PRELIMINARY EXPERIMENT ON COMPRESSION AND RELAXATION BEHAVIOUR OF BULK SESAME SEEDS AT VARYING FORCES AND SPEEDS

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Abstract
The article examined the loading and unloading behaviour of bulk sesame seeds in relation to different forces between 1.5 and 4.5 kN and speeds between 1 and 10 mm·min^{-1}. The testing device (Labortech, MPTest 5.050, Germany) of a maximum load of 5 kN was used for the compression test. The bulk sesame seeds sample was measured at an initial height of 40 mm using the vessel diameter of 60 mm with a plunger. Based on the compression test; the loading time of 737.150±15.127, 500±10.267 and 60.500±9.334 s was observed at speeds of 1, 5 and 10 mm·min^{-1} and maximum force of 4.5 kN. Maximum deformation of 12.320±0.269 mm with a corresponding strain of 0.308±0.007 (-) and deformation energy of 25.495±0.191 J was observed at the lowest speed and maximum force. The applied forces at the various speeds did not initiate rupture of the bulk sesame seeds sample, hence there was no oil recovery. Using the multivariate analysis technique, the calculated parameters were statistically significant ($p<0.05$).

Keywords*: Bulk sesame seeds sample; compression test; loading rate; multivariate analysis.*

INTRODUCTION

The loading and relaxation behaviour of agricultural products is vital in food processing and storage as well as transport technologies for characterization of products (*Leblicq, Vanmaercke, Ramon & Saeys, 2015*; *Chakespari, Rajabipour & Mobli, 2010a*; *Chou, Sydow, Martin, Bridgwater & Wilson, 2003).* In the linear compression test, constant force and speed have been mostly applied for analyzing the mechanical and relaxation behaviour of bulk oilseeds (*Herak, Sleger, Mizera & Sedlacek, 2015*; *Divisova, Herak, Kabutey, Sleger, Sigalingging & Svatonova, 2014*; *Herak, Kabutey, Sedlacek & Gurdil, 2012*; *Herak, Kabutey & Sedlacek, 2011*). The relaxation time is also an important rheological property which shows how fast a material can dissipate stress after receiving a sudden deformation (*Maraldi, Molari, Regazzi & Molari, 2017*; *Chakespari, Rajabipour & Mobli, 2010a*; *Bargale, Irudayarj & Marquis, 1995*). The relaxation time of 30.33 s and 90 s has been reported on pear and apples (*Chakespari, Rajabipour & Mobli, 2010a*; *Wang, 2003*). Theoretically, the compression or load-deformation curve can be transformed into stress and strain relationship where the linear elastic region reaching the proportional limit or at the point of the relaxation process is extremely relevant for the design of an optimal processing technology (*Herak & Sedlacek, 2017; Hrabe & Sedlacek, 2016*; *Bargale, Irudayarj & Marquis, 1995*). It is important, however, to understand the varying compression factors such as force and loading rates on the mechanical behaviour of bulk oilseeds to identify the key processing parameters. The objective of the preliminary study was to describe the loading and unloading curves of bulk sesame seeds sample at different forces and speeds. Maximum deformation (mm), deformation energy (J), strain (-), and volume energy (J·m^{-3}) were also calculated.

MATERIALS AND METHODS

Bulk sesame seeds procured from the Czech Republic was used for the experiment. The moisture content of the sample was determined to be 8.42±0.24 % (w.b.) using the standard oven drying method (*Deli, Farah Masturah, Tajul Aris & Wan Nadia, 2011*; *Izli, Unal & Sincik, 2009*; *ISI, 1996*). The compression device (Labortech, MPTest 5.050, Germany) of a maximum load of 5 kN was used to

record the loading and unloading curves of bulk sesame seeds sample measured at an initial pressing height of 40 mm using a vessel diameter of 60 mm with a plunger (Fig.1). Compression forces of 1.5, 3 and 4.5 kN and speeds of 1, 5 and 10 mm·min^{-1} were applied. The relaxation time of 5 minutes after maximum compression was allowed. The test was repeated twice and the results averaged. The deformation, strain, deformation energy and volume energy were respectively calculated from the relations given by (*Kabutey, Herak, Dajbych, Divisova, Boatri & Sigalingging, 2014; Chakespari, Rajabipour & Mobli, 2010b*). The SPSS software was used to analyse the calculated parameters.

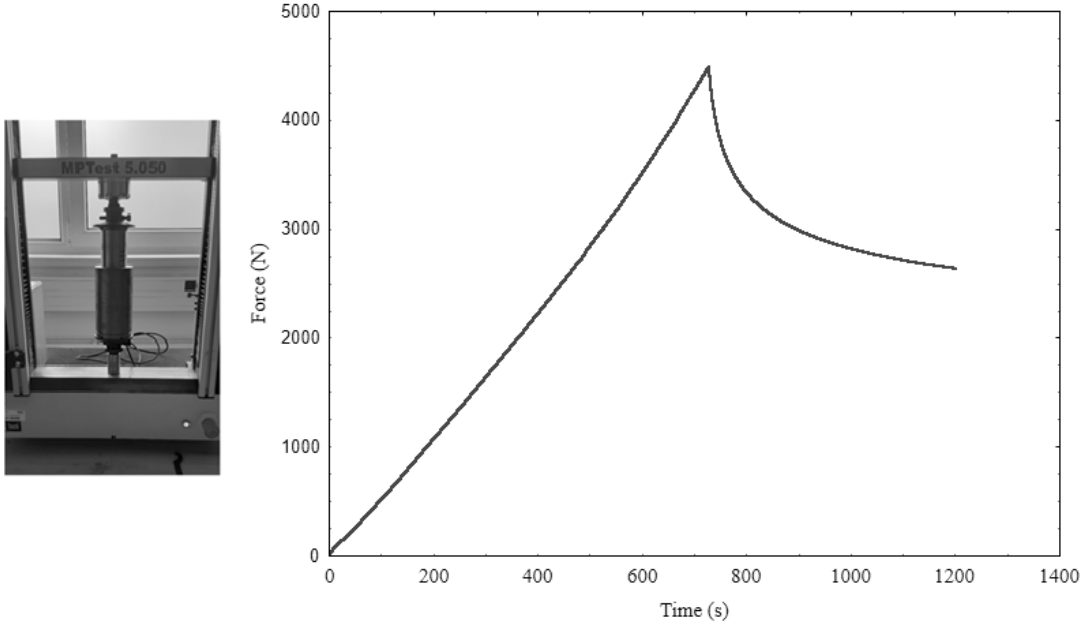

Fig. 1 Compression and relaxation test of bulk sesame seeds at force 4.5 kN and speed 1 mm·min^{-1}

RESULTS AND DISCUSSION

The characteristic load-deformation curves of bulk sesame seeds sample showed a smooth behaviour without any serration effect (*Divisova, Herak, Kabutey, Sleger, Sigalingging & Svatonova, 2014; Gupta & Das, 2000*). Maximum deformation of 12.320±0.269 mm with a corresponding strain of 0.308±0.007 (-) and deformation energy of 25.495±0.191 J was observed at the lowest speed and maximum force. There was no permanent deformation of the bulk sesame seeds sample. The loading time of 737.150±15.127, 500±10.267 and 60.500±9.334 s was observed at speeds of 1, 5 and 10 mm·min^{-1} and maximum force of 4.5 kN. The mean and standard deviation values of the calculated parameters are presented in Tab. 1.

Tab. 1 Calculated parameters of bulk sesame seeds at different force and speed

Force kN	Speed mm·min^{-1}	Maximum deformation mm	Strain	Deformation energy J	Volume energy ·10^4 J·m^{-3}
	1	4.805±0.049	0.120±0.001	3.435±0.078	3.037±0.069
1.5	5	4.245±0.064	0.106±0.002	3.235±0.021	2.861±0.019
	10	4.455±0.205	0.111±0.005	3.255±0.134	2.878±0.119
	1	8.925±0.375	0.223±0.009	12.795±0.304	11.312±0.269
3	5	8.080±0.693	0.202±0.017	11.955±0.778	10.569±0.706
	10	8.150±0.424	0.204±0.011	11.900±0.684	10.521±0.688
	1	12.320±0.269	0.308±0.007	25.495±0.191	22.541±0.169
4.5	5	10.630±0.863	0.266±0.022	22.945±0.559	20.285±0.494
	10	10.060±1.556	0.252±0.039	22.255±1.464	19.675±1.294

The limit deformation of the bulk sesame seeds sample without oil leakage showed that the forces applied at different speeds were not great in magnitude to initiate rupture. Therefore, a greater force at a specific speed is required to recover the optimum oil (*Kabutey, Herak, Choteborsky, Dajbych, Sigalingging & Akangbe, 2017*). The normality test of the calculated parameters is given in Tabs. 2 and 3 respectively. From the Shapiro-Wilk test (for small dataset) it can be seen that the data is normally distributed since the p-values were greater than the significance level of 5%. The normality test results of strain and volume energy were similar to the deformation and deformation energy since the strain was determined based on the ratio of the deformation and the initial pressing height of the bulk sesame seeds sample while the volume energy was determined based on the ratio of the deformation energy and volume of the pressing vessel.

Tab. 2 Test of normality of deformation and deformation energy of bulk sesame seeds sample in relation to force

Determined parameters	Force kN	Kolmogorov-Smirnov[a] Statistic	df	P-value	Shapiro-Wilk Statistic	df	P-value
Deformation, mm	1.5	0.260	6	0.200*	0.887	6	0.302
	3	0.211	6	0.200*	0.955	6	0.780
	4.5	0.214	6	0.200*	0.948	6	0.723
Deformation Energy, J	1.5	0.185	6	0.200*	0.968	6	0.876
	3	0.300	6	0.098	0.846	6	0.146
	4.5	0.220	6	0.200*	0.931	6	0.589

*This is a lower bound of the true significance
[a] Lilliefors significance correction

Tab. 3 Test of normality of deformation and deformation energy of bulk sesame seeds sample in relation to speed

Determined parameters	Speed $mm \cdot min^{-1}$	Kolmogorov-Smirnov[a] Statistic	df	P-value	Shapiro-Wilk Statistic	df	P-value
Deformation, mm	1	0.206	6	0.200*	0.879	6	0.264
	5	0.209	6	0.200*	0.910	6	0.435
	10	0.211	6	0.200*	0.919	6	0.498
Deformation energy, J	1	0.210	6	0.200*	0.855	6	0.174
	5	0.200	6	0.200*	0.871	6	0.229
	10	0.191	6	0.200*	0.894	6	0.339

*This is a lower bound of the true significance
[a] Lilliefors significance correction

The multivariate analysis of the calculated parameters (deformation, deformation energy, strain and volume energy) is shown in Tab. 4. The results were statistically significant ($p<0.05$). The corrected model indicated R squared values of 0.971 and 0.997 respectively. However, the interaction effect of force and speed on the calculated amounts was not statistically significant ($p>0.05$). The regression coefficients and the statistical significance of each parameter are given in Tabs. 5 to 8. The determined coefficients were statistically significant ($p<0.05$).

Tab. 4 Multivariate analysis of determined parameters of bulk sesame seeds

Source	Dependent variables	Sum of sqaures	df	Mean square	F-value	P-value
Corrected Model	Deformation	135.141[a]	8	16.893	37.212	0.000
	Deformation energy	1249.657[b]	8	156.207	365.027	0.000
	Strain	0.084[a]	8	0.011	37.212	0.000
	Volume energy	97672760738.748[b]	8	12209095092.344	365.027	0.000
Intercept	Deformation	1141.464	1	1141.464	2514.484	0.000
	Deformation energy	3056.056	1	3056.056	7141.431	0.000
	Strain	0.713	1	0.713	2514.484	0.000
	Volume energy	238860300087.757	1	238860300087.757	7141.431	0.000
Force	Deformation	128.415	2	64.208	141.440	0.000
	Deformation energy	1236.951	2	618.476	1445.262	0.000
	Strain	0.080	2	0.040	141.440	0.000
	Volume energy	96679682391.941	2	48339841195.970	1445.262	0.000
Speed	Deformation	4.694	2	2.347	5.170	0.032
	Deformation energy	7.118	2	3.559	8.317	0.009
	Strain	0.003	2	0.001	5.170	0.032
	Volume energy	556374297.748	2	278187148.874	8.317	0.009
Force *speed	Deformation	2.032	4	0.508	1.119	0.406
	Deformation energy	5.587	4	1.397	3.264	0.065
	Strain	0.001	4	0.000	1.119	0.406
	Volume energy	436704049.058	4	109176012.265	3.264	0.065
Error	Deformation	4.086	9	0.454		
	Deformation energy	3.851	9	0.428		
	Strain	0.003	9	0.000		
	Volume energy	301024097.580	9	33447121.953		
Total	Deformation	1280.691	18			
	Deformation energy	4309.565	18			
	Strain	0.800	18			
	Volume energy	336834084924.085	18			
Corrected Total	Deformation	139.226	17			
	Deformation energy	1253.508	17			
	Strain	0.087	17			
	Volume energy	97973784836.328	17			

df = Degree of freedom; [a] R Squared = 0.971; [b] R Squared = 0.997;

Tab. 5 Regression coefficient of the dependent variable: Deformation (mm)

Source	Unstandardized coefficients B	Standard error	Standardized coefficients Beta	t value	P-value
Intercept	2.107	0.546		3.861	0.002
Force, kN	0.002	0.000	0.954	14.671	0.000
Speed, mm·min^{-1}	-0.121	0.049	-0.160	-2.463	0.026

Tab. 6 Regression coefficient of the dependent variable: Deformation energy (J)

Source	Unstandardized coefficients B	Standard error	Standardized coefficients Beta	t value	P-value
Intercept	-6.399	0.749		-8.548	0.000
Force, kN	0.007	0.000	0.991	33.322	0.000
Speed, mm·min^{-1}	-0.155	0.067	-0.068	-2.303	0.036

Tab. 7 Regression coefficient of the dependent variable: Strain (-)

Source	Unstandardized coefficients B	Standard error	Standardized coefficients Beta	t value	P-value
Intercept	0.053	0.014		3.861	0.002
Force, kN	$5.418 \cdot 10^{-5}$	0.000	0.954	14.671	0.000
Speed, mm·min^{-1}	-0.003	0.001	-0.160	-2.463	0.026

Tab. 8 Regression coefficient of the dependent variable: Volume energy (J·m^{-3})

Source	Unstandardized coefficients B	Standard error	Standardized coefficients Beta	t value	P-value
Intercept	-56569.493	6618.168		-8.548	0.000
Force, kN	59.695	1.791	0.991	33.322	0.000
Speed, mm·min^{-1}	-1372.497	595.933	-0.068	-2.303	0.036

CONCLUSIONS

The loading test in relation to the applied forces and speeds did not initiate rupture of the bulk sesame seeds sample. The loading time of 737.150±15.127, 500±10.267 and 60.500±9.334 s was observed at speeds of 1, 5 and 10 mm·min^{-1} and maximum force of 4.5 kN. The calculated parameters (deformation, deformation energy, strain and volume energy) were statistically significant ($p<0.05$) based on the general linear model analysis. The normality test based on Shapiro-Wilk significance indicated that the data is normally distributed (p-value>0.05) confirming the reliability of the results. The follow-up communication would consider applying a higher compressive force at similar speeds for recovering the maximum oil and describing the load-deformation curves and the stress relaxation behaviour of bulk sesame seeds sample using appropriate mathematical models.

ACKNOWLEDGMENT

This research through the project ''supporting the development of international mobility of research staff at CULS Prague, grant number CZ.02.2.69/0.0/0.0/16_027/0008366" was funded by ''EU, Managing Authority of the Czech Operational Programme Research, Development and Education'', and "The APC was funded by the project "supporting the development of international mobility of research staff at CULS Prague, grant number CZ.02.2.69/0.0/0.0/16_027/0008366".

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