Optimization of Operational parameters for Enhancement of Oil Recovery from Mustard Seeds Using Mechanical Expression

Pawanpreet Singh and A.K. Singh

Department of Processing and food engineering
Punjab Agricultural University-Ludhiana, Punjab, India
Email: grewal829@gmail.com

Abstract

The experiments were carried out with the objectives to determine the various operational parameters for better recovery of oil from two varieties of Mustard seed i.e. PBR-91 and RLC-1. The experiments were designed using response surface methodology for making various combinations of moisture content (6, 9, 12, 15 and 18%w.b.), heating time (2,4, 6, 8 and 10 min), heating temperature (40,60,80,100 and 120°C) and enzyme concentration (1, 2, 3, 4 and 5%) and the experiments were conducted using single chamber oil expeller. The effect of independent variables i.e. moisture content, enzyme concentration and heating temperature on oil yield and residual oil in cake of PBR-91 and RLC-1 variety were found significant however the effect of the heating time was found non-significant in both the varieties. The moisture content had a significant effect on the acid number and peroxide value. The optimum condition for maximum oil recovery are 9% moisture content, 4% enzyme concentration, 60°C heating temperature and 8 minutes heating time for PBR-91 variety whose predicted value for oil recovery is 29.82%, acid number 0.8315 and peroxide value of 5.42whereas for RLC-1 variety are 9% moisture content, 4% enzyme concentration, 60°C heating temperature and 4 minutes heating time whose predicted value for oil recovery is 29.00%, acid number 0.69 and peroxide value 4.70. There is 8% increase in the yield of the oil for PBR-91 extracted at optimum parameter level whereas in RLC-1 there is 8.89% increase in the oil yield compared to untreated seeds.

Keywords : *Mustard seeds, enzymes, oil extraction*

1 INTRODUCTION

Oil and fats are the most concentrated source of energy in our diet and also act as carrier for liposoluble vitamins viz A, D, E, and K. Vegetable oils are an important ingredient for several foodstuffs and non-food products. These are also recognized as one of the richest source of essential fatty acids. India contributes about 6-7% of the world oilseeds production. Export of oil meals, oilseeds and minor oils has increased from 5.06 million tonnes in the year 2005 to 7.3 million tonnes in the year 2006. In terms of value, realization has gone up from Rs. 5514 crores to Rs.7997 crores. India accounted for about 6.4 per cent of world oil meal export (fcamin.nic.in).

Extraction of oils from oilseeds is a key step for their commercialization. The extraction process has a direct effect on the quality and quantity of protein and oils obtained [4]. Mechanical screw pressing is the most popular method of oil separation from vegetable oilseeds in the world [6]. Nearly 90% of the total oilseeds produced in India are crushed employing this method. The mechanical screw presses (oil expellers) used in India are, however, inefficient as they leave 8 to 14 % of the residual oil in the cake [7] and thus, a large quantity of precious edible oil (about 0.6 million tonnes) goes into the deoiled cake.

Recently, enzymatic pre-treatment has emerged as a novel and an effective means to improve the oil yield in mechanical pressing and aqueous extraction techniques [6]. The use of enzymes in oil extraction process has been studied by several researchers [3]. The main purpose of using the enzymes in oil extraction process is to hydrolyze the structural polysaccharides which form the cell wall of oilseeds or the proteins which form the cell and lipid body membrane.

Enzyme assisted pressing, because of its nontoxic and noninflammable standing, seems to be an ideal alternative for oilseed extraction [1]. The enzyme assisted pressing has been employed for extraction of oils from palm, canola, soybean, Chilean hazelnut and rosehips [2]. In these studies, an enhancement of oil yields and, in most of the cases, an improvement in product quality was observed.

Therefore, the present study was conducted to investigate the effect of enzyme treatment on oil recovery by mechanical expression from mustard seeds.

2 Experimental design and data analysis:

Response surface methodology was used in designing the experiment. Independent variables such as seed moisture content, enzyme concentration, heating temperature and heating time were used. Five levels of each of the four variables were chosen, according to a

central composite rotatable design. The coded and actual parameter values were carefully chosen base on the limited literature available on the enzymatic hydrolysis of oilseeds .

Mustard seed varieties PBR-91 and RLC-1 having 10% moisture were obtained from Seed department, Punjab Agricultural University. The commercial enzyme Allzyme was used for preparing enzyme solution.

For each experiment, a sample of 200 gm mustard seed was taken and calculated amount of enzyme solution was mixed to make the moisture content from 10% to 45% (w.b).

Table 1:
Coded and decoded parameter levels

Parameter	-2 (Extreme points)	-1 (Factorial points)	0 (Centre points)	+1 (Factorial points)	+2 (Extreme points)
Moisture content (% w.b.)	6	9	12	15	18
Enzyme concentration (%)	1	2	3	4	5
Heating temperature (°C)	40	60	80	100	120
Heating time (min)	2	4	6	8	10

The sample was completely mixed with enzyme by stirring and then it was kept in incubator for 6-8 hours at 45°C. The hydrolyzed samples were dried in hot air oven at 70°C to inactivate the enzyme [8] and also to reduce the moisture content to desired levels.

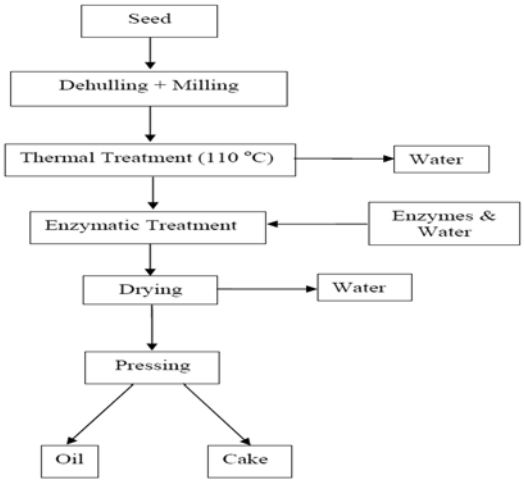

Fig 1: Flow chart for enzyme treated oil expression

The enzyme used for the treatment purpose is allzyme with following composition

- Lactobacillus acidophilus
- Saccharomyces cervisiae
- Amylase
- Protease
- Lipase
- Cellulase
- Phytase
- Alpha galactosidase
- Glucanase
- Pectinase
- Xylanase

The extraction was carried out in single chamber oil expeller (Komet, IBG Monforts and Germany). The expeller operates on gentle mechanical press principle that does not involve mixing and tearing of seeds.

Table 2:
Specifications of the oil expeller

Capacity in [kg] of input material / hour (depending on type and Bulk of Density of oil seed to be processed)	3 – 5
Electric Power of Drive Motor in [kW]	1.1
Weight in [kg] (net only, without input material)	80
Dimensions in [mm]	
Length	680
Width	580
Height	600

The percent yield of the oil recovered was determined by employing the use of the following equations [5]:

$$\text{The per cent oil yield (Y)} = \frac{W_{OE}}{Ws} \times 100$$

W_{OE} = weight of oil expressed (gm)

W_s = weight of sample before expression (gm)

The data on oil yield for different treated combinations was analyzed with response surface methodology.

3 Results and Discussion:

For the optimization of different operational parameters of screw press on oil recovery, residual oil in cake, the effect of four factors at five levels was studied using RSM design trial version 8.0.4.1 Central Composite Rotatable Design (CCRD) Technique, experimental combinations of factors . The various factors were the moisture content (6,9,12,15 and 18%),enzyme concentration (1,2,3,4 and 5) ,heating temperature (40,60,80,100 and 120 ^{o}c) and heating time (2, 4,6,8 and 10 min),. Each factor was assigned a higher and a lower value in a particular range and the response was analyzed. The results obtained after experimentation are shown in Tables 3 and 4.

Table 3:
Result for oil yield of PBR-91

Run	Factor 1	Factor 2	Factor 3	Factor 4	Response 1	Response 2
	MC (% w.b.)	Enzyme conc. (%)	Heating temp (°C)	Heating time (min)	Oil yield (g)	Percent oil yield (%)
1	15	2	100	4	25.70	12.16
2	15	2	60	8	32.69	15.30
3	15	4	60	8	36.00	17..00
4	15	4	100	8	28.50	13.50
5	12	3	80	2	41.40	20.20
6	12	3	80	10	39.00	19.02
7	6	3	80	6	60.00	31.20
8	18	3	80	6	20.00	9.10
9	12	5	80	6	47.80	23.30
10	15	4	60	4	37.76	17.80
11	15	2	60	4	31.30	14.70
12	12	3	40	6	50.60	24.70
13	9	2	60	4	56.00	28.20
14	12	3	80	6	39.50	19.20
15	12	3	80	6	42.30	20.60
16	9	4	60	4	61.50	31.00
17	15	2	100	8	26.70	12.60
18	9	4	100	8	50.60	25.50
19	12	3	80	6	40.50	19.70
20	12	3	80	6	41.40	20.20
21	9	2	100	8	45.00	22.70
22	12	3	80	6	44.00	21.40
23	9	4	60	8	64.00	32.30
24	9	2	60	8	55.00	27.90
25	12	1	80	6	34.00	16.60
26	9	2	100	4	46.00	23.20
27	15	4	100	4	30.00	14.15
28	12	3	120	6	26.70	13.02
29	9	4	100	4	48.00	24.24
30	12	3	80	6	41.00	20.00

Table4:
Result for oil yield ofRLC-1

Run	Factor 1	Factor 2	Factor 3	Factor 4	Response 1	Response 2
	MC (% w.b.)	Enzyme conc. (%)	Heating temp (°C)	Heating time (min)	Oil yield (g)	Percent oil yield (%)
1	12	1	80	6	31.31	15.27
2	15	4	60	4	35.90	17.00
3	12	3	80	6	36.80	17.95
4	12	3	120	6	30.30	14.80
5	15	2	100	4	22.50	10.60
6	12	3	80	6	37.76	18.40
7	9	4	60	4	59.80	30.20
8	15	2	60	4	33.15	15.60
9	15	4	100	8	24.40	11.50
10	15	2	100	8	23.00	10.80
11	9	2	100	4	44.20	22.30
12	12	3	80	2	41.00	20.00
13	12	3	80	6	36.38	17.74
14	6	3	80	6	59.00	30.50
15	9	2	60	4	54.30	27.40
16	9	4	100	4	46.97	23.70
17	12	3	80	6	39.60	19.30
18	12	3	80	10	38.60	18.80
19	15	2	60	8	32.23	15.20
20	12	5	80	6	44.20	21.56
21	9	2	60	8	53.40	26.98
22	12	3	40	6	47.80	23.36
23	9	2	100	8	42.30	21.39
24	12	3	80	6	38.20	18.60
25	18	3	80	6	19.30	8.79
26	9	4	60	8	63.50	32.09
27	15	4	60	8	34.50	16.29
28	15	4	100	4	26.00	12.24
29	9	4	100	8	49.70	25.10
30	12	3	80	6	40.50	19.76

The percent oil yield in table 3 varied from 9.10 to 32.30% of PBR-91 variety Mustard seeds whereas for RLC-1 variety it ranged from 8.79 to 32.09%. As the moisture content increased the percent oil yield decreased because the seed become soft with absorption of moisture so less force is applied by screw on the seed due to which the seed slide along with the screw. Moisture acted as lubricant in the barrel which resulted in insufficient friction and reduced level of compression and contributed to poor oil recovery.

The heating temperature also affected the oil yield as increase of temperature from 40 to 100°C the percent oil yield decreased because the heating process changed the moisture content and structure of the seed. There was also frequent choking and jamming of the screw because of high temperature as cake becomes hard and choke the outlet.

The enzyme concentration increased the percent oil yield till concentration level of 4% after that is not much increase .

Table 5 :
ANOVA for oil recovery based on enzyme concentration ,heating time and heating temperature, for PBR-91 variety of Mustard seeds

Source	Sum of squares	df	Mean Square	F value	p-value Prob > F	
Model	994.81	4	248.70	172.84	<0.0001	significant
A-Moisture content	805.62	1	805.62	559.87	<0.0001	
B-Enzyme concentration	50.26	1	50.26	34.93	<0.0001	
C-Heating temperature	138.77	1	138.77	96.44	<0.0001	
D-Heating time	0.17	1	0.17	0.12	0.7352	
Residual	35.97	25	1.44			
Lack of Fit	28.05	20	1.40	0.88	0.6236	Not significant
Pure Error	7.93	5	1.59			
Cor Total	10300.79	29				

The multiple regression analysis result the following equations:

For Oil recovery:-

$+48.95933 - 1.93125X_1 + 1.44708X_2 - 0.12023X_3 - 0.041875X_4$

X_1= Moisture content

X_2 = Enzyme concentration

X_3 = Heating temperature

X_4 = Heating time

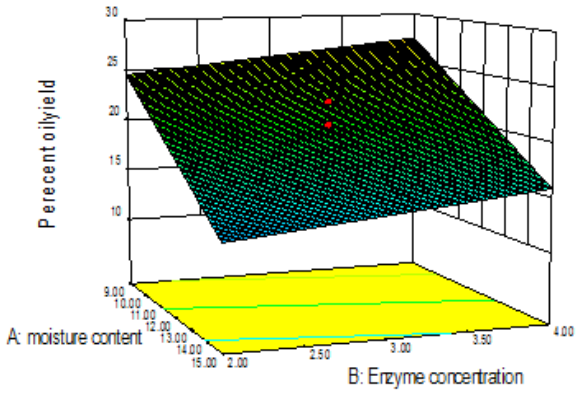

Fig 2: Surface plot for moisture content and enzyme concentration on response of oil recovery for PBR-91 Mustard seeds

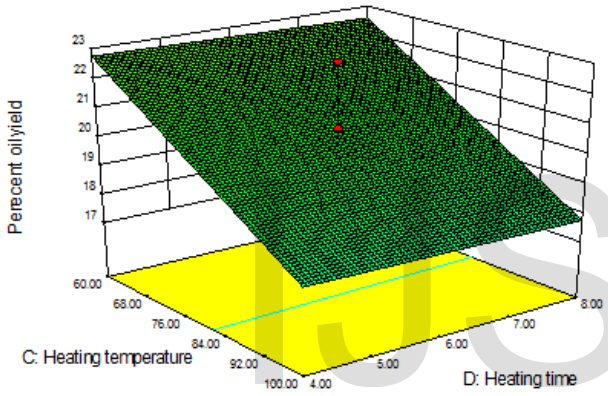

Fig 3: Surface plot for heating temperature and heating time on response of oil recovery for PBR-91 variety of Mustard seeds

The multiple regression analysis was tested to fit the high order polynomial to the experimental combinations .The linear model equation was fitted to experimental data and regression coefficient was obtained. The value for determination coefficient R^2 was 0.9651 for oil recovery. However correlation by ANOVA for oil recovery, enzyme concentration and heating temperature was found to be significant. Heating time was non-significant as there is slight change with change in time (Table 5).

The correlation between experimental verses actual results was found to be perfectly good for oil recovery. The surface plots for the responses are shown in Fig.2-3.The response surface graphs were generated for different interactions of two variables while keeping the other two constant. From the figures it was concluded that oil recovery was found to decrease with increase in moisture content because of sliding of the seeds along the rotating screw as moisture acted as lubricant in the barrel, which resulted in insufficient friction and less crushing force is offered by the screw to the seeds at high moisture content. However oil recovery with respect to enzyme concentration showed increase in oil recovery whereas with increase in heating temperature the oil recovery decreased and the residual oil in cake increased because high temperature resulted in frequent choking and jamming of the press as well as burning of oil and cake. The structure and the moisture content of the seed also changed due to the heating process.

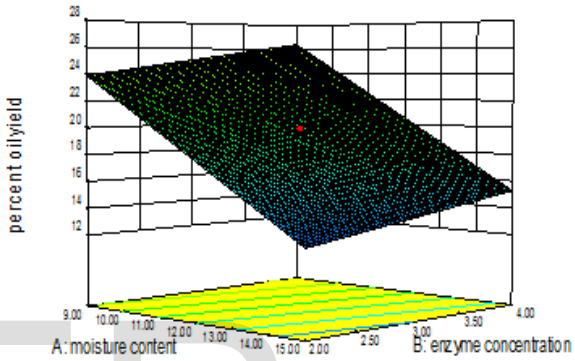

Fig 4: Surface plot for moisture content and enzyme conc. on response of oil recovery for RLC-1 variety of Mustard seeds

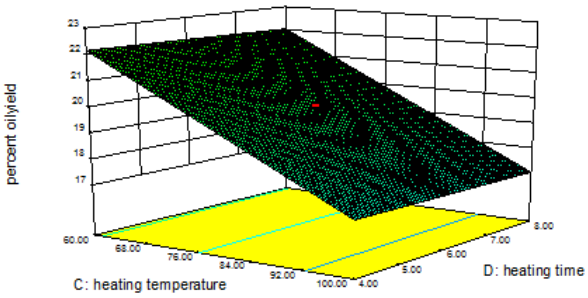

Fig 5: Surface plot for heating temperature and heating time on response of oil recovery for RLC-1 variety of Mustard seeds

The multiple regression analysis results the following equations:

For Oil recovery:-

$+48.30800 - 1.85764X_1 + 1.26458X_2 - 0.12569X_3 - 0.026458X_4$

The multiple regression analysis was tested to fit the high order polynomial to the experimental combinations .The linear model equation was fitted to experimental data of each dependent variable for oil recovery . The value for determination coefficient R^2 was 0.9380 for oil recovery. However the effect of moisture content and heating temperature on oil recovery and residual oil in cake was found significant but heating time was found non-significant (Tables 6).

Table 6 : Anova based on oil recovery based on enzyme concentration, heating time, heating temperature for RLC-1 variety of mustard seeds

Source	Sum of squares	df	Mean Square	F value	p-value Prob > F	
Model	935.48	4	233.87	94.63	< 0.0001	S
A-Moisture content	745.38	1	745.38	301.61	< 0.0001	
B-Enzyme concentration	38.38	1	38.38	15.53	0.0006	
C-Heating temperature	151.65	1	151.65	61.37	< 0.0001	
D-Heating time	0.067	1	0.067	0.027	0.8703	
Residual	61.78	25	2.47			
Lack of Fit	58.41	20	2.92	4.34	0.0554	NS
Pure Error	3.37	5	0.67			
Cor Total	997.26	29				

The linear terms had significant effect in explaining the data at 1% level of significance, linear model was suggested for optimization of percent oil yield. The surface plots for the responses are shown in Fig.4 and 5. From the figures plots it was observed that oil recovery was found to decrease with increasing moisture content because of sliding of the seeds along the rotating screw as moisture acted as lubricant in the barrel which resulted in insufficient friction and less crushing force offered by the screw to the seeds at high moisture content. The oil recovery decreased with increase in heating temperature as increased barrel temperature beyond 80ºC caused frequent choking and jamming of the press as well as burning of oil and cake, change in structure of the seed also take place due to heating process. However oil recovery with respect to heating time was found to be slightly constant

Moisture content: With decrease in moisture content there is increase in oil yield i.e 18 to 9% because of sliding of the seeds along the rotating screw and less crushing force offered by the screw to the seeds at high moisture content, whereas at 6% moisture the seed become too hard to be pressed.

Enzyme concentration: With increase in enzyme concentration there is slight increase in oil yield, but after 4% there is not any further increase.

Heating temperature: The increase in barrel temperature leads to decrease in oil yield due to change of moisture content and structure of the seeds during the heating process which this condition actually related to production of oil.

4 Conclusions

The study found that optimum condition for mechanical extraction of PBR-91 is using 9% moisture, 4% enzyme concentration, 60ºC heating temperature and 4 minutes heating time and for RLC-1 are 9% moisture content, 4% enzyme concentration, 60ºC heating temperature and 8 minutes heating time. The highest amount of oil yield is 32.30% at 9% moisture for PBR-91 and 32.09% for RLC-1 at 9% moisture level. The effect of all the parameters was found to be significant ($P<0.01$) on oil yield except heating time

5 References

1) Bhattacharjee, Singhal P R S, and Tiwari S R (2006) Supercritical carbon dioxide extraction of cottonseed oil. *J Food Engg* **79**: 892-989.
2) Cheah S C, Augustin M A and Ooi L C (1987). Enzymatic extraction of palm oil. Palm Oil Research Institute of Malaysia (PORIM), Kuala Lumpur, Bulletin No. **20**: 12-14.
3) Dominguez H, Nunez M J and Lema J M (1994) Enzymatic pretreatment to enhance oil extraction from fruits and oilseeds: a review. *Food Chemistry* **49**: 271– 286.
4) Mrema G C and McNulty P B (1985) Mathematical models of mechanical oil expression from oil seeds. *J Agric Engg Res* **31**:361-70.
5) Olaniyan A Bhattacharjee, Singhal P R S, and Tiwari S R (2006) Supercritical carbon dioxide extraction of

cottonseed oil. *J* M (2007) Development of mechanical expression rig for dry extraction of shea butter from shea kernel. *J Food Sci Technol*, **44(5)**:465-470.

6) Rosenthal A, Pyle D L and Niranjan K (1996) Aqueous and enzymatic processes for edible oil extraction. *Enzyme Microbial Technology* **19**: 402–420.
7) Srikantha P V R (1980) A search for an appropriate technique for village industry. AIDA, Lucknow Publications.pp 11-15.
8) Zuniga M E, Chamy R, and Lema J M (2001) Canola and Chilean hazelnut products obtained by enzyme-assisted cold-pressed oil extraction. In Proceedings of the world conference and exhibition on oilseed processing and utilization (R.F.Wilson, ed.). Pp 210-213.AOCS Press, Champaign.