AATCC Review

09 November 2024: Received
31 January 2025: Revised
21 February 2025: Accepted
25 February 2025: Available Online

https://aatcc.peerjournals.net/

Original Research Article

Open Access

Development and optimization of ohmic heating device for extraction of oil from enzymatically hydrolyzed rapeseedslurry using multilevel factorial design

Sheshrao Kautkar[1*], Jai Prakash Pandey[2], Anupama Singh[2], Anil Kumar[2], Rehana Raj[3], Amit Kumar Patil[4], Manoj Kumar Mahawar[1], P Jagajanantha[1], Ashok Kumar Bharimalla[1] and Sanjay Kumar Singh[4]

[1]*ICAR-Central Institute for Research on Cotton Technology, Mumbai, Maharashtra, India*
[2]*G. B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India*
[3]*ICAR-Central Institute of Fisheries Technology, Cochin, Kerala, India*
[4]*ICAR-Indian Grassland and Fodder Research Institute, Jhansi, Uttar Pradesh, India*

ABSTRACT

Preferred technique of oil extraction such as mechanical expression has lower extraction efficiencies, it is labour-intensive, consumes higher energy and higher initial setup cost. Also, solvent extraction method uses flammable solvents, has higher initial equipment cost, high operating costs and high energy requirements. To address aforesaid issues the novel process for extraction of oil using ohmic heating was developed for the enhancement of oil yield from enzymatically hydrolyzed rapeseed slurry and the process parameters were optimized using multilevel general factorial design. Pectinase enzyme was used for enzymatic hydrolysis. The effect of ohmic heating parameters like voltage gradient (9-15 V/cm), endpoint temperature (70-100 ºC) and holding time (0-10 min) on oil yield, free fatty acids (FFA) and color of the extracted oil were investigated. The oil yield, FFA and color value varied from 63.69 to 89.54 %, 0.447 to 1.410 % and 49.08 to 61.67 respectively. The optimum conditions were obtained at 13.65 V/cm voltage gradient, 91.12˚C end point temperature and 10 min holding time which resulted in the oil yield of 86.22 %, 1.62 % FFA and color value of 59.89. The FFA of the extracted oil was below the acceptable limit prescribed by BIS and PFA standards.

Keywords: *Aqueous extraction, Ohmic heating, electrical conductivity, Free fatty acids, Oil extraction, Oil yield, Rapeseeds, Multivariate factorial design*

INTRODUCTION

Rapeseed (*Brassica rapa),* is the second major contributor in the world's oilseed economy among 40 different oilseeds whose oil can be consumed [20]. It contains 38-46% of oil and 20-30% of high-quality protein with some anti-nutritional compounds like phenols, glucosinolates and phytic acid [29].The oil obtained from rapeseeds is best known for its culinary fats. This oil exhibits a unique fatty acid distribution containing omega-3, omega-6 and omega-9 fatty acids and it is also a good source of tocopherols and phytosterols, the components that offer antioxidant and bioactivity for skincare purpose [7]. The edible oil extracted from rapeseeds is a rich source of unsaturated fatty acid with a low concentration of saturated fatty acid which makes it nutritionally better than other oil.

Mechanical extraction and solvent extraction are the preferred methods used for the extraction of rapeseeds oil. Mechanical extraction is used to extract oil from oilseeds containing more than 33 % oil [2]. It is based on the compression or pressing of oilseed materials at predetermined pressure after which the oil is separated from the oilseeds under the action of compressive external forces in the machines called mechanical press or expellers.

Corresponding Author: **Sheshrao Kautkar*

DOI: https://doi.org/10.21276/AATCCReview.2025.13.01.482

This method has lower extraction efficiencies, it is labor-intensive, consumes higher energy and higher initial setup cost. Solvent extraction is the preferred and commercially used method for extracting oil from the oilseeds containing less than 20% of oil [27]. It is a process of separating the liquid from a liquid-solid mixture with the use of a solvent like pentane, hexane, heptanes and octanes. The flammable nature of the solvents, higher initial equipment cost, high operating costs and high energy requirements are the major limitation of this method. Also, residual chemical solvents in extracted oil and cake are harmful to human health and the environment. Therefore, the development of cost and energy effective, eco-friendly novel method with higher oil yield is the need of the hour.

Enzyme assisted aqueous extraction (EAAE) process is an environmentally friendly method of simultaneously isolating protein and oil from oilseeds [28]. It involves the cooking of the oilseeds followed by the application of enzymes that digest the solid material and at the end, the separation of the residual enzymes and oil using centrifugation [17]. An enzyme softens and breaks the seed structure, increases the porosity of oilseeds and hence assists in the extraction of oil from the oilseeds. A lot of research has been done by several researchers on EAAE of oil from many oil-containing materials such as soybeans [22], and rapeseed [29]. However, the major drawback of this method is low oil recovery which is mainly due to the inadequacies of enzymatic pre-treatments in disintegrating the cellular structure of oilseeds [15].

Ohmic heating is being popularized as green technology in the field of food processing. It is known by various terms like Joule heating, electro conductive heating, and electro heating and electrical resistance heating [11; 9]. This novel thermal food processing method works on the principle of electrical heating by utilizing the inherent electrical resistance of food material such as liquid, liquid-particulates or pump able foods [14; 5]. Several studies revealed that Ohmic heating was successfully used to increase the soy milk from soybeans, juice extraction from potato and apple [19], sucrose from sugar beet [3] and oil from rice bran [10]. Based on the outcome of different investigations, it was hypothesized that, Ohmic heating when coupled with enzymatic hydrolysis could be a modern, cost-effective, environmentally friendly and energy-efficient approach enhancement of oil yield from rapeseed slurry. The main advantage of using Ohmic heating for oil extraction is its rapidity and uniformity in the heating process which could be useful in avoiding the losses of nutritional components of the oil [18; 16].Therefore, the present study aimed to develop and optimize a novel Ohmic heating process coupled with enzymatic hydrolysis for enhancement of oil yield from rapeseed slurry.

MATERIAL AND METHODS

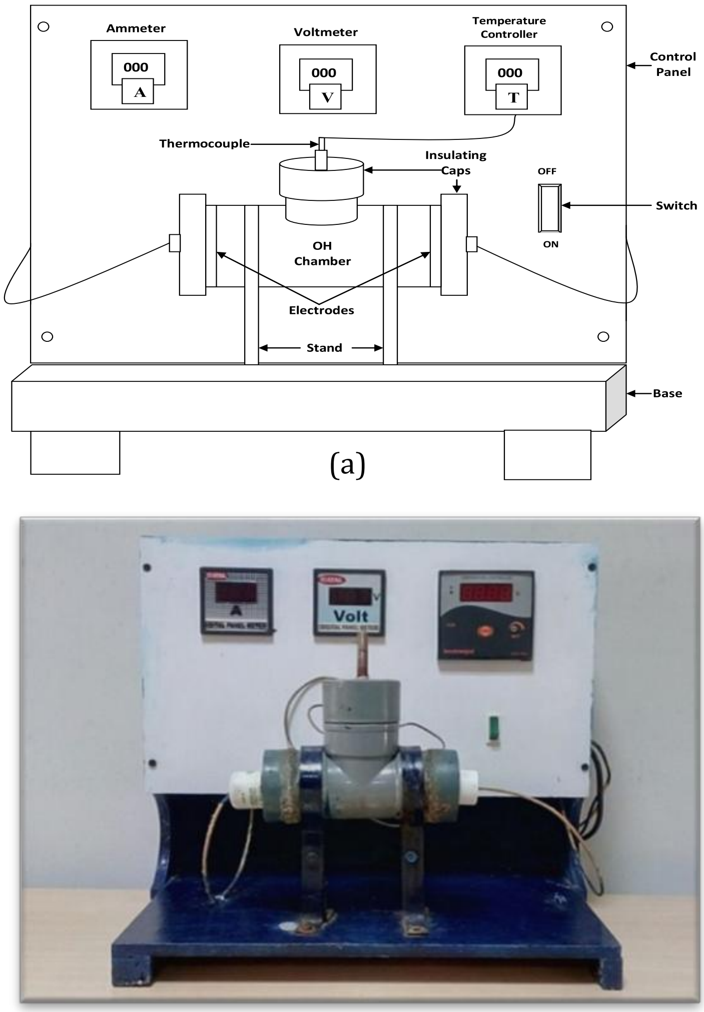
Sample preparation

Rapeseeds (Pant Pili Sarson-1) were procured from Crop Research Centre, G. B. Pant University of Agricultural Engineering and Technology, Pantnagar (Uttarakhand, India). The seed samples were thoroughly cleaned from all sorts of impurities and foreign material. The moisture content of the rapeseed sample was measured by the oven drying method at 105 °C [1] and was found to be 8.69 % (db.). The dried rapeseeds were ground in laboratory mixer-grinder and the ground sample was passed through an 80-mesh sieve to get rapeseed flour with particle size suitable for oil extraction [8]. The rapeseed flour sample was packed and sealed in airtight polythene bags and kept in the refrigerator until used to avoid rancidity and free fatty acid formation [12].Commercial pectinase enzyme (Macerozyme R-10) from *Aspergillus Niger* was procured from standard suppliers. The procured enzyme was stored at 4°C temperature in a refrigerated, so that to keep its enzymatic activity unchanged during the period of investigation [25].The total oil content of the sample was determined by solvent extraction method using the soxhlet apparatus. The initial oil yield obtained from rapeseeds was 42.06 g per100 g rapeseeds flour.

Development of Ohmic heating device

The conceptual diagram and experimental Ohmic heating device used for extraction of oil from enzymatically hydrolyzed rapeseed slurry is shown in Figure 1. The heating container/chamber of the device employed a T-shaped cylindrical geometry made up of PVC material of 16.8 cm in length, 8 cm in diameter and 0.2 cm in thickness. Two food-grade and electrochemically active stainless steel circular electrodes of 5.5 cm diameter and 0.1 cm thickness were fixed 14 cm apart at both the ends of the heating chamber. Both the electrodes were connected to the AC power supply of 50 Hz and 0-240 V through a control panel to deliver the required amount of voltage according to the experimental design. Three insulator caps made up of PVC material were provided at all the three ends of T-shaped geometry to make the Ohmic heating device electrically safe and to avoid heat loss during experiments. The control panel, with temperature controller (Range: 0-600 ºC), ammeter (Range: 0-60A), voltmeter (Range: 0-220V) and AC variance was fixed on 44 cm long, 12 cm wide and 11.5 cm tall wooden body to record and control the Ohmic heating parameters. A thermocouple was fixed in the geometric center of the Ohmic heating chamber to record the temperature of the rapeseed slurry.

Electrical conductivity which is the materials ability to transport or convey electric current through it, is the most important factor in Ohmic heating. It depends on the factors like ionic content, microstructure of food material, temperature and voltage [6; 17].The electrical conductivity was determined at experimental range of voltage gradients and temperatures using Microprocessor-304 digital conductivity meter and was found in the range of 46.6 mS/cm to 59.7mS/cm [4].



(a)

(b)

Fig 1. (a) Conceptual diagram and (b) Experimental Ohmic heating device.

Plan of experiment

Four levels of voltage gradient (9, 11, 13 and 15 V/cm), four levels of endpoint temperature (70, 80, 90 and 100 ºC) and three levels of holding time (0, 5 and 10 min.) were identified as independent variable whereas oil yield, FFA and color value were the responses selected for the study. The experiments were planned using a multilevel categoric (general factorial) design. Optimization of the identified Ohmic heating parameters was done for the enhancement of oil yield from enzymatically hydrolyzed rapeseed slurry.

Experimental procedure

The detailed process flow diagram of various unit operations involved in the experimental process is shown in Figure 2.

It consists of cleaning of rapeseeds, grinding, hull removal, heating the rapeseed slurry, treatment it with pectinase enzyme, incubation, heating comically at experimental conditions, aqueous extraction and separation of oil by centrifugation. Some preliminary experiments and data from a few previous studies helped to select the constant values of several influential parameters like sample size, rapeseed flour to water ratio, enzyme and its concentration, incubation temperature, time, pH, agitation rate and speed and time of centrifugation.

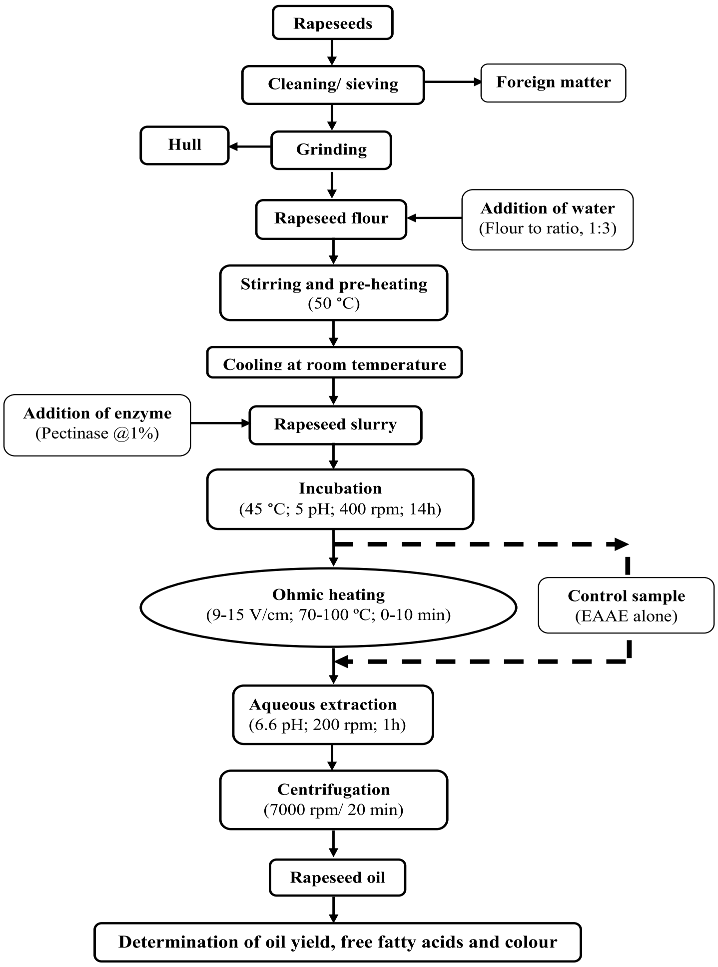


Fig 2.Processflow diagram of ohmic heating process for enhancement of oil yield from enzymatically hydrolyzed rapeseed slurry

Dependent variables

Oil yield

The amount of oil obtained from enzymatically treated rapeseeds was expressed in terms of percentage oil yield. It was determined by using Eq. (1).Percent increase in oil yield over enzyme assisted aqueous extraction (EAAE or control process) alone was calculated using Eq. (2).

$$\text{Oil yield (\%)} = \frac{\text{Amount of oil obtained after extraction (g)}}{\text{Initial amount of oil present in the sample (g)}} \times 100 \quad (1)$$

$$\text{\% increase in oil yield} = \frac{\text{\% oil yield by EAAE+ohmic heating} - \text{\% oil yield by EAAE alone}}{\text{\% oil yield by EAE alone}} \times 100 \quad (2)$$

Free fatty acids (FFA)

FFA is the indicative measure of the rancidity of oil as it normally generates during the decomposition of glycerides present in the oil. It was measured by dissolving 1 g of oil sample in 50 ml of hot neutralized ethanol and titrated with 0.1 N NaOH solution utilizing phenolphthalein indicator in a conical flask till the pink color was seen[1].The FFA as % oleic acid was determined using equation given below:

$$\text{FFA (\%)} = \frac{28.2 \times \text{Volume of NaOH (ml)} \times \text{Normality of NaOH}}{\text{Weight of the sample (g)}} \quad (3)$$

Color

The color of oil is one of the most important qualities for its acceptance. It is the consumer's criteria of selection, as a method of judging the quality of oil. The systronics 119 UV-Vis spectrophotometer was used to determine the absorbance of extracted oil samples. The samples were diluted ten times with carbon tetrachloride to make the absorbance of the oil samples in the working range of spectrophotometer. The readings of absorbance were noted down for the wavelengths of 430, 454, 484 and 670 nm at which peaks of absorbance was noticed and the color of oil was determined using Eq. (4) [24].

$$\text{Color} = 1.29\,(A_{430}) + 69.7\,(A_{454}) + 41.2\,(A_{484}) - 56.4\,(A_{670}) \quad (4)$$

Data analysis and process optimization

The statistical analysis of experimental data and process optimization were carried out through a multilevel general factorial design using Design expert 11.0 statistical software package [23]. The multiple regression analysis was carried out to investigate the individual and combined effect of experimental variables on dependent variables. The 3D surface plots were also drawn to picturize the effect of process variables on selected responses.

RESULTS AND DISCUSSION

Effect of process variables on responses

The effect of selected experimental variables on responses in terms of oil yield, FFA and color were determined and statistically analyzed as below.

Oil yield

The oil yield obtained from enzymatically hydrolyzed rapeseed slurry coupled with Ohmic heating ranged from 63.69 to 89.54 % over the entire range of experiments. However, it was found to be 60.12 to 68.24 % in the case of EAAE alone. Therefore, the percent increase in oil yield by EAAE in combination with Ohmic heating over EAAE alone varied from 5.94 to 31.21 %. The maximum oil yield (89.54 %) was observed when rapeseed slurry was ohmically heated at 90 ˚C using voltage gradient of 13 V/cm for 10 min of holding time.

A full second-order regression model was fitted for the oil yield of rapeseed slurry using multiple regression analysis (Table 1). The model was found highly significant at 1 % level of significance with a non-significant lack of fit. The R^2 (coefficient of determination) for the model of oil yield was 0.92 which means that the model can hold for 92% data. The CV (coefficient of variation) of 2.63 % also indicates minimum variability in data fitted in the model. Hence, the second-order model was accepted for predicting the effect of experimental variables on the oil yield of rapeseed slurry. The regression equation which represents an empirical relationship between oil yield and independent variables is shown below by Eq. (5).

Oil yield (%) =

$$79.69+4.82X_1+3.20X_2+4.28X_3+0.2308X_1X_2+1.22X_1X_3-0.1477X_2X_3-5.98X_1^2-2.32X_2^2-0.1806X_3^2 \quad (5)$$

The significance of process variables with their interaction in the second-order regression model can be seen from Table 1. It was found that, at a linear level, all the independent variables showed a highly significant effect on the oil yield at 1 % level of significance however the interactive effect of the product of voltage gradient and holding time showed significant ($p < 0.05$) effect on the oil yield.

It was also found that, the voltage gradient and end point temperature showed a highly significant ($p < 0.01$) effect on oil yield at the quadratic level.

Table 1: Regression coefficients and significance of each process variable on the responses

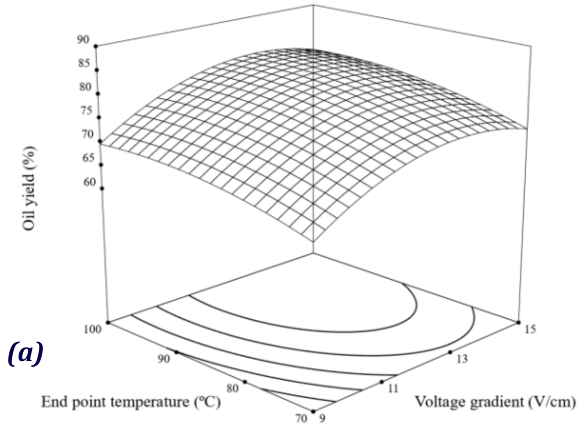
Source	Oil yield (%)		FFA (%)		Color	
	Coefficients	p-Value	Coefficients	p-Value	Coefficients	p-Value
Constant	79.69	< 0.0001**	0.6957	< 0.0001**	57.72	< 0.0001**
X_1	4.82	< 0.0001**	0.1969	< 0.0001**	1.66	< 0.0001**
X_2	3.20	< 0.0001**	0.1961	< 0.0001**	3.38	< 0.0001**
X_3	4.28	< 0.0001**	0.0152	0.2985	0.6759	< 0.0001**
$X_1 X_2$	0.2308	0.6549	0.0115	0.5896	0.6409	0.0058**
$X_1 X_3$	1.22	0.0127*	0.0158	0.4166	-0.0793	0.6942
$X_2 X_3$	-0.1477	0.7538	0.0015	0.9377	-0.0381	0.8502
X_1^2	-5.98	< 0.0001**	0.0691	0.0127*	-0.8161	0.0050**
X_2^2	-2.32	0.0009**	0.0853	0.0026**	-0.8095	0.0054**
X_3^2	-0.1806	0.7664	-0.0106	0.6730	-0.3528	0.1802
R^2	0.9278		0.8970		0.9386	
Adj-R^2	0.9107		0.8726		0.9240	
Pred-R^2	0.8774		0.8217		0.8962	
C.V. (%)	2.63		10.50		1.49	
F value	54.23		36.76		64.50	
LOF	NS		NS		NS	

NS = non-significant, ** & * =significant at 1% and 5% level of significance.

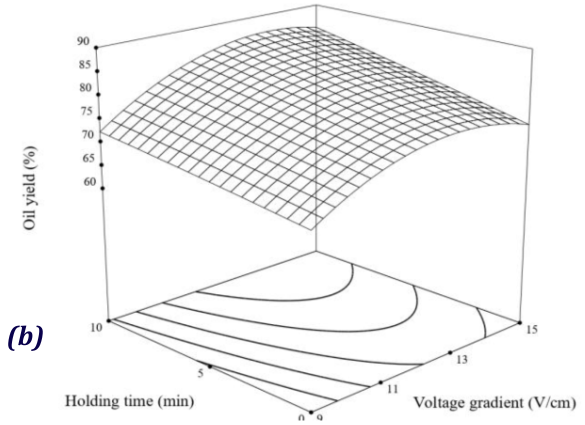
X1: Voltage gradient (V/cm), X2: End point temperature (°C) and X3: Holding time (min)

Although the oil yield was affected significantly by all three variables, yet the effect of voltage gradient and holding time was stronger than the end point temperature. The polynomial Eq. (6) given below is the modified second-order model of oil yield containing only significant terms of Eq. (5).

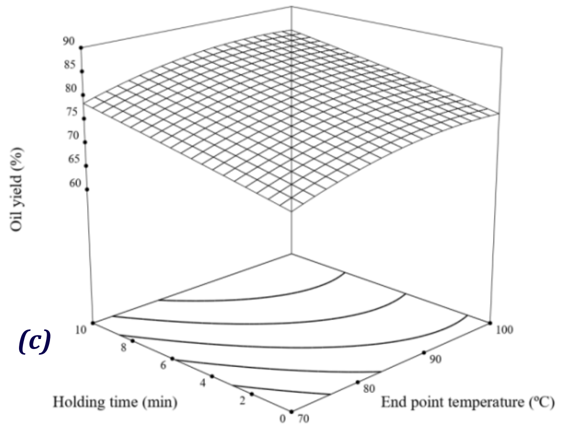
$$\text{Oil yield (\%)} = 79.69+4.82X_1+3.20X_2+4.28X_3+1.22X_1X_3-5.98X_1^2-2.32X_2^2 \quad (6)$$



(a)



(b)



(c)

Fig 3.Effect of Ohmic heating parameters on oil yield (a) voltage gradient and end point temperature, (b) voltage gradient and holding time (c) end point temperature and holding time.

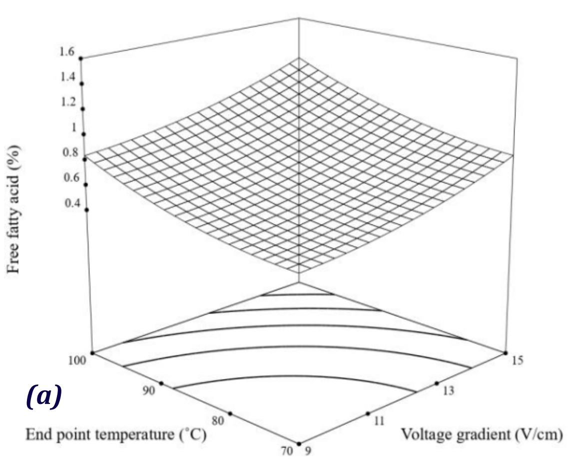
The 3D response surface plots in Figure 3 show the effect of studied variables on the oil yield of rapeseed slurry. The oil yield was found to increase with an increase in all three independent variables. The increased oil yield with voltage gradient might be because, increased voltage gradient results in the generation of electroporation (electro-permeabilization) phenomenon which induces the transmembrane potential utilizing an externally applied electric field strength causes an increase in rupture, conductivity and permeability of cell wall membrane. This leads to create certain aqueous pathways in the lipid layer for oil to ooze out. Thus, electro-permeabilization and thermal softening of the oil-bearing cells together explains the increased oil yield caused by applied voltage [13].However, the oil yield was found to decrease at a voltage gradient higher than 13 V/cm. It may be because at higher voltage gradient and temperature above some threshold, the cell breakage surpasses at the optimum limit which leads to opening the complete cell matrix to the aqueous phase of rapeseed slurry. This phenomenon of unwanted cellular rupture may decline the oil yield at higher levels of voltage gradients (13-15 V/cm). [26] Reported similar findings.

Free fatty acids (FFA)

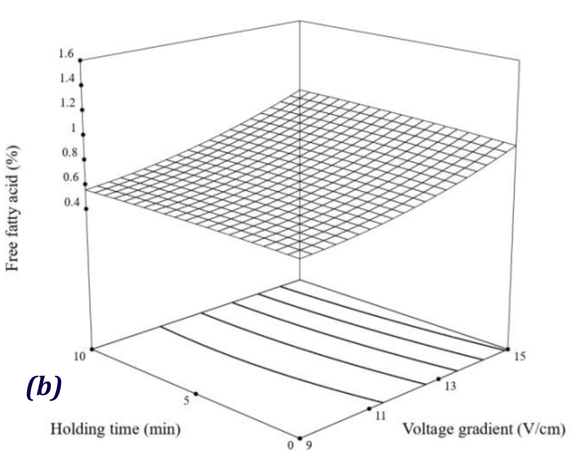
The FFA as % oleic acid of extracted rapeseed oil varied from 0.447 to 1.410. The FFA data was fitted into second-order regression model (Eq. 7) and the respective coefficients were obtained. The model was highly significant at 1 % level of significance (P<0.01). The R^2 of 0.89 also suggests the regression is significant and the model could account for 89.70% of data. Thus, the second-order empirical model was found to be satisfactory in describing the FFA of oil.

$$FFA\ (\%) = 0.6957+0.1969X_1+0.1961X_2+0.0152X_3+0.0115X_1X_2+0.0158X_1X_3+0.0015X_2X_3+0.0691X^2+0.0853X_2^2-0.0106X_3^2 \quad (7)$$

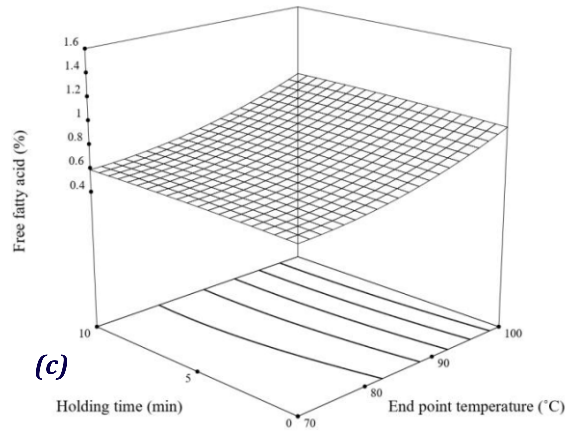
Table 1 shows the ANOVA of various studied variables on FFA. At the linear level of experimental variables, the voltage gradient and endpoint temperature had a highly significant effect at 1 % level of significance (P<0.01) whereas holding time was found to have a non-significant effect on FFA of rapeseed oil. At quadratic level, the effect of voltage gradient was significant (P<0.05) and that of endpoint temperature was highly significant (P<0.01) on FFA of rapeseed oil at 5% and 1% level of significance respectively. Considering the significance, the Eq. (7) is modified as Eq (8) that shows FFA content of rapeseed oil depends on voltage gradient and end point temperature.



(a)



(b)



(c)

Fig 4.Effect of Ohmic heating parameters on FFA(a) voltage gradient and end point temperature, (b) voltage gradient and holding time (c) end point temperature and holding time.

Figure 4 depicts the interactive 3D surface plot of process variables against FFA of extracted rapeseed oil. The FFA increased significantly with increasing voltage gradient and end point temperature. It might be due to the increased thermal effect. The increased temperature in combination with voltage gradient increased the hydrolysis of triglycerol[9],which leads to fatty acid chain degradation and free oleic acid compounds formation (i. e. FFA). Initially the holding time might have used for increasing the temperature of rapeseed slurry due to which the formation of the free fatty acid chain did not taken place hence FFA formation was slower during the beginning of the holding time. However, as soon as the temperature was increased with time, the fatty acid chain might have started breaking, causing a slight increase in FFA of oil.

Color

The color values obtained from the oil extracted by Ohmic heating in combination with enzymatically hydrolyzed rapeseed slurry ranged from 49.08 to 61.67. A full second-order model was fitted for color value data of rapeseed oil. The model was highly significant at a 1 % level of significance and its lack of fit was non-significant. The R^2 obtained for this regression was 0.93. The CV of 1.49% also confirms minimum variability in the data fitted in this model. Therefore, second-order regression model was found precise to dictate the color value of extracted rapeseed oil. The Equation is given bellow:

$$Color = 57.72+1.66X_1+3.38X_2+0.6759X_3+0.6409X_1X_2-0.0793X_1X_3-0.0381X_2X_3-0.8161X_1^2 0.8095X_2^2-0.3528X_3^2 \quad (9)$$

The ANOVA of color value data is presented in Table 1. The linear effect of all the process variables was highly significant (P<0.01) at a 1% level of significance on the color of rapeseed oil. At interactive levels, the combination of voltage gradient and end point temperature had a highly significant (P<0.01) effect on color. The quadratic effect of voltage gradient and end point temperature on the color of rapeseed oil was highly significant at a 1% level of significance. The simplified imperial model for the color of rapeseed oil considering only significant terms is given below:

$$Color = 57.72+1.66X_1+3.38X_2+0.6759X_3+0.6409X_1X_2-0.8161X_1^2-0.8095X_2^2 \quad (10)$$

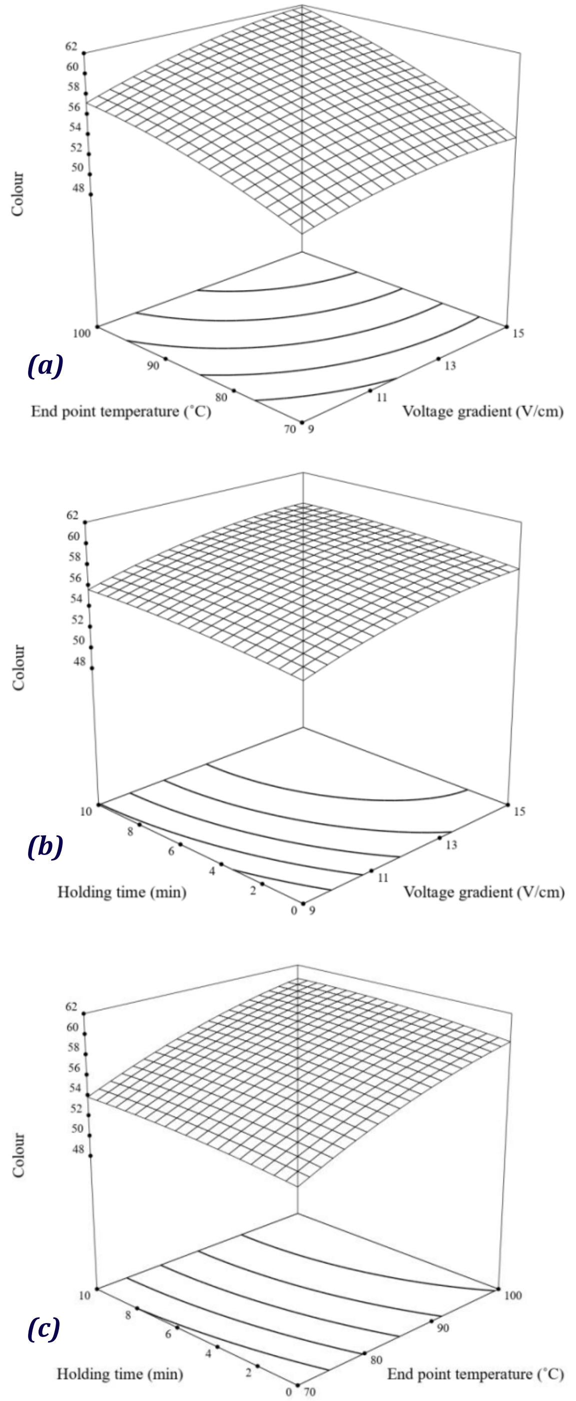


Fig 5.Effect of Ohmic heating parameters on the color of rapeseed oil (a) voltage gradient and end point temperature, (b) voltage gradient and holding time (c) end point temperature and holding time.

As shown in Figure 5 the darkness in the extracted oil was found to increase with voltage gradient and end point temperature. The darkness (higher color value) was also found to increase slightly from holding time of 0 min to 10 min. The effect of end point temperature on the color of extracted rapeseed oil was more than the other two parameters. The temperature plays a vital role in increasing the brownness and darkness by decreasing the greenness cum yellowness of the oil. This phenomenon of increased darkness may be due to disintegration of thermolabile components like phospholipids, carotenoids and chlorophylls at the higher temperatures. This disintegration of thermolabile components is accelerated with increased holding time and hence results in the rapid change in oil color. [19] Observed similar findings in extraction process of soybean oil.

Optimization of Ohmic heating parameters

This investigation aimed to get the optimized results of ohmic heating parameters (voltage gradient, end point temperature and holding time) to maximize the oil yield with keeping the FFA and color in range within the acceptable limit. Therefore, all the independent variables were set at "in range" criteria to get maximum oil yield. Based on the selected criteria, the numerical optimization was carried out in Design expert 11.0 statistical software [23].The goal-seeking was started at a random starting point and further preceded up and down the steepest slope for a maximum value of the selected response. The desirable solution was selected based on the acceptable desirability (0.861) with satisfied constraints in the optimization. The optimum values of Ohmic heating parameters were obtained at 13.65 V/cm voltage gradient, end point temperature 91.12˚C and holding time 10 min. At these conditions, the responses were 86.22% oil yield, 1.62 % FFA and a color value of 59.89.

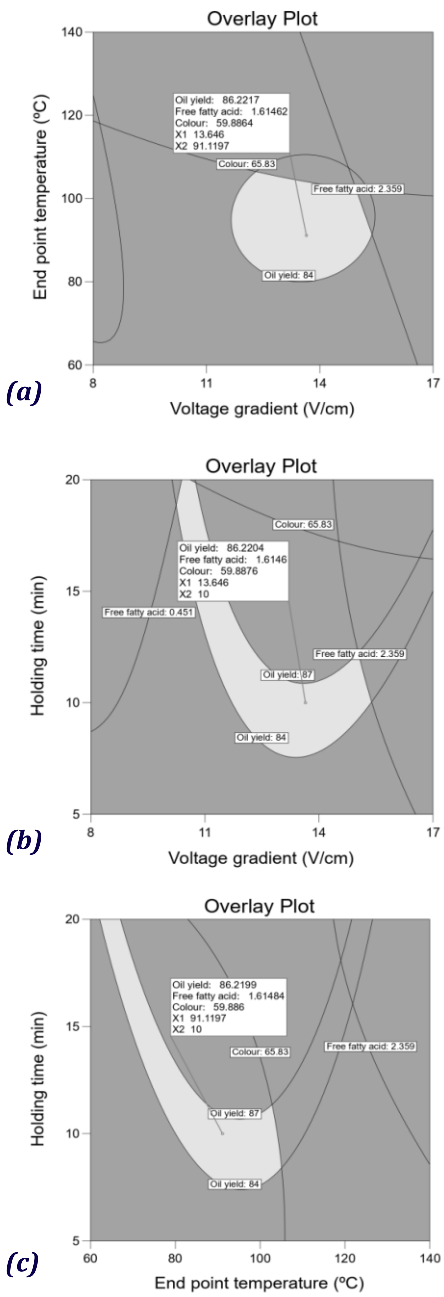


Fig 6. Super imposed overlay plots of (a) voltage gradient and end point temperature, (b) voltage gradient and holding time and (c) end point temperature and holding time.

The overlay contour plot for the selection of an optimum range of independent variables is illustrated in Figure 6. It represents the graphical optimization of independent variables in the form of range selection instead of selecting a single optimal solution [21].It highlights the area of acceptable response values. The silver color area on the plot shows where the entire range of all intervals meets the specified criteria. The optimized values of independent variables reported in the flagged areas of overlay plot are equal to the values obtained in the numerical optimization.

CONCLUSIONS

The novel method of oil extraction was developed and process parameters were optimized using Ohmic heating coupled with enzyme assisted aqueous oil extraction by taking voltage gradient, end point temperature and holding time as independent variables. The responses were oil yield, FFA and color of the extracted oil. Oil yield using the process of Ohmic heating in combination with EAAE ranged from 63.69 to 89.54 % whereas, it was 60.12 to 68.24 % in case of EAAE alone. Hence, increase in percentage of oil yield through ohmic heating coupled with enzymatic hydrolysis ranged from 5.94 to 31.21 % over the control treatment. The optimum combination of ohmic heating parameters was obtained at 13.65 V/cm voltage gradient, endpoint temperature 91.12˚C and holding time 10 min. At optimum conditions, the values of the responses were 86.22% oil yield, 1.62 % FFA and a color of 59.89. The FFA of the extracted rapeseed oil was below the acceptable limit of 0.5-3% and 3 % prescribed by BIS and PFA standards respectively. The combination of voltage gradient and high temperature for longer exposure time enhanced the oil yield due to electro-permeabilization effect with thermal softening of cellular tissues. Therefore, the results of this study indicate that the application of ohmic heating coupled with EAAE process is a effective alternative for the industrial extraction of oil from oilseeds. However, future scope involves large scale trials for recommendation of the reported technology to be used for industrial applications.

CONFLICT OF INTEREST

The authors declare that they have no known conflicts of interest that could have influenced the work reported in this paper.

ACKNOWLEDGMENTS

We gratefully acknowledge the University Grants Commission for the financial support provided to this research through Rajiv Gandhi National Fellowship.

REFERENCES

1. Cunniff P, AOAC International (1997) Official methods of analysis of AOAC International. Gaithersburg, Md: AOAC International.

2. Kalia VC, Rashmi, Lal S, Gupta MN (19

3. 01) Using enzymes for oil recovery from edible seeds. J SciInd Res 60:298-310. http://hdl.handle.net/123456789/26476.

4. Katrokha I, Matvienko A, Vorona L, Kupchik M, Zaets V (1984) Intensification of sugar extraction from sweet sugar beet cossettes in an electric field. Sakharnaya Promyshlennost7:28-31.

5. Kautkar S, Pandey RK, Richa R, Kothakota A (2015) Temperature dependent electrical conductivities of ginger paste during ohmic heating, Int J Agric Environ Biotechnol 8(1):21-27. https://doi.org/10.5958/2230-732X.2015.00003.0.

6. Kautkar, S, Pandey, JP (2018) An Elementary Review on Principles and Applications of Modern Non-Conventional Food Processing Technologies. Int. J. Curr. Microbiol. App. Sci, 7(5), 838-849.

7. Kautkar, S, Pandey, JP, Singh, A, Kumar, A, & Shukla, AK (2018) Effect of temperature and voltage gradient on electrical conductivity of rapeseed slurry during ohmic heating. Int. J. Chem. Stud., 6(6), 371-375.

8. Khansili N, Rattu G (2017) A comparative study of hidden characteristics of canola and mustard oil. Int J Chem Stud 5(3):632-635. http://www.chemijournal.com.

9. Latif S, Diosady LL, Anwar F (2008) Enzyme-assisted aqueous extraction of oil and protein from canola (Brassica napus L.) seeds. Eur J Lipid Sci Tech 110(10):887-892. https://doi.org/10.1002/ejlt.200700319.

10. Momeny E, Rahmati S, Ramli N (2012) Effect of microwave pretreatment on the oil yield of mango seeds for the synthesis of a cocoa butter substitute. J Food Process Technol 3(7):1-7. https://doi.org/10.4172/2157-7110.1000164.

11. Nair GR, Divya VR, Prasannan L, Habeeba V, Prince MV, Raghavan GSV (2014) Ohmic heating as a pre-treatment in solvent extraction of rice bran. J Food SciTechnol51(10): 2692-2698.10.1007/s13197-012-0764-2https://doi.org/.

12. Palaniappan S, Sastry SK (1991) Electrical conductivities of selected foods during ohmic heating. J Food Process Eng14:221–236. https://doi.org/10.1111/j.1745-4530.1991.tb00093.x.

13. Pare A, Nema A, Singh VK, Mandhyan BL (2012) Combined effect of ohmic heating and enzyme assisted aqueous extraction process on soy oil recovery. J Food SciTechnol 51(8):1606–1611. https://doi.org/10.1007/s13197-012-0685-0.

14. Praporscic I. Lebovka NI, Ghnimi S, Vorobiev E (2006) Ohmically heated, enhanced expression of juice from apple and potato tissues. BiosystEng93(2):199-204. https://doi.org/10.1016/j.biosystemseng.2005.11.002.

15. Qihua T, Jindal VK, Winden J (1993) Design and performance evaluation of an ohmic heating unit for liquid foods. Comput Electron Agric 9(3):243-253. https://doi.org/10.1016/0168-1699(93)90042-Y.

16. Rosenthal A, Pyle DL, Niranjan K (1998) Simultaneous aqueous extraction of oil and protein from soybean: mechanisms for process design. Food Bioprod Process 76(4):224-230. https://doi.org/10.1205/096030898532124.

17. Sakharam, K. S., Pandey, J. P., Singh, A., Kumar, A., & Shukla, A. K. (2016). Development of ohmic heating apparatus for extraction of rapeseed oil. International Journal for Innovative Research in Science & Technology, 2, 211-215.

18. Sari P (2006) Preliminary design and construction of a prototype canola seed oil extraction machine. (Unpublished Ph.D. Thesis) Ankara, Turkey: Middle East Technical University.

19. Sarkis JR, Mercali GD, Tessaro IC, Marczak LDF (2013) Evaluation of key parameters during construction and operation of an ohmic heating apparatus. Innov Food SciEmergTechnol18:145-154. https://doi.org/10.1016/j.ifset.2013.02.001.

20. Seth S, Agrawal YC, Ghosh PK, Jayas DS (2010) Effect of moisture content on the quality of soybean oil and meal extracted by isopropyl alcohol and hexane, Food BioprocTechnol3(1):121-127. https://doi.org/10.1007/s11947-008-0058-x.

21. Sharma M, Gupta SK, Mondal AK (2012) Production and trade of major world oil crops. In Technological Innovations in Major World Oil Crops, Volume 1 (pp. 1-15). Springer, New York, NY. https://doi.org/10.1007/978-1-4614-0356-2_1.

22. Singh KP, Poddar RR, Agrawal KN, Hota S, Singh MK (2015) Development and evaluation of multi millet thresher. J Appl Nat Sci 7(2):939-948. https://doi.org/10.31018/jans.v7i2.711.

23. Smith DD, Agrawal YC, Sarkar BC, Singh BPN (1993) Enzymatic hydrolysis pretreatment for mechanical-expelling of soybean. J Am Oil ChemSoc 70(9):885-890. https://doi.org/10.1007/BF02545348.

24. Stat-Ease I (2005) Design-expert. Minneapolis, MN, USA. Vol. 7(0), 2005.

25. Sutherland JW, Ghaly TF (1982) Heated air drying of oilseeds. J Stored Prod Res 18(2):43–54. https://doi.org/10.1016/0022-474X(82)90002-9.

26. Tabtabaei S Diosady LL (2013) Aqueous and enzymatic extraction processes for the production of food-grade proteins and industrial oil from dehulled yellow mustard flour. Food Res Int 52:547–556. https://doi.org/10.1016/j.foodres.2013.03.005.

27. Terigar BG, Balasubramanian S, Sabliov CM, Lima M, Boldor D (2011) Soybean and rice bran oil extraction in a continuous microwave system: Fromlaboratory-to pilot-scale. J Food Eng104(2):208-217. https://doi.org/10.1016/j.jfoodeng.2010.12.012.

28. Uquiche E, Jerez M, Ortiz J (2008) Effect of pretreatment with microwaves on mechanical extraction yield and quality of vegetable oil from Chilean hazelnuts. Innov Food SciEmergTechnol 9(4):495-500. https://doi.org/10.1016/j.ifset.2008.05.004.

29. Yusoff MM, Gordon MH, Niranjan K (2015) Aqueous enzyme assisted oil extraction from oilseeds and emulsion de-emulsifying methods: A review. Trends Food SciTechnol 41(1):60–82. https://doi.org/10.1016/j.tifs.2014.09.003.

30. Zhang SB, Wang Z, Xu SY (2007) Optimization of the aqueous enzymatic extraction of rapeseedoil and protein hydrolysates, J Am Oil Chem 84(1):97–105. https://doi.org/10.1007/s11746-006-1004-6.

