Agronomy Research **16**(3), 634–645, 2018
https://doi.org/10.15159/AR.18.145

Optimising cold compressive recovery of oil from the seeds of Sesame (*Sesamum indicum* L.)

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Abstract. Effects of the time rate of deformation and aspect ratio on mechanical response and performance in single cycle cold compression scheme were investigated for bulk sesame seeds and response forms fitted using forward stepwise multiple regression technique. The degree of deformation was dependent on the time rate of its induction and the equipment's aspect ratio. Energy requirement correlated positively with deformation rate and aspect ratio. Energy expenditure was however more efficient with larger aspect ratios than with smaller ones, given the associated volume energy demands. Strain resistance correlated positively with each of the two influence factors. The time rate of deformation was the most important predictor of oil yield and performance. All the fitted forms had highly significant effects in predicting the responses investigated with 76.7–99.6% of the behaviours of the system explained. The results are valid within the ranges of the influence parameters investigated.

Key words: oilseed, cold pressing, compressive stress, strain, energy.

INTRODUCTION

Abstracting oil from bulk volumes of oilseeds using cold compressive means is particularly dependent on the extent and effectiveness of the deformation of the material matrix that is achievable under the physical, machine and process conditions obtaining during expression. Cold oils are arguably the best quality edible vegetable oils available (Wroniak et al., 2008; Prescha et al., 2014) and the process for obtaining them is well specified to preclude techniques such as physico-chemical or thermo-mechanical treatments capable of altering the natural oil or its quality (Siger et al., 2008; FAO/WHO, 2015). Cold expression is only guaranteed using pure mechanical means (FAO/WHO, 2015). Selecting proper crop, machine and process parameters is the main perceptible route for optimising the yield and performance of the scheme. Existing studies on cold compressive expression detail process limiting parameters to include limit deformation, understood chiefly as attainable via loss of void capacity (Faborode & Favier, 1996; Raji & Favier, 2004). These are all however reported in relation to single cycle compressions and treatment considerations for optimisation were concentrated within physical, chemical and thermo-mechanical domains (Willems et al., 2008; Wiacek et al., 2012;

Lazouk et al., 2015). Multiple cycle compression schemes have been proposed which offer promise of significant improvements in the efficiency of cold compression schemes (Akangbe & Herák, 2018). An alternative approach however is to maximise the yield of single cycle systems through proper understanding of the process. Geometrical parameters have been shown to influence the performances of compression schemes (Owolarafe et al., 2007; Wiacek et al., 2012; Divišová et al., 2014). A generalisable rendition of some of these parameters such as the depth of the product charge to the characteristic dimension of the compression chamber as some aspect ratio (Tumuluru, 2015) is therefore a fitting treatment of the presenting constraints by which the behaviour of the system may be better understood and which will serve to characterise hydraulic compression machines. Deformation in biological materials translates into strain. Productive deformation is that which accomplishes an intended outcome. Many studies appear to present results on observable strain during compressive expression of oil from oilseeds (Faborode & Favier, 1996). However, only very little mention or reference to the rate of induction of such strains may be found in literature (Bargale et al., 2000; Santoso & Inggrid, 2014). One major determinant of the rate of strain is the time rate of induction of deformation, perceivable through the linear approach velocity of the plunger head.

Sesame is an important food crop and an emerging oilseed (Tunde-Akintunde & Akintunde, 2004). In this study, the effects of a geometrical characteristic crop and machine parameter, namely the aspect ratio and the time rate of induction of deformation were investigated and response surfaces modelled using forward stepwise regression technique with a view to optimising the yield and performance of a cold compression scheme.

MATERIALS AND METHODS

Material

The oilseed material used was a batch of whole and cleaned seeds of sesame (*Sesamum indicum* L.) obtained from Czech Republic. The moisture content of the batch of oilseeds used was 6.04 ± 0.66%, in dry basis.

Test procedure, Instrumentation and Design of Experiment

The apparatus used is described in an earlier study (Akangbe & Herák, 2017a). In this study, the internal diameter of the pressing vessel was 60 mm. The base plate was 20 mm thick and oil was discharged laterally through 10 orifices (ϕ 3 mm) equispaced along the circumference of the pressing vessel, and just above the top face of the base plate. For each test, a sample of sesame seeds was fed to a depth in the pressing chamber corresponding to an aspect ratio. The pressing rate was then set and compression induced gradually from zero (0) to a full load corresponding to 26.53 MPa. The load source was a 50 tonne capacity Tempos® model universal test rig – the ZDM50 (TEMPOS, spol. s.r.o., Czech Republic) – operated using the TIRAtest software (TIRA GmbH, Germany). Subsequently, the setup was unloaded and ancillary data acquired. Crop moisture content was determined using oven drying method in accordance with ASAE standards S352.2 for moisture determination in unground grains and seeds. A Gallenkamp type hot air oven (Memmert GmbH, Germany) was used. Temperatures were maintained at 103 ± 2 °C for this purpose. All weight measurements were obtained using the Kern 440–35N (Kern & Sohn GmbH, Stuttgart, Germany) top loading type balance. Pressure applied at the oil point was measured using an auxiliary device with digital output mounted adjacent to the pressing vessel during the test. This is the minimum pressure required to occasion the show and flow of oil. For the determination of the initial bulk density of the seeds, the capacity of the test cylinder used was 0.00035 m^3.

The aspect ratio is the ratio of the depth of product in the compression chamber of the pressing vessel to its diameter and is dimensionless. The time rate of deformation on the test rig was effectuated as the linear velocity of the crosshead (in mm min^{-1}). Three aspect ratios (0.5, 1.0 and 1.5) and three pressing rates (1, 5.5 and 10 mm min^{-1}) were investigated necessitating 3 × 3 = 9 treatments. These were implemented in 3 repetitions leading to 3 × 3 × 3 = 27 experimental runs. The study was conducted as a full (3 × 3) factorial experiment, fitted into a completely randomized design and thus provided more data points for optimising the response surfaces than would normally be required.

Physical, Mechanical Response and Performance Parameters

Physical parameters of the batch of sesame seeds used which are relevant to the measurement of the behaviour of the bulk seeds and the performance of the cold compression scheme adopted were determined using standard methods described in literature (Mohsenin, 1986; Sirisomboon et al., 2007). Bulk density of sesame seeds before oil expression was obtained by dividing the mass of replicate samples by the respective known free–fill volumes they occupy without compaction, as outlined in literature (Arozarena et al., 2012). The true density was established using solvent displacement technique, that is the method of the pycnometer and toluene. True density was determined as a function of the specific gravity of the crop (γ_S), specific gravity of the batch of toluene used (γ_T), mass of the seed sample (m_S) and mass of the displaced volume of toluene (m_{TD}) as shown in Eq. 1 (Mohsenin, 1986):

$$\gamma_s = \left(\gamma_T \times \frac{m_s}{m_{TD}} \right) \tag{1}$$

The material's porosity (or packing factor), P_f (%) was computed based on the bulk density, ρ_b (kg m^{-3}) and the true density, ρ_t (kg m^{-3}) using Eq. 2 (Mohsenin, 1986; Sirisomboon et al., 2007):

$$P_f = \left(1 - \frac{\rho_b}{\rho_t} \right) \times 100 \tag{2}$$

Peak deformation refers to highest value of deformation attainable during a compression test. Induced strain ϵ (–) was measured as the ratio of peak deformation, δ_c (mm) to initial product depth, δ_o (mm) (Eq. 3).

$$\in = \frac{\delta_c}{\delta_o} \tag{3}$$

The initial volume of compressed material, V (mm^3) may be determined using Eq. 4.

$$V = \frac{\pi D^2}{4} \times \delta_O \tag{4}$$

D (mm) is the internal diameter of the pressing vessel. The bulk density of the compressed oilseed material, γ_{CM} (kg m^{-3}) was determined as a function of the mass, m_c of the compressed material and its attained volume, V_c (Eq. 5).

$$\gamma_{CM} = \frac{m_c}{V_c} \tag{5}$$

The volume of the compressed material, V_c (mm^3) was determined using Eq. 6

$$V_c = \frac{\pi D^2}{4} \times \delta_f \tag{6}$$

δ_f (mm) is the depth of the compressed oilseed material in the pressing vessel.

The methods used to compute mechanical parameters and the relevant performance indices are as set forth in literature (Herák et al., 2012). Requisite energy E (J) for achieving observed deformation in the compressed sample was evaluated using Eq. 7:

$$E = \sum_{n=0}^{n=i-1} \left[\left(\frac{F_{n+1} + F_n}{2} \right) \times \left(\delta_{n+1} - \delta_n \right) \right] \tag{7}$$

where, i is the number of subdivisions of the deformation axis, which in this case was logged by the test equipment in incremental steps of 0.01 mm; F_n (N) is the compressive force for a known deformation, δ_n (mm). Volume specific mechanical energy demand was evaluated as a function of the initial volume of the compressed oilseed material (Akangbe & Herák, 2017a).

The deformation modulus, M_n (MPa) of the compressed oilseed was determined as the slope of the stress and strain or deformation curve at the specified force. This is numerically given by Eq. 8:

$$M_n = \left[\frac{4 \times \delta_o}{\pi \times D^2} \left(\frac{F_{n+1} - F_n}{\delta_{n+1} - \delta_n} \right) \right]_{n=0}^{n=i-1} \tag{8}$$

The applied pressure required to occasion the show of oil during each test was observed using the auxiliary digital indicator mounted adjacent to the pressing vessel on the test rig (Akangbe & Herák, 2017b).

For any mass of pressed seeds, m_{SS} (g) and the amount of oil recovered from it during expression, m_O (g) oil yield, OY (kg t^{-1}) may be obtained as (Eq. 9):

$$OY = \frac{m_O}{m_{SS}} \cdot 1{,}000 \tag{9}$$

The percentage yield of oil, POY (%) may be similarly determined (Ajibola et al., 1993) as (Eq. 10):

$$POY = \frac{m_O}{m_{SS}} \cdot 100 \tag{10}$$

Oil expression efficiency is determinable only in reference to the actual quantity of oil present in each batch of pressed seeds. It was therefore necessary to determine the quantity of oil present in the batch of oilseeds used for this study using Soxhlet extraction technique, in accordance with the ISO 659: 2009 reference method for oilseeds. The seeds were milled sufficiently to pass through a size 10 sieve. Samples were defatted in a soxhlet unit using petroleum ether. Standard evaporation techniques were used for solvent recovery as stipulated in the guideline. Three replicate tests were conducted. Oil content, OC (%) was then determined using Eq. 11 as the ratio of extracted oil to the mass of the seeds sample (International Organization for Standardization, 2009):

$$OC \frac{m_{OC}}{m_s} \cdot 100 \quad (11)$$

where m_{OC} (g) is the mass of oil extracted and m_S (g) is the mass of the sample. Mechanical oil expression efficiency, η_{OE} (%) was thereafter determined, using Eq. 12, as a ratio of the expressed oil to the total quantity of oil contained in the oilseed (Ajibola et al., 1993):

$$\eta_{OE} = \frac{POY}{OC} \cdot 100 \quad (12)$$

Data analysis

Data obtained in the course of this study were subjected to the analysis of variance using the generalised linear model in Genstat. Numerical computations were done using MS Excel. Treatment effects were compared using Duncan's multiple range test. Curvilinear forms were fitted to the response data on Minitab 17 platform using forward-stepwise multiple regression technique. Detailed description of the curve fitting and validation procedure is reported in literature (Kutner et al., 2005). Surfaces of the form presented below (Eq. 13) were obtained.

$$Y = \beta_0 + \beta_1 D_R + \beta_2 A_R + \beta_3 D_R^2 + \beta_4 A_R^2 + \beta_5 A_R D_R \quad (13)$$

where Y is the response parameter and β_0 is the intercept. $\beta_1, \beta_2, \beta_3\ \beta_4$ *and* β_5 are slope coefficients. A_R is aspect ratio and D_R is the time rate of deformation. There are ample treatments of the suitability of curvilinear forms to problems of this nature in literature (Granato & Calado, 2014). The equations were fitted with a view to establishing conditions for optimum performance. Optimisation was carried out using the response optimiser in Minitab.

RESULTS AND DISCUSSION

Physical properties of the batch of sesame seeds used for this study showing the initial state of the seeds are presented in Table 1. The seed moisture content was approximately 6%, in dry basis. Bulk and true densities ranged between 626.4 to 696.3 kg m^{-3} and 1,064.9 to 1,099.7 kg m^{-3}, respectively and porosity between 36.2 to 42.5%.

Table 1. Physical properties of the batch of sesame seeds used depicting initial condition of the seeds

Measure	Moisture Content, %, d.b.	Mass, g	Porosity, %	†Bulk density, kg m^{-3}	True density, kg m^{-3}
Mean	6.04	227.9	40.3	651.2	1,091.6
SD*	0.66	5.9	1.6	17.0	13.6

*SD = standard deviation. †n = 20.

Results of the analysis of variance on the test data are presented in Table 2. Both time rate of deformation and equipment aspect ratio had significant effects on mechanical response and the performance parameters investigated. Main effects of the two factors and those of their interactions on deformation, energy and deformation modulus were highly significant. Each of the two factors had a highly significant effect on oil point pressure, but not their interaction. Only the time rate of deformation had significant effect on induced strain, amount of recoverable oil and the performance of the cold expression scheme.

Table 2. Effects of deformation rate and aspect ratio on response variables

Response parameter	Source of Variation		
	Deformation Rate, D_R	Aspect Ratio, A_R	$D_R \times A_R$
Deformation, δ	0.001**	0.001**	0.001**
Strain, ϵ	0.001**	0.094^{ns}	0.202^{ns}
Deformation Energy, E	0.001**	0.001**	0.001**
Volume Energy, e_v	0.001**	0.001**	0.001**
Deformation Modulus, M_n	0.001**	0.001**	0.001**
Bulk Density of Compressed Material, γ_{CM}	0.329^{ns}	0.416^{ns}	0.414^{ns}
Oil Point Pressure, OPP	0.001**	0.001**	0.981^{ns}
Oil Yield, OY	0.001**	0.362^{ns}	0.111^{ns}
Oil Expression Efficiency, η_{OE}	0.001**	0.362^{ns}	0.111^{ns}

ns = not significant at the 5% level; * = significant (at the 5% level); ** = highly significant (at the 1% level).

When treatment means were compared using Duncan's multiple range test, deformation was observed to increase significantly as aspect ratio increased (Table 3) and as the rate of deformation slowed (Table 4). From the force and deformation profiles of the seeds it (Fig. 1), it can be seen that very wide margins are indicated between deformation recorded at lower rates of deformation over those obtained at higher ones; the lower the rate of deformation, the higher the deformation. This was true for all aspect ratios. The incidence of higher deformation at higher aspect ratios is due in part to the larger initial void capacity and volume of the solid material. In their work (Divišová et al., 2014) deformation was positively correlated with the depth of product in the compression chamber. The effectiveness of the compression process appears however to be more dictated by the rate of induction of deformation.

Higher levels of strain were induced as deformation rate was lowered. The slower the rate of induction, the higher was the strain. This effect establishes the time dependence of deformation since strain induction is more effective at the slower rates and agrees with similar observations by Liu et al. (2015). However, in their treatment, reciprocal strain is presented as compression ratio. Deformation and strain improve with time and are functions of the sensitivities of the compressed material under the influence conditions (Savoire et al., 2010). Average strain appeared to be similar for all the aspect ratios investigated (Tables 3 and 4).

Reducing the rate of deformation had the effect of elevating energy requirement for deformation significantly (Table 3), as did also increasing the aspect ratio. Energy expenditure at the lower pressing rates is a function of time as more energy is expended in sustaining incremental compression while working the product mass for much longer periods. Higher aspect ratios however result in better energy efficiency when factored around each bulk volume of material processed. For example, energy expenditure per unit volume of pressed oilseeds reduced significantly from 8.80–0.91 MJ m^{-3} when the aspect ratio was changed from 0.5 to 1.5. The implication therefore is that whereas higher amounts of energy might be required in mills operating with high aspect ratios, the energy efficiency in such systems is better than in mills which may be operated with lower aspect ratios.

Table 3. Main effects of the time rate of deformation on oil expression and compression parameters (*Mean ± SD*, n = 9*)

Response Parameters	Deformation rate, D_R (mm min^{-1})		
	1.0	5.5	10
Deformation, δ (mm)	35.77 ± 15.90^a	31.35 ± 13.65^b	30.39 ± 12.99^c
Strain, ϵ (-)	0.5932 ± 0.0155^a	0.5218 ± 0.00708^b	0.5066 ± 0.0099^c
Deformation energy, E (J)	407.5 ± 179.0^a	340.8 ± 134.0^b	323.6 ± 122.0^c
Volume energy, e_v (MJ m^{-3})	4.34 ± 3.96^a	3.86 ± 3.65^b	3.66 ± 3.42^c
Deformation modulus, M_n (MPa)	343.6 ± 13.21^b	383.7 ± 38.24^a	370.5 ± 67.63^a
Bulk density of compressed material, γ_{CM}(kg m^{-3})	1,503.0 ± 986.0^a	1,141.0 ± 23.6^a	1,150.0 ± 22.5^a
Oil point pressure, OPP (MPa)	3,247 ± 0.447^c	4,077 ± 0.202^b	4,626 ± 0.255^a
Oil yield, OY (kg t^{-1})	266.5 ± 51.0^a	177.0 ± 6.6^b	144.5 ± 9.23^c
Oil expression efficiency, η_{OE} (%)	59.8 ± 11.5^a	39.7 ± 1.5^b	32.4 ± 2.1^c

Means comparison is row-wise. Similar alphabets indicate homogeneous subsets. Significant effects are valid at the 5% level of significance.

The modulus of deformation represents the compressed material's resistance to strain. At deformation rates of 5.5 and 10 mm min^{-1}, deformation moduli were statistically similar. However, deformation modulus was much less when the rate of deformation was lowered to 1 mm min^{-1}. In essence, the compressed materials were more easily deformed at the lower rates. Increasing aspect ratio does have a significant impact on deformation modulus (Table 4). The mass of material processed given each unit of applied compressive stress increases, as does strain resistance as aspect ratio increases.

Table 4. Main effects of equipment aspect ratio on oil expression and compression parameters (*Mean ± SD*, n = 9*)

Response Parameters	Aspect ratio, A_R (-)		
	0.5	1.0	1.5
Deformation, δ (mm)	16.04 ± 1.16^c	32.74 ± 2.16^b	48.73 ± 4.36^a
Strain, ϵ (-)	0.5346 ± 0.0385^a	0.5456 ± 0.0361^a	0.5414 ± 0.0484^a
Deformation energy, E (J)	186.6 ± 13.5^c	365.1 ± 30.1^b	520.1 ± 74.7^a
Volume energy, e_v (MJ m^{-3})	8.80 ± 0.64^a	2.15 ± 0.18^b	0.91 ± 0.13^c
Deformation modulus, M_n (MPa)	330.3 ± 15.9^c	357.5 ± 28.7^b	410.0 ± 48.8^a
Bulk density of compressed material, γ_{CM} (kg m^{-3})	1,475.0 ± 995.9^a	1,163.0 ± 23.5^a	1,156.0 ± 45.6^a
Oil point pressure, OPP (MPa)	4,299 ± 0.690^a	3,840 ± 0.618^b	3,811 ± 0.603^c
Oil yield, OY (kg t^{-1})	185.2 ± 51.8^a	203.3 ± 62.7^a	199.5 ± 69.9^a
Oil expression efficiency, η_{OE} (%)	41.6 ± 11.6^a	45.6 ± 14.1^a	44.8 ± 15.7^a

Means comparison is row-wise. Similar alphabets indicate homogeneous subsets. Significant effects are valid at the 5% level of significance.

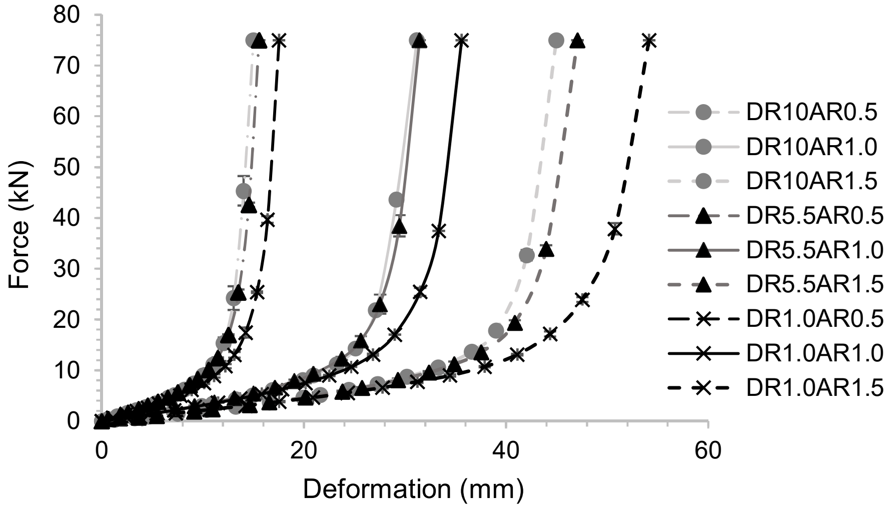

Figure 1. Force and deformation characteristics for aspect ratios of 0.5, 1.0 and 1.5 (AR0.5, AR1.0 and AR1.5, respectively) and at deformation rates of 10, 5.5 and 1.0 mm min^{-1} (or DR10, DR 5.5 and DR 1.0, respectively).

Similar amounts of densification were achieved at all aspect ratios and deformation rates investigated (Tables 3 and 4). The bulk density of the compressed oilseed mass represents a state of loss of void capacity. Whereas the two parameters influenced mechanical response and performance variedly, the bulk density of the compressed seed mass represented an attainable limit, which was similar at the levels of each investigated parameter, the relative contributions of each parameter to the system's response notwithstanding.

At the lower deformation rates, the onset of oil was obtained at lower levels of stress. Oil point pressures increased as deformation rates increased (Table 3). Oil point pressures were, however, lower as aspect ratios increased. In other words, the bigger the aspect ratio, the less was the magnitude of applied stress required to occasion the show and flow of oil (Table 4).

The occasioning of the show and flow of oil at lower pressures observed with bigger aspect ratios did not translate into significant improvements in the yield of oil from the compressed material (Table 4) but higher strains and deformations did which were better as the rate of deformation slowed. The correlation of these parameters with oil yield is in consonance with observations by Liu et al. (2015). The main contributor to improvement in the yield of oil was the time rate of deformation (Table 3). As deformation rate decreased, oil yield increased significantly, and so did the oil expression efficiency. At a deformation rate of 1 mm min^{-1}, an average of 266 kg of oil may be recovered from every tonne of sesame seeds compressed. This represented an oil expression efficiency of 60% and compares favourably with expression at higher pressing rates (Table 3). Existing works (Bargale et al., 2000) confirm the time-dependence of oil yield during compressive expression. As the deformation rate slows, more time is expended in working the product mass. Some attributions of this are with respect to the effectiveness of the process and flow (Adesina & Bankole, 2013; Adekola, 2014).

Table 5. Summary of curvilinear trends fitted to the response indices

Response and performance indicators	β_0	β_1	β_2	β_3	β_4	β_5	S	P > F	R^2	$R^2_{adj.}$
Deformation, δ (mm)	0.450	-0.793	36.765	0.0851		-0.741	0.9427	< 0.001	99.61	99.54
Strain, ϵ (-)	0.6167	-0.0249		0.001385			0.0114	< 0.001	92.55	91.92
Deformation energy, E (J)	-25.1	-7.94	508.8	1.222	-46.9	-14.83	14.8253	< 0.001	99.17	98.97
Volume energy, e_v (MJ m^{-3})	22.063	-0.276	-30.190	0.00712	10.811	0.123	0.1601	< 0.001	99.84	99.80
Deformation modulus, M_n (MPa)	318.5	4.63	9.0	-1.318		12.86	22.4248	< 0.001	80.66	77.14
Oil point pressure, OPP (Pa)	4,230,591	2,29,180	-2,210,485	-6,904	861,402		223,660	< 0.001	90.11	88.31
Oil yield, OY (kg t^{-1})	294.1	-29.0		1.404			30.1934	< 0.001	76.65	74.7
Oil expression efficiency, η_{OE} (%)	65.98	-6.51		0.315			6.7744	< 0.001	76.65	74.70

β_0 is the intercept on the response axis. $\beta_1 - \beta_5$ are slope coefficients to model parameters D_R, A_R, D_R^2, A_R^2, and $D_R A_R$, repectively. S is the standard error of model estimate. P > F is the model probability statistic, significant at $p < 0.05$. R^2 and R^2_{adj} are the coefficient of determination and adjusted coefficient of determination of the model, respectively.

Table 6. Regions of maximum response on the fitted trends

Response and performance indicators	Regions				95%*CI*		95%*PI*	
	D_R	A_R	*Fit*	*SE Fit*	*LL*	*UL*	*LL*	*UL*
Deformation, δ (mm)	1.0	1.5	53.78	0.471	52.80	54.76	51.59	55.96
Strain, ϵ (-)	1.0		0.5932	0.0038	0.5854	0.6010	0.5685	0.6180
Deformation energy, E (J)	1.0	1.5	603.64	7.680	587.66	619.62	568.92	638.36
Volume energy, e_v (MJ m^{-3})	1.0	1.5	9.46	0.083	9.29	9.64	9.09	9.84
Deformation modulus, M_n (MPa)	9.07	1.5	440.40	9.520	420.66	460.15	389.88	490.93
Oil point pressure, OPP (Pa)	10	0.5	4.94	0.096	4.74	5.14	4.44	5.48
Oil yield, OY (kg t^{-1})	1.0	1.5	266.5	10.1	245.70	287.20	200.8	332.2
Oil expression efficiency, η_{OE} (%)	1.0	1.5	65.97	3.020	59.71	72.24	51.97	79.98

LL – lower limit; *UL* – upper limit; *CI* – confidence interval; *PI* – prediction interval; *Fit* – maximised value of the response parameter; *SE Fit* – standard error of fit.

A summary of equations fit to mechanical response and pressing performance data with respect to the influence of the time rate of deformation and equipment aspect ratio is presented in Table 5. The model fit was Eq. 10. The effects of all the fitted forms in predicting mechanical response and pressing performance were highly significant ($p < 0.001$). Between 76.65%–99.61% of the various responses were explained by the generated trends, given their respective coefficients of determination.

The aspect ratio was the more important contributor to predicting achievable deformation, deformation modulus, deformation energy and volume energy demand than the time rate of deformation. Deformation rate contributed more to predicting strain, oil point pressure, oil yield and oil expression efficiency than the aspect ratio. Regions of maxima for the presented trends and the prediction intervals are presented in Table 6. From the results, maximum yield may be obtained at a deformation rate of 1.0 mm min^{-1} with an aspect ratio of 1.5. This region coincides exactly with those of the occurrences of maximum deformation, strain, deformation energy and volume energy demand but not the maximum resistance of the material to strain (9.08 mm min^{-1} and 1.5) or maximum oil point pressure (10 mm min^{-1} and 0.5). In essence, operating in this region will result in maximum yield and performance of the cold compression scheme.

CONCLUSIONS

In this study, the effects of equipment aspect ratio, time rate of deformation and their interactions on mechanical response and performance in single cycle cold compressive expression of oil from sesame seeds was investigated at 6.04% crop moisture content (in dry basis) and an applied compressive stress of 26.53 MPa. The amount of deformation achieved was dependent on the rate of its induction and the aspect ratio, as well as their interaction. Energy requirement was lower at the higher rates of deformation and smaller aspect ratios. For every unit volume of oilseeds processed, more energy was expended at the lower deformation rates while less energy was expended using bigger aspect ratios. Energy expenditure is therefore more efficient with bigger aspect ratios. The moduli of deformation indicate that resistance to strain is less at lower rates of deformation and smaller aspect ratios compared to the higher settings. Time rate of deformation was the most important predictor of the quantity of oil recovered and the efficiency of the single cycle cold compression scheme. This dependence is explained by the magnitude of induced strain which correlated positively and was dependent mainly on the time rate deformation. The effectiveness of the fitted forms in predicting the respective response parameters was highly significant ($p < 0.001$) with 76.7 to 99.6% of the behaviour of the system explained.

ACKNOWLEDGEMENTS. This study has been supported by Integral Grant Agency of Faculty of Engineering, Czech University of Life Sciences Prague, grant number: 2017: 31130/1312/3111.

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