+1)	40 (+1)	70 (0)	50 (-1)

Moisture conditioning of sunflower

The determination of the moisture content of whole and dehulled sunflower was carried out by hot air oven method at 105ºC until the sample reached constant weight (AOAC, 2000) [1]. The conditioning of the whole and dehulled sunflower seeds were done at different moisture content (6, 8 and 10% w.b.). The higher moisture content in the sample was obtained by adding distilled water and thorough mixing by hand and stored in sealable bags at 5°C in refrigerator for 24 h (Mridula *et al.*, 2011 and 2017) [6, 10]. The amount of distilled water to be added was calculated using the following formula (Chakraverty, 1988) [2]:

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

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 expelling

A Komet screw press (model CA59G, Germany) was used for the expelling of sunflower seeds in a single pass. The screw shaft had140 mm length, 30 mm screw diameter and 15 mm pitch with die having inside diameter of 8 mm. The press head was heated to the desired temperature (70±2ºC) using an electrical resistance heating ring before the initiation of the oil expelling process. The sunflower seeds were initially pressed for 20-30 min to obtain stable flow of oil and meal; thereafter, the samples at different moisture content were fed to screw press in ascending order as per the experimental plan. The samples with different moisture content were pressed at 70±2ºC.

For optimizing the press head temperatures for higher oil recovery from sunflower, another set of experiment was carried out as per experimental design at constant sample moisture of 6%. The obtained sunflower oil and residual meal samples were evaluated for important physico-chemical quality characteristics.

During the screw pressing of experimental samples, the oil and meal sample's temperatures were recorded with a multi-thermometer (least count=0.1°C, range = -50 to +150 °C) by inserting the measuring probe of thermometer in the oil oozing out below the barrel. After completion of pressing for each experimental sample, crude oil and meal was collected and the expelling time was recorded using a stopwatch. The crude oil and meal samples were weighed using a weighing balance (least count=0.0001g) and the press rate was calculated using the following formula (Mridula *et al.*, 2015) [7]:

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

Residual oil in cake

The residual oil content in the sunflower meal/cake samples was determined using the procedure as per AOAC (2000) [1].

Sediment content of oil

The sediment in the crude oil is the solid content per unit weight of unfiltered crude oil. These solid particles were filtered from the oil using pre-weighed filter paper to obtained actual oil weight. The filtered solid samples thus filtered were rinsed with petroleum ether and heated to 50°C in a hot air oven for evaporating the solvent followed by weighing of the filter paper with solids and sediment content in oil samples was calculated.

Oil recovery

Oil recovery (OR) from sunflower is the ratio of oil in sample to original oil present in experimental sample. The oil recovery was obtained with the following formula (Zheng *et al.*, 2003) [25].

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

Physico-chemical characteristics of sunflower oil

The determination of free fatty acid (FFA) value in sunflower oil was done as per the standard procedure (Ranganna, 1986) [15]. Colour quality (L, a, b values) of the meal samples was measured (Singh *et al.*, 2013) [17] after 12 h of oil expelling experiments using Hunter Colorimeter (Model no. 45/0-L, U.S.A).

Statistical analysis

The 'Design Expert 8.0' (version 8.0.2, Stat-Ease Inc, USA) was used for statistical analysis of experimental results. Multiple regression analysis was used to fit the model to the experimental data and represented by an equation. The adequacy of the developed models was evaluated using F-ratio, coefficient of correlation (R^2) and lack of fit. The numerical optimization technique of software was used for optimization of the responses.

Results and Discussion

Effect of process parameters on sunflower oil recovery

The oil recovery indicates the efficiency of the expelling process of oilseeds. It was observed that there was a significant increase in the oil recovery with decrease in sample moisture (Fig.1, Table 2a). This increase in oil recovery might be due to increased frictional resistance occurring at low sample moisture in the barrel during pressing of sunflower seeds. On the other hand, higher seed moisture acts as a lubricant inside the barrel (Singh *et al.*, 2002; Mridula *et al.*, 2019) [18, 27] that might have reduced the oil recovery. Whole sunflower in the sample mixture indicated a slight increase in the oil recovery with increasing proportion in the sample mixture. The whole sunflower might have increased the frictional resistance in the barrel, may be due to the presence of hull. This may be reason of higher oil recovery with increasing level of whole sunflower in the sample.

Table 2a: ANOVA of linear, quadratic and interactive terms of sunflower oil expelling process variables on responses

Term	Oil recovery, %	Residual oil in cake, %	Press rate, kg/h	Sediment content, %	Oil temperature, °C	Cake temperature, °C	Free fatty acid, %	L value	a value	b value
Model	87.44**	89.69**	439.02**	0.65	1.39	0.73	1.13	1.19	1.02	0.14
A-Moisture, %	708.46**	613.85**	3355.74**	2.62	0.081	2.51	1.29	0.12	1.41	0.023
B-Whole sunflower, g	4.98	0.43	0.12	0.023	1.96	0.10	1.57	0.039	0.077	3.823E-006
C-Dehulled sunflower, g	1.30	1.03	2.45	4.261E-003	0.061	0.20	1.14	0.021	0.15	0.24
A*B	0.94	0.086	0.68	0.40	0.011	0.10	0.20	1.23	0.13	0.13
A*C	1.16	4.14	0.65	1.36	0.018	1.05	1.33	1.74	1.39	0.022
B*C	0.78	0.049	4.42	1.27	1.03	0.016	0.18	0.24	0.34	9.648E-003
A*A	68.64**	185.88**	580.30**	9.104E-005	3.83	2.114E-003	1.60	3.06	4.25	0.75
B*B	0.075	0.26	0.55	0.086	2.34	0.23	1.77	3.17	1.14	8.104E-003
C*C	0.15	0.31	0.083	0.041	3.56	2.42	1.28	0.42	4.838E-003	0.022
Lack of fit	2.03	0.31	6.32	0.12	0.20	4.77	0.62	0.56	1.72	0.39
C.V. %	0.47	2.20	0.76	25.28	3.46	1.61	6.94	4.34	33.53	19.92
R^2	0.991	0.991	0.998	0.454	0.642	0.484	0.593	0.605	0.568	0.151

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

At a given level of dehulled sunflower (70g), oil recovery decreased from 91.01% at 6.2 % moisture content to 85.45% at 8 % moisture content, which further decreased to 83.53% at 9.5 % moisture content. The oil recovery (91.63%) was found maximum with 6% moisture content, 70g de-hulled sunflower and 40g whole sunflower while the minimum oil recovery (83.06%) was observed at 10% moisture content, 20g whole sunflower and 70g de-hulled sunflower. Mridula *et al.*, (2015) [7] also reported maximum oil recovery (82.9%) at 70% dehulled and 30% whole flaxseed. The regression model indicated significant ($p \leq 0.05$) impact of moisture content on oil recovery with coefficient of regression (R^2) as 0.99, thus indicating that second order model was adequate to predict the response and interpret the effect of studied independent variables on oil recovery using following equations: Oil recovery at variable moisture content (%) = $+85.57 - 3.81*A + 0.32*B + 0.16*C - 0.20*A*B - 0.22*A*C + 0.18*B*C + 1.63*A^2 - 0.054*B^2 + 0.076*C^2$ (1)

where, A - sample moisture content, % ; B - whole sunflower, g ; C – dehulled sunflower, g

Table 2b: ANOVA of linear, quadratic and interactive terms of sunflower oil expelling process variables on responses

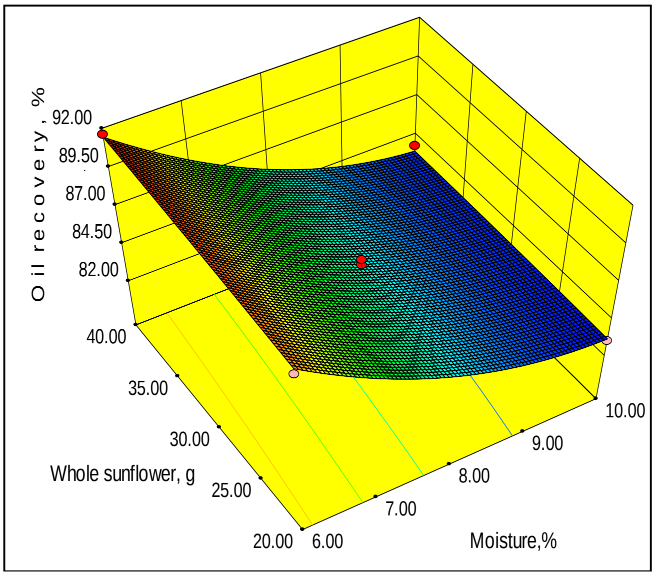
Term	Oil recovery, %	Residual oil in cake, %	Press rate, kg/h	Sediment content, %	Oil temperature, °C	Cake temperature, °C	Free fatty acid, %	L value	a value	b value
Model	20.58**	898.06**	52.55**	1.09	10.71**	7.81**	545.45**	0.77	0.84	0.82
A-Press head Temperature, °C	74.87**	213.99**	59.67**	0.025	65.37**	56.05**	4597.45**	1.43	0.76	2.87
B-Whole sunflower, g	0.17	170.42**	1.54	0.88	0.49	0.42	1.34	0.050	1.09	0.081
C-Dehulled sunflower, g	2.12	4.50	6.83*	0.072	3.01	2.93	2.43	1.03	2.26	2.17
A*B	0.54	7.75*	2.67	1.20	1.49	4.06	0.93	2.531E-003	0.12	0.12
A*C	0.30	0.084	1.97	0.79	0.074	0.29	0.013	0.30	0.082	0.24
B*C	0.037	1.84	0.69	0.50	0.066	0.93	0.81	0.99	8.490E-004	0.15
A*A	106.53**	7597.56**	393.83**	1.79	25.27**	5.31	303.16**	0.30	1.43	1.13
B*B	1.78	0.078	0.084	4.87	5.482E-003	4.833E-005	0.61	0.31	0.20	0.21
C*C	0.21	9.22*	1.42	7.533E-004	0.99	0.38	0.75	2.64	1.79	0.55
Lack of fit	0.54	4.46	0.80	14.40	0.31	1.34	0.10	2.50	0.55	0.89
C.V. %	1.42	0.62	3.29	5.04	5.91	5.76	0.76	3.72	5.14	3.68
R^2	0.964	0.999	0.985	0.584	0.932	0.909	0.999	0.497	0.520	0.514

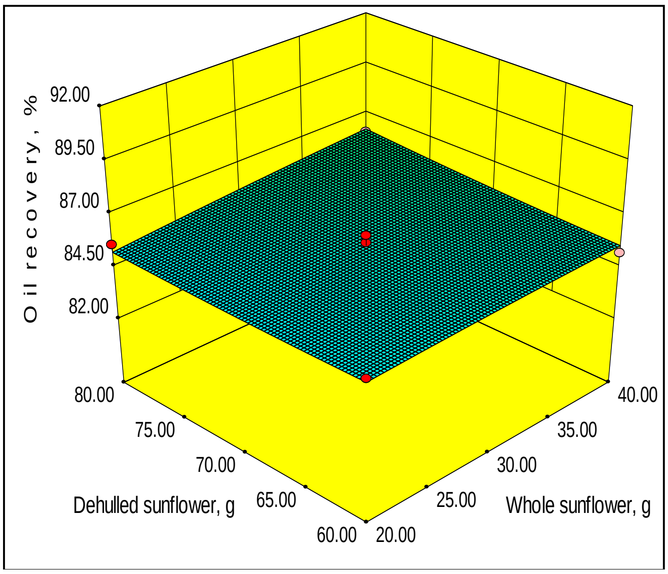
* ($p \leq 0.05$), ** ($p \leq 0.01$)

Oil recovery from de-hulled sunflower increased with increasing press head temperature up to 70 °C, but further increase in temperature reduced the oil recovery (Table 2b) as also observed in another study (Mridula *et al*., 2019) [27]. The oil recovery (90.81%) was found maximum with 70 °C, 60g de-hulled sunflower and 20g whole sunflower while the minimum oil recovery (78.52%) was observed at 50 °C, 80g de-hulled sunflower and 30g whole sunflower. At a given level of dehulled sunflower (70g), oil recovery increased from 79.54% at 55 °C to 90.23% at 68°C while further increase in temperature from 68 to 90 °C showed a marked decreased in oil recovery from 90.23% to 88.03%. This enhancement in the oil recovery up to 70 °C might be due to heating of oil seeds causing the oil to flow out from the seeds (Ward, 1976) [23]. On the other hand, decreased oil recovery with increase in temperature from 70 °C to 90 °C may be due to internal binding between oil and proteins within the seed structure that prevent the flow of oil from the seeds (Soetaredjo *et al.*, 2008). The regression model indicated significant impact of press head temperature on oil recovery with regression coefficient (R^2) as 0.96 and non-significant lack of fit (Table 2b). The relationship between press head temperature and oil recovery may be expressed by the following predictive quadratic regression equations

Oil recovery at variable press head temperature (%) = $+89.19 + 3.76*A + 0.18*B - 0.63*C + 0.45*A*B - 0.34*A*C + 0.12*B*C - 6.18*A^2 + 0.80*B^2 + 0.28*C^2$ (2)

where, A – press head temperature, °C; B - whole sunflower, g; C – dehulled sunflower, g





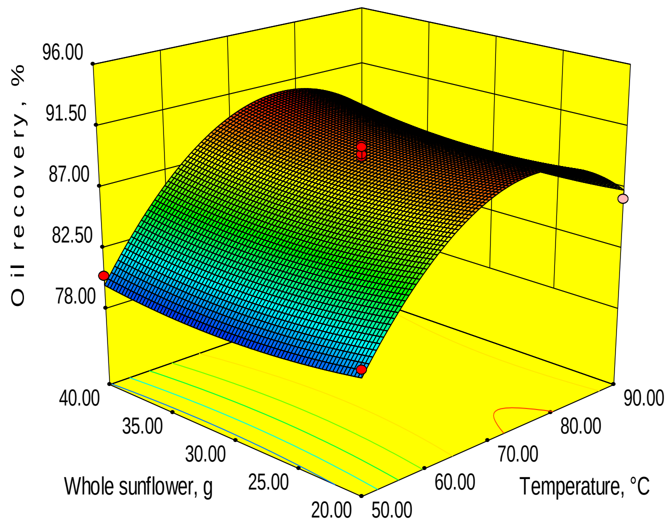


Fig 1: Effect of whole and dehulled sunflower, sample moisture and press head temperature on oil recovery

Effect of process parameters on residual oil in cake

The sample moisture significantly affected the residual oil content in cake that ranged from 6.20 to 10.20% (Table 2a). The residual oil in cake varied between 6.20-6.88%, 9.45-9.99%, and 10.05-10.20% at 6, 8 and 10% (w.b.) sunflower moisture, respectively. The increased residual oil content in meal was found with increasing sunflower moisture and was maximum at 10% moisture content ($p<0.05$). Studies also showed decreased residual oil content in meal/ cake with reducing moisture content for pressing of oilseeds (Singh *et al*., 2002; Singh *et al*., 1984; Mridula *et al*., 2015, 2019) [18, 20 7, 27]. Mridula *et al.* (2015) [7] also observed a proportional increase in residual oil in flaxseed cake with increase in moisture content. This might be attributed to increased frictional resistance at lower moisture content of seed in the barrel during the pressing of de-hulled sunflower. Hoffmann (2013) [3] and Reuber (1992) [16] viewed that lower seed moisture increases friction, whereas higher moisture content acts as a lubricant during pressing of oilseeds. Residual oil content in cake of different experimental oil samples, expelled at 50-90ºC press head temperature varied between 7.05 to 9.88%. The press head temperature affected the residual oil in meal with minimum residual oil content at 70ºC (Table 2b) as also reported for oil expelling of dehulled sunflower (Mridula *et al*., 2019) [27]. Multiple regression analysis for studying the effect of independent variables on residual oil content in meal 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 at variable moisture content (%) = $+9.71 + 1.75*A - 0.047*B + 0.072*C + 0.029*A*B - 0.20*A*C - 0.022*B*C - 1.33*A^2 + 0.050*B^2 - 0.054*C^2$ (3)

where, A - sample moisture content, % ; B - whole sunflower, g ; C – dehulled sunflower, g

Residual oil at variable press head temperature (%) = $+7.26 - 0.27*A - 0.24*B + 0.039*C - 0.072*A*B + 0.007*A*C + 0.035*B*C + 2.19*A^2 + 0.007*B^2 + 0.076*C^2$ (4)

where, A – press head temperature, °C ; B - whole sunflower, g ; C – dehulled sunflower, g

Effect of process parameters on press rate

The press rate of de-hulled sunflower with whole sunflower was ranged from 1.91 to 1.94, 2.47 to 2.55 and 2.64 to 2.68 kg/h, respectively at 6, 8 and 10% (w.b.) moisture content of sunflower sample mixture. The press rate was found maximum at 10% moisture content, 70g dehulled sunflower and 20g whole sunflower while minimum was observed at 6% sample moisture, 70g dehulled sunflower and 40g whole sunflower in sample mixture. The higher press rate at 10% sample moisture might be attributed to low resistance inside the screw barrel and lubricant effect of sample moisture. Singh *et al.* (2010) [19] reported a slight increased press rate at enhanced flaxseed moisture of whole flaxseed. Increased press rate during screw pressing of dehulled and whole flaxseed was also reported by Mridula *et al.* (2015) [7]. Similarly, Singh *et al.* (2002) [18] reported decrease in press rate from 5.8 to 5.2 kg/h and 6.1 to 5.2 kg/h for uncooked and cooked crambe seeds with decreased moisture from 9.2 to 3.6% d.b.

The press rate of different de-hulled sunflower samples with whole sunflower was also influenced by the press head temperature with minimum at 50ºC and maximum at 90ºC (Table 2b). The press rate of de-hulled sunflower with whole sunflower expelled at 50, 70 and 90ºC varied between 2.64 to 2.79, 1.68 to 1.95 and 2.23 to 2.47 kg/h, respectively. The relationship between press head temperature, seed moisture and level of de-hulled sunflower and whole sunflower on press rate may be expressed by following predictive quadratic regression equations.

Press rate at variable moisture content (kg/h) = $+2.51 + 0.37*A + 0.0022*B - 0.010*C - 0.007*A*B + 0.007*A*C - 0.019*B*C - 0.21*A^2 - 0.006*B^2 - 0.002*C^2$ (5)

where, A - sample moisture content, %; B - whole sunflower, g ; C – dehulled sunflower, g

Press rate at variable press head temperature (kg/h) = $+1.82 - 0.19*A + 0.031*B + 0.065*C - 0.058*A*B + 0.050*A*C - 0.029*B*C + 0.69*A^2 - 0.010*B^2 + 0.041*C^2$ (6)

where, A – press head temperature, °C; B - whole sunflower, g ; C – dehulled sunflower, g

Effect of process parameters on sediment content in oil

The sediment content of samples at moisture content of 6, 8% and 10% w.b. varied from 4.26 to 5.80, 3.11 to 6.70 and 3.19

to 4.23%, respectively. The statistical analysis indicated that sample moisture as well as level of whole sunflower and de-hulled sunflower did not bring any significant impact on sediment content in oil samples (Table 2a). Similarly, Singh *et al.* (2010) [19] did not observe significant impact of oilseed moisture in case of pretreated whole flaxseed on sediment content in crude oil while Mridula *et al.* (2015) [7] reported the low sediment content at higher oilseed moisture during mechanical expelling of a mixture of whole and dehulled flaxseed.

Sediment content in crude oil of de-hulled sunflower sample with whole sunflower, expelled at different level of press head temperature was ranged from 5.75 to 5.98, 5.69 to 6.53, and 5.24 to 6.48% at 50, 70 and 90˚C, respectively. Though variability in the amount of sediment content was observed in crude sunflower oil samples, obtained following different press head temperatures but the variation was statistically similar (Table 2b). Contrary to this, Mridula *et al.* (2015) [7] observed statistically significant affect of press head temperature with lowest sediment value at 120°C with three studied temperature as 80 to 120 ºC. The variability in the findings in different studies may be due to the variation in the level of studied parameters and the crop properties. The effect of press head temperature, seed moisture and level of de-hulled sunflower and whole sunflower on sediment content in crude oil is expressed by following predictive quadratic regression equations.

Sediment content at variable moisture content (%) = +4.26 - 0.63*A - 0.060*B - 0.026*C + 0.35*A*B + 0.65*A*C + 0.62*B*C + 0.005*A^2 + 0.16*B^2 + 0.11*C^2 (7)

where, A - sample moisture content, %; B - whole sunflower, g ; C – dehulled sunflower, g

Sediment content at variable press head temperature (%) = +5.84 - 0.017*A - 0.098*B - 0.028*C - 0.16*A*B + 0.13*A*C - 0.1*B*C - 0.19*A^2 + 0.32*B^2 - 0.004*C^2 (8)

where, A – press head temperature, °C ; B - whole sunflower, g ; C – dehulled sunflower, g

Effect of process parameters on oil and cake temperatures

The temperature of oil samples in this study, obtained by pressing at constant press head temperature i.e. 70ºC and variable sample moisture (6 to 10%) ranged from 49.4 to 59.2ºC, which was statistically similar. The temperature of oil, obtained by pressing of sample mixture at constant moisture (6%) with variable temperature (50-90ºC) ranged between 38.2 to 60.5ºC, which was found affected ($p<0.05$) with the variation of press head temperature (Table 2b). Predictive equations for oil temperature are as follows:

Oil temperature at variable sample moisture (°C) = +53.34 - 0.19*A + 0.92*B + 0.16*C + 0.100*A*B - 0.13*A*C + 0.95*B*C - 1.78*A^2 + 1.39*B^2 + 1.72*C^2 (9)

where, A - sample moisture content, %; B - whole sunflower, g ; C – dehulled sunflower, g

Oil temperature at variable press head temperature (°C) = +55.70 + 8.91*A + 0.77*B - 1.91*C + 1.90*A*B + 0.42*A*C - 0.40*B*C - 7.64*A^2 - 0.11*B^2 + 1.51*C^2 (10)

where, A – press head temperature, °C ; B - whole sunflower, g ; C – dehulled sunflower, g

The cake temperature may bring a significant impact on the quality characteristics of the resultant meal. Higher oil expelling temperature can result in the darker meal/ cake that may not be suitable for utilization for food purposes. Therefore it is desirable to carry out the oilseeds expelling at appropriate oilseed moisture and temperature to obtain the good quality resultant meal. Both, press head temperature during expelling and sample moisture affected the cake temperature (Table 2a & 2b). Cake temperature of different samples at variable sample moisture was 47.4 to 49.8˚C while at different press head temperature; it was ranged from 35.4 to 58.7ºC. Zheng *et al.* (2005) [26] also reported enhanced meal/ cake temperature with increasing press head temperature at similar flaxseed moisture content (6.3%). Mridula *et al.* (2015) [7] also found the minimum meal/ cake temperature at lower i.e. 80ºC with maximum at 120ºC press head temperature. Predictive equations for cake temperature are as follows:

Cake temperature at variable sample moisture (°C) = +48.76 - 0.44*A + 0.087*B + 0.13*C - 0.13*A*B + 0.40*A*C - 0.05*B*C - 0.018*A^2 + 0.18*B^2 - 0.59*C^2 (11)

where, A - sample moisture content, %; B - whole sunflower, g ; C – dehulled sunflower, g

Cake temperature at variable press head temperature (°C) = +52.38 + 7.81*A + 0.68*B - 1.79*C - 2.97*A*B - 0.80*A*C - 1.42*B*C - 3.31*A^2 + 0.010*B^2 + 0.89*C^2 (12)

where, A – press head temperature, °C ; B - whole sunflower, g ; C – dehulled sunflower, g

Effect of process parameters on physico-chemical quality

The colour quality i.e. *L*, *a*, *b* values of the cake obtained by pressing the sample mixture of whole and de-hulled sunflower at different moisture content (6-10%) varied between 78.60 to 90.64, -3.73 to -0.88 and 20.72 to 44.99, respectively; whereas the same at different press head temperature were 83.53 to 93.43, -4.29 to -3.55, 39.20 to 43.86, respectively. It was observed that there was no significant effect of moisture and press head temperature on the colour quality of meal obtained from oil expelling of whole and de-hulled sunflower (Table 2a & 2b).

Free fatty acids (FFA) are formed in oil due to hydrolysis of triglycerides, an important oil quality parameter that influences the flavour, aroma and other oil characteristic (O'Brien, 2004). FFA content in the sunflower oil samples, obtained following 6-10% sample moisture and constant press head temperature (70ºC) ranged from 0.39 to 0.50% with minimum in the oil sample, obtained at 8% sample moisture (Fig. 2, Table 2a).Whereas sample mixture expelled at 50 to 90ºC indicated 0.31 to 0.45% FFA in various oil samples with minimum at 50ºC and maximum at 90ºC press head temperature (Table 2b) but it was less than 2% that may be considered for edible purposes (Nagaraj, 2009) [11]. This enhancement in FFA in sunflower oil samples might be due to the decomposition of glycerides at increased press head temperature (Kordylas, 1990; Young, 1996). In view of lower FFA value, the meal obtained in this study from de-hulled sunflower with whole sunflower may be considered for food purposes. The relationship between press head temperature, seed moisture and level of whole sunflower in sample on FFA content in cake may be expressed by following predictive quadratic regression equations:

Free fatty acid at variable moisture content (%) = +0.44 - 0.013*A + 0.014*B - 0.012*C - 0.007*A*B - 0.018*A*C - 0.007*B*C - 0.019*A^2 + 0.02*B^2 + 0.017*C^2 (13)

where, A - sample moisture content, %; B - whole sunflower, g ; C – dehulled sunflower, g

Free fatty acid at variable press head temperature (%) = +0.36 + 0.068*A - 0.001*B - 0.002*C - 0.001*A*B + 0.002*A*C - 0.001*B*C + 0.024*A^2 + 0.001*B^2 - 0.001*C^2 (14)

where, A – press head temperature, °C ; B - whole sunflower, g ; C – dehulled sunflower, g

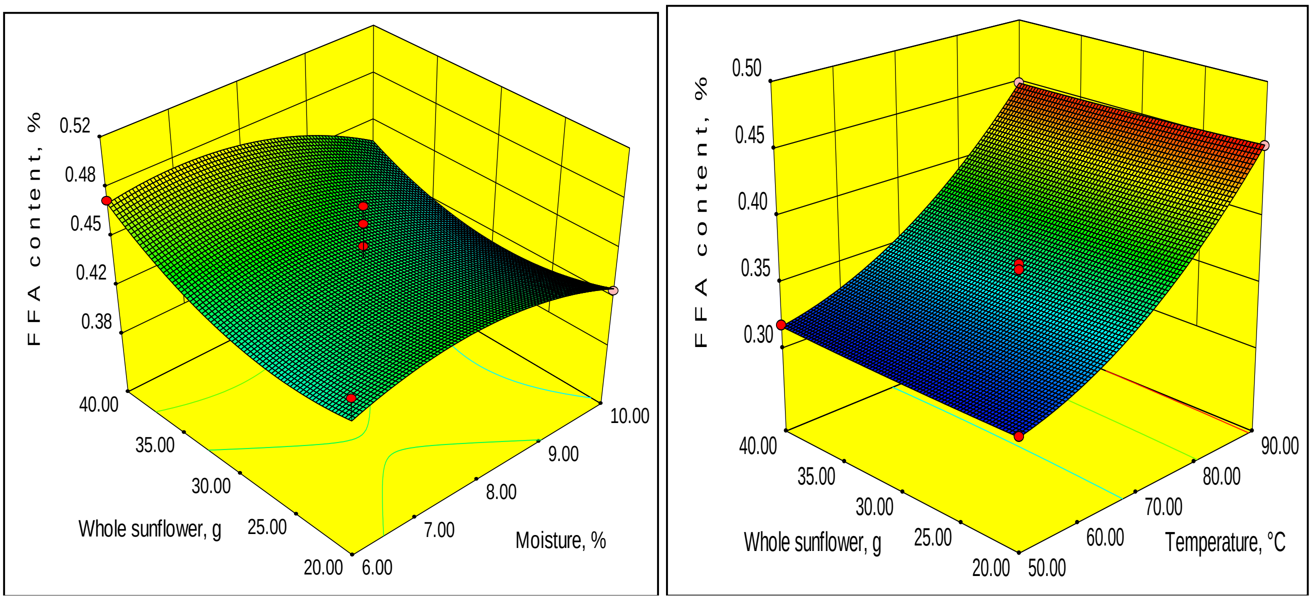


Fig 2: Effect of whole sunflower, sample moisture and press head temperature on free fatty acid (FFA) of expelled oil

Optimization and validation of oil expelling parameters

Optimum conditions were determined based upon maximizing oil recovery while minimizing residual oil in cake, sediment content in oil, oil and cake temperature, and FFA whereas independent parameters were kept within range. Based upon the statistical analysis, 60g de-hulled sunflower, 27.41g whole sunflower with 6% sample moisture while 75.53g de-hulled sunflower, 40g whole sunflower with 71.48°C press head temperature indicated the maximum desirability 0.812 and 0.850 at studied sample moisture and press head temperature, respectively. These optimized parameters were followed for further validation by analyzing the responses for the sample prepared following above optimized process parameters, which have been presented in Table 3. Non-significant validation results of responses using t-test indicated the validity of the optimized parameters at variable sample moisture as well as press head temperature.

Table 3: Optimized parameters for oil expelling from whole and dehulled sunflower

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: Moisture, %	in range (3)	6-10	6.00		A: Press head temperature, ° C	in range (3)	50-90	71.50	
B: Whole sunflower, g	in range (3)	20-40	27.41	0.812	B: Whole sunflower, g	in range (3)	20-40	40.00	0.850
C: Dehulled sunflower, g	in range (3)	60-80	60.00		C: Dehulled sunflower, g	in range (3)	60-80	75.53	
Responses			**Predicted value**	**Experimental value**	**Responses**			**Predicted value**	**Experimental value**
Press rate, kg/h	in range (3)	1.91-2.68	1.93	1.87	Press rate, kg/h	in range (3)	1.68-2.79	1.86	1.81
Residual oil, %	minimize (5)	6.20-10.2	6.32	6.21	Residual oil, %	minimize (5)	7.05-9.88	7.08	6.95
Oil recovery, %	maximize (5)	83.06-91.63	90.61	90.13	Oil recovery, %	maximize (5)	78.52-90.81	90.24	90.02
Oil temperature, ° C	minimize (1)	49.4-59.2	53.30	52.98	Oil temperature, °C	minimize (1)	38.2-60.5	53.32	52.86
Cake temperature, ° C	minimize (1)	47.4-49.8	48.81	48.38	Cake temperature, °C	minimize (1)	35.4-58.7	51.87	51.25
Free fatty acid, %	minimize (1)	0.39-0.50	0.44	0.42	Free fatty acid, %	minimize (1)	0.31-0.45	0.36	0.34

Conclusion

Response Surface Methodology is successfully applied for optimization of important parameters for oil expelling of dehulled sunflower at variable sample moisture and press head temperature. Oil recovery was influenced due to variation in sunflower moisture and press head temperature, thereby demonstrating the importance of optimizing process parameters for expelling of dehulled sunflower to achieve higher oil recovery and good quality meal. This study indicated that 68.64% dehulled sunflower with 31.36% whole sunflower with 6% sample moisture may be considered for oil expelling of dehulled sunflower at 71.5 ˚C press head temperature.

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