OPTIMIZATION OF INPUT FACTOR LEVELS FOR PROCESSING BULK HEMP SEEDS UNDER LINEAR PRESSING

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Abstract
The study optimized the input processing factor levels for extracting hempseeds oil under linear pressing using a vessel diameter of 60 mm with a plunger under a pressing speed of 5 mm/min and load of 300 kN. The Box Behnken design of experiment (BBD) of the input processing factors at three levels each were the heating temperature: 40, 50 and 60 °C, the heating time: 30, 45 and 60 min and pressing height: 60, 80 and 100 mm. The BBD generated 17 experimental runs involving 12 factors-combinations and 5 replications at centre values. The output responses were the mass of oil, oil yield, oil expression efficiency and deformation energy. The response surface methodology (RSM) statistical technique was used to evaluate the input factors and the output parameters from the BBD. The determined optimal input processing factors were the heating temperature of 60 °C, heating time of 52.5 min and sample pressing height of 60 mm.

Keywords: *Compression process; Box-Behnken design; response surface regression; oil output parameters, energy demand*

INTRODUCTION

The complex nature of processing factors and the susceptibility of bioactive substances to pretreatment techniques provide significant barriers to the optimization of oil extraction from hempseeds. The large amount of unsaturated fatty acids, antioxidants, and other bioactive substances in hempseed oil makes it valuable for both industrial and health purposes (*Doneva et al., 2024; Stamenković, Kostic, Radosavljevic & Veljkovic, 2018*). However, cold-pressing processes are safer, they produce less than ideal amounts of oil, and solvent-based extraction methods, for example, are toxic to the environment and may cause environmental problems (*Baldino et al., 2022*). Hempseed oil is very susceptible to oxidative deterioration, thus precise processing conditions are necessary to preserve quality and prolong shelf life (*; Stamenković, Kostic, Radosavljevic & Veljkovic, 2018*). Enhancing oil production while maintaining the oil's nutritional and functional integrity requires the development of precise, optimum processing methods, such as the use of pretreatment methods. Recently, the response surface approach has been used to optimize oil production and quality by adjusting variables including temperature, time, and compressive forces (*Baldino et al., 2022; Demirel et al., 2022*). The study investigates the optimal effect of input factors combinations of heating temperature, heating time and sample pressing height on oil output parameters and energy demand of bulk hempseeds under linear pressing involving a pressing vessel with a plunger.

MATERIALS AND METHODS

Samples of bulk hemp oilseeds were used for the study. The samples were purchased from Stredi, Prague, Czech Republic. The samples were kept under laboratory conditions before the experiments. The sample moisture content was determined to be 7.49 ± 0.08 (% w.b.) according to *Blahovec (2008)* as described in equation (1).

$$MC = \left[\left(\frac{m_b - m_a}{m_b}\right) \cdot 100\right] \quad (1)$$

where MC is the percentage of moisture content of sample (% w.b.), m_a and m_b are the masses of the sample before and after oven drying (g). The sample percentage oil content of 32.84 ± 0.70 % was determined according to the Soxhlet extraction procedure (*Danlami, Arsad & Zain, 2015; Niu, Chen & Xu, 2014*). The input processing factors (heating temperature, heating time and pressing height) at three levels each were designed using STATISTICA 13 software (*Statsoft 2013*) by employing the Box-Behnken experimental design (BBD) (*Chanioti & Tzia 2017*). The heating temperature values were 40,

50 and 60 °C, the heating time values were 30, 45 and 60 min and the pressing height values were 60, 80 and 100 mm. The BBD design generated 17 experiments comprising twelve combinations of input factors and five replications at the center points (Tab. 1). The input factor levels were coded from –1 (low value) to +1 (high value) with 0 being the center value according to equation (2) (*Ocholi, Menkiti, Auta & Ezemagu, 2018*).

$$x_i = \frac{X_i - X_0}{\Delta X} \tag{2}$$

where x_i is the coded value of the i^{th} variable, X_i is the uncoded value of the i^{th} test variable, X_0 is the uncoded value of the i^{th} test variable at the center point and ΔX is the step change in the real value of the variable *i* corresponding to the variation in a unit for the dimensionless value of the variable *i*.

Tab. 1 Box-Behnken experimental design with twelve combinations and five replications.

	Input processing factors at three levels			Coded values using Eq. (2)		
Run	H_{TP} (° C)	H_{TM} (min)	P_{HT} (mm)	H_{TP} (° C)	H_{TM} (min)	P_{HT} (mm)
1	40	30	80	-1	-1	0
2	60	30	80	1	-1	0
3	40	60	80	-1	1	0
4	60	60	80	1	1	0
5	40	45	60	-1	0	-1
6	60	45	60	1	0	-1
7	40	45	100	-1	0	1
8	60	45	100	1	0	1
9	50	30	60	0	-1	-1
10	50	60	60	0	1	-1
11	50	30	100	0	-1	1
12	50	60	100	0	1	1
13	50	45	80	0	0	0
14	50	45	80	0	0	0
15	50	45	80	0	0	0
16	50	45	80	0	0	0
17	50	45	80	0	0	0

H_{TP}: Heating temperature; H_{TM}: Heating time and P_{HT}: Initial pressing height of sample

The samples of bulk hemp seeds were preheated according to the design presented in Tab. 1 using the standard oven equipment (MEMMERT GmbH + Co. KG, Buechenbach, Germany). The universal compression testing machine (ZDM 50, Czech Republic) of a maximum load of 500 kN was used together with a pressing vessel of diameter 60 mm with a plunger (Fig. 1a). Based on a preliminary test of the sample's hardness after the test (Fig. 1b) the input force for all tests conducted was set at 300 kN at a pressing speed of 5 mm/min. The extracted hemp seed oil is shown in Fig. 1c.

Fig. 1 (a) Compression test of bulk hempseeds sample (b) sample after test and (c) extracted hempseed oil for all tests conducted.

The oil yield was determined according to *Chanioti & Tzia, (2017)* as given in equation (3).

$$O_{YD} = \left[\left(\frac{M_{OL}}{M_{SP}}\right) \cdot 100\right] \quad (3)$$

where O_{YD} is the oil yield (%), M_{OL} is the mass of oil determined as the difference of the mass of the seedcake and the initial mass of the sample M_{SP} (g). The oil expression efficiency was determined according to *Hernandez-Santos et al., (2016)* as given in equation (4).

$$O_{EF} = \left[\left(\frac{O_{YD}}{O_{CT}}\right) \cdot 100\right] \quad (4)$$

where O_{EF} is the oil expression efficiency (%) and O_{CT} is the percentage of oil content (%) in the seeds sample determined by soxhlet extraction. The deformation energy was determined according to *Herak et al., (2015)* as given in equation (5).

$$E_{NG} = \sum_{n=0}^{n=i-1} \left[\left(\frac{F_{n+1} + F_n}{2}\right) \cdot (x_{n+1} - x_n)\right] \quad (5)$$

where E_{NG} is the deformation energy (J), $F_{n+1} + F_n$ and $x_{n+1} - x_n$are the compressive force (kN) and deformation (mm), n is the number of data points and i is the number of sections in which the axis deformation was divided. The experimental data obtained were statistically analyzed at a 0.05 significance level by employing descriptive statistics and response surface regression technique using STATISTICA 13 software (*Statsoft 2013*).

RESULTS AND DISCUSSION

The determined output parameters from the BBD experimental runs with the input processing factors combinations are presented in Tab. 2. The mass of oil values ranged from 20.53 to 34.75 g. The oil yield values ranged from 15.94 to 22.09 %. The oil expression efficiency values ranged from 48.55 to 68.39 % whereas the energy efficiency values ranged from 722.55 to 1179.6 J. The factors combinations (runs 8, 11, 7 and 12) generated higher output mass of oil (34.75, 32.26, 31.88 and 31.25 g) in that order of magnitude. However, run 8 (heating temperature: 60 °C; heating time 45 min and sample height of 100 mm) produced the highest magnitude of 34.75 g. Their corresponding energies were 1179.6, 1051.14, 1143.53 and 1092.21 Joules (J). To understand the BBD experimental runs (Tabs. 1 & 2) with the force-deformation curves (Figs. 2a–2d), it is important to highlight that the force-deformation curves for runs 1 to 4 and runs 13 to 17 were obtained at a constant pressing height of 80 mm with varying input factors (heating temperature and heating time). Runs 5, 6, 9 and 10 were obtained at a constant pressing height of 60 mm with varying input factors (heating temperature and heating time). Runs 7, 8, 11 and 12 were obtained at a constant pressing height of 100 mm with varying input factors (heating temperature and heating time). Runs 13 to 17 were five replications at the center values of the input factors (50 °C, 45 min and 80 mm). Generally, it was observed that the factor combinations under the pretreatment conditions caused an increment in the force-deformation curves and the calculated parameters. The area under the force-deformation curve is the deformation energy. Preceding the maximum oil output is the serration effect characterized by the ejection of seedcake through the pressing holes because of high pressure among other factors such as moisture content, pressing speed, vessel diameter and quality of raw material (*Gupta & Das, 2000; Divisova et al., 2014; Kabutey et al., 2015*). This phenomenon usually leads to the vibration of the compression machine thereby limiting the percentage recovery of the oil production. Based on the predicted and desirability profile of the oil expression efficiency (Fig. 3), the determined optimal input processing factors were the heating temperature of 60 °C, heating time of 52.5 min and 60 min and sample pressing height of 60 mm and 100 mm with a desirability value of 1 for processing maximum oil from bulk hempseeds under linear pressing process. Similar profiles with the optimal values were obtained for the mass of oil and oil yield which are interrelated. For the energy profile, the higher levels of the input processing factors increased the energy demand. The predicted values of the mass of oil, oil yield and energy demand are stated in the conclusion.

Tab. 2 Determined amounts of oil output and energy of bulk hempseeds from the BBD.

Run	Input factors (Predictors)			Calculated parameters (Responses)			
	H_{TP} (° C)	H_{TM} (min)	P_{HT} (mm)	M_{OL} (g)	O_{YD} (%)	O_{EE} (%)	E_{NG} (J)
1	-1	-1	0	20.53	15.94	48.55	920.94
2	1	-1	0	26.46	20.55	62.57	934.74
3	-1	1	0	25.26	19.62	59.73	829.49
4	1	1	0	27.72	21.53	65.55	972.28
5	-1	0	-1	20.87	21.15	64.40	811.15
6	1	0	-1	21.8	22.09	67.27	818.03
7	-1	0	1	31.88	19.62	59.74	1143.53
8	1	0	1	34.75	21.39	65.12	1179.6
9	0	-1	-1	20.96	21.24	64.68	778.24
10	0	1	-1	21.37	21.66	65.94	722.55
11	0	-1	1	32.26	19.85	60.45	1051.14
12	0	1	1	31.25	19.23	58.56	1092.21
13	0	0	0	25.33	19.67	59.90	1009.92
14	0	0	0	25.15	19.53	59.47	876.28
15	0	0	0	26.89	20.88	63.59	909.25
16	0	0	0	24.73	19.20	58.48	886.91
17	0	0	0	28.92	22.46	68.39	886.46

H_{TP}: Heating temperature; H_{TM}: Heating time; P_{HT}: Initial pressing height of sample; M_{OL}: Mass of oil extracted; O_{YD}: Percentage oil yield; O_{EE}: Percentage oil expression efficiency and E_{NG}: Deformation energy.

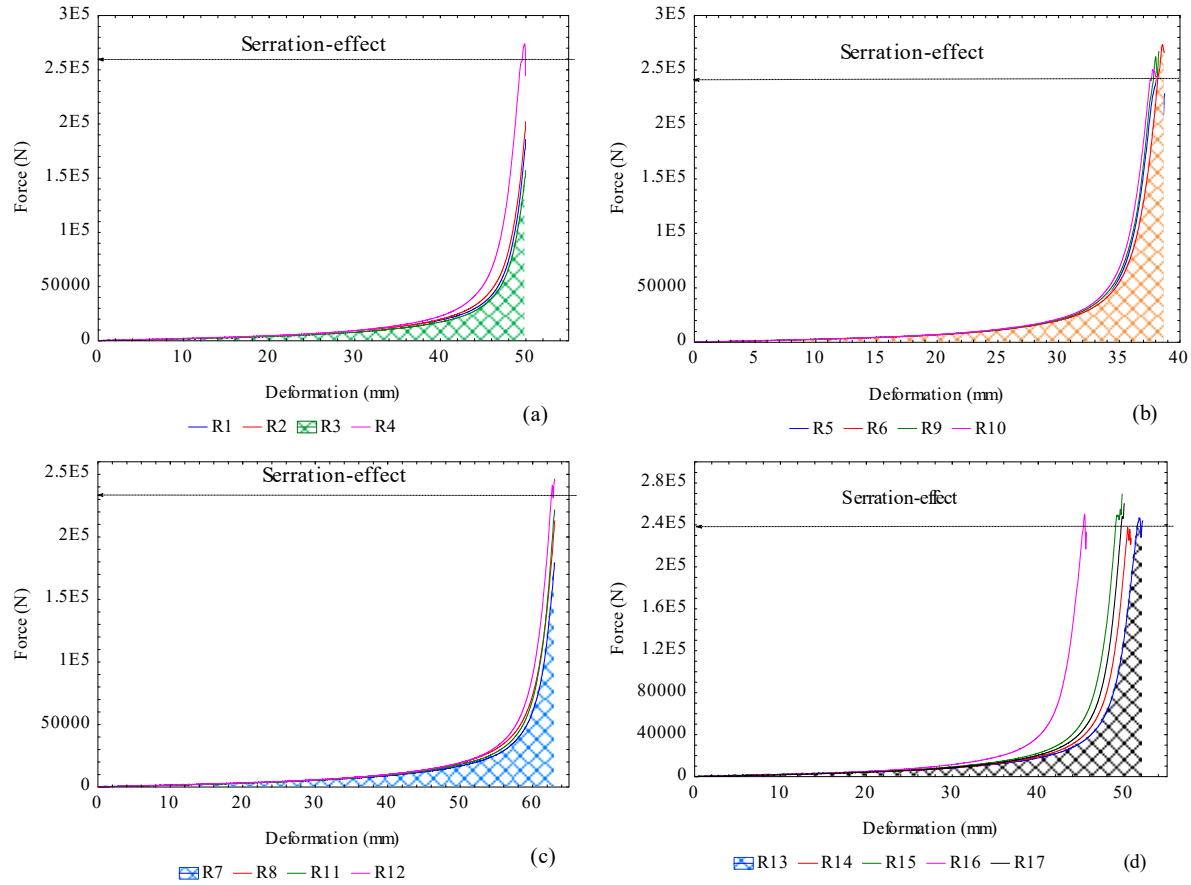

Fig. 2 Force-deformation curves of bulk hemp seeds at constant pressing height, H (a) 80 mm (b) 60 mm (c) 100 mm and (d) 80 mm at centre factor levels. Tthe area under the curve represents the deformation energy.

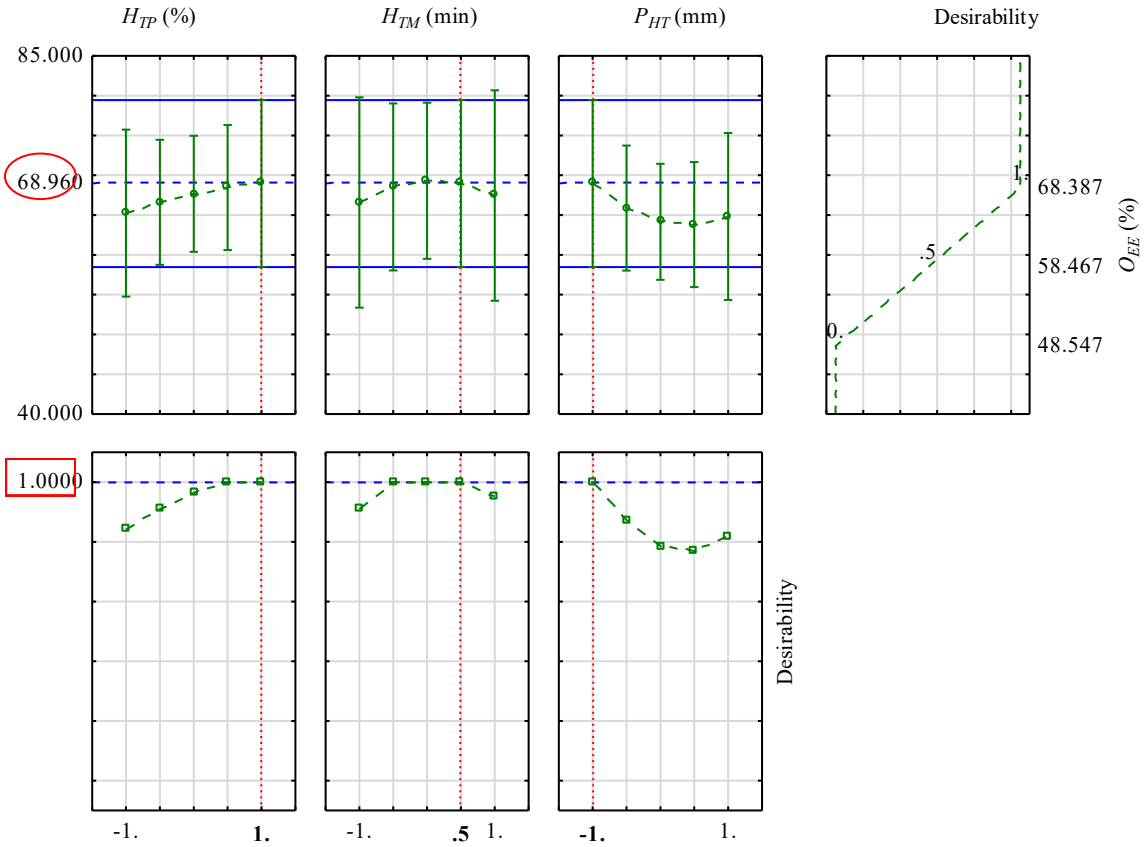

Fig. 3 Profile of predicted values and desirability of oil expression efficiency, O_{EE}. H_{TP}: Heating temperature (+1: optimal level of 60 °C); H_{TM}: Heating time (0.5: optimal level of 52.5 min) and P_{HT}: Initial pressing height of sample (-1: optimal level of 60 mm).

CONCLUSIONS

The maximum compressive force of 273.34 kN was obtained at the combinations of the factors (heating temperature of 60 °C, heating time of 45 min and pressing height of 60 mm) without the serration-effect pattern or the seedcake ejection process. The mass of the oil profile predicted an amount of 34.976 g with optimal processing input factors (heating temperature: 60 °C (+1), heating time: 45 min (0) and sample pressing height: 100 mm (+1)). The oil yield profile predicted an amount of 22.647 % with optimal processing input factors (heating temperature: 60 °C (+1), heating time: 52.5 min (0.5) and sample pressing height: 60 mm (-1)). The oil expression efficiency predicted profile achieved an amount of 68.96 (%) with the optimal processing input factors of heating temperature: 60 °C (+1), heating time: 52.5 min (0.5) and sample pressing height: 60 mm (-1). The energy profile predicted an amount of 1197 (J)) with optimal processing input factors (heating temperature: 60 °C (+1), heating time: 60 min (+1) and sample pressing height: 100 mm (+1)). These factors combinations achieved a desirability value of 1 indicating a high reliability for predicting the oil output parameters (mass of oil, oil yield and oil expression efficiency) and energy of bulk hemp seeds under a linear compression process.

ACKNOWLEDGMENT

The study was supported financially by the Internal Grant Agency of the Czech University of Life Sciences Prague (IGA Project Number – 2024:31130/1312/3108).

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