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Compression and relaxation properties of biomass for briquetting

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ABSTRACT The compression and relaxation properties of selected biomass (canola and wheat straw) were investigated to determine the correlation with variables (pressure, particle size (hammer mill screen size), moisture content, and temperature). The applied pressure ranged from 7.03 MPa to 14.06 MPa. Three screen sizes (19.05, 25.40, and 31.75 mm) of the hammer mill were used to grind the biomass samples. The ground biomass materials were conditioned to moisture contents of 9%, 12%, and 15% (w.b.). The results indicated that the compact density of biomass increased with the increase of pressure and moisture content. The relaxation properties of selected materials were affected by the set variables. Biomass materials had a higher stress relaxation with higher moisture content.

Keywords: compression, stress relaxation, density, and biomass.

INTRODUCTION Mechanical compaction is one of the effective methods to reduce the volume of biomass. Pellets, cubes, and briquettes have a higher density than bales or grinds that is advantageous for transportion and storage. Also, these aforementioned densified forms reduce wastage or dust compared to the ground form during the shipping and use (Johnson et al., 2013). Agricultural biomass, such as wheat and canola straws, commonly used as feedstock for biofuel production, is a viscoelastic material. It is important to know the rheological behavior of these materials during compaction, in order to optimize compaction equipment design, to reduce energy consumption and improve quality of products (Mani et al., 2004b).

Compaction and relaxation properties of different biomass materials are different from each other depending on the physical-chemical properties and the method of compaction (Mani et al., 2004a). Researchers have studied various powder materials. Previous studies indicated that the elastic and plastic deformation happens during the compression/compaction of viscoelastic materials. In general, the densification of materials needs two stages to shape: particles rearrangement and deformation (Faborode and O'Callaghan, 1987, 1989; Kaliyan and Morey, 2009; Mani et al., 2002). In the first stage, particles rearrange to reduce the voids between each other and bring them close together; small stress is needed to overcome the interparticle and particle-to-wall friction (Mani et al., 2003). The particles retain their properties; elastic deformation mainly occurs during this phase (Cooper and Eaton, 1962). In the next stage, with the increase of applied pressure, most of the air is pushed out, and elastic-plastic deformation of particles occurs (Cooper and Eaton, 1962; Faborode and O'Callaghan, 1987, 1989; Kaliyan and Morey, 2009; Mani et al., 2002; Nona et al., 2014). Previous researches had built pressure-density equations to describe the compression characteristics of some metal or non-metallic powders (Cooper and Eaton, 1962; Heckel, 1961; Jones, 1960; Panelli and Filho, 2001; Walker, 1923). These equations may also be used for the compaction behavior of biomass grinds. Tabil (1996) had studied four of these models and shown that Cooper-Eaton model was the best fit to the compaction of alfalfa grinds. It was also verified to fit fiber material grinds by Mani et al. (2002). The Kawakita-Ludde model had an excellent fit for ground canola, wheat, barley, and oat straw materials (Johnson et al., 2013).

In commercial briquetting/pelleting, the stress relaxation of compressed material results in the expansion of volume and decrease of density. After compression, the residual stress in the compressed samples begins to be released. Then, the relaxed density of compressed samples gradually decreases to a stable value. The relaxation behavior depends on many factors, such as, dimensions of briquette, compression method, and the properties of material (Ndiema et al., 2002). Understanding the influence of these factors is essential in investigating the compression and relaxation of biomass materials on the briquetting.

The objective of this study is to determine the compaction and relaxation properties of selected biomass materials at different pressure, moisture content, and particle size.

MATERIALS AND METHODS

Materials Wheat and canola straw samples were acquired as small square bales (0.45 ×0.35×1.00 m) from the Central Butte area (50.83˚ N, 106.51˚ W, SK, Canada) during the summer of 2008 (Tumuluru et al., 2014). Wheat straw sample was initially chopped to about 44 mm using a Cutter (Model #: CTR, Belfast Mini Mills Ltd., PEI, Canada). Then, both samples were further chopped with a hammer mill (Serial No. 6M13688, Glen Mills, Inc., Maywood, NJ) using screen sizes of 19.05, 25.4, and 31.75 mm (Adapa et al., 2011).

Each of the chopped straw was conditioned to a moisture content of 9%, 12%, or 15% (w.b.) by adding appropriate amount of distilled water to the samples contained in Ziploc bags, stored in a cool room at 4°C for 72 h. The moisture contents of the straw samples were measured per ASABE standard S358.2 (2008).

To determine the geometric mean length of chopped straw, samples of about 150 g were sieved for two minutes using the screen shaker with sieve sizes 26.9, 18.0, 8.98, 5.61, and 1.65 mm. The geometric mean length of each straw samples were calculated per ASABE standard S424.1 (2012).

Compression and relaxation tests An Instron Universal Testing Machine (Model: 600DX, Instron Corp., Norwood, MA) with a load cell having a maximum load of 600 kN was used in this study. A computer with the Partner software (Instron Corp., Norwood, MA) was connected to the testing machine.

The experiment was conducted using a single plunger-die set. The bottom part (i.e., compression die) had a cylindrical cavity of 73.7 mm diameter and put on the bottom platform of testing machine. The upper plunger was fixed on the testing machine and a level marked line was drawn on it that the test could start from a same position. Chopped straw samples were hand-filled into the compression die. The charge was 20 g for chopped wheat straw sample; it was 30 g for chopped canola straw sample because of its higher bulk density.

The straw samples were compressed under four levels of preset load, 30, 40, 50, and 60kN, i.e., preset pressures were 7.03, 9.38, 11.72, and 14.06 MPa. The die was filled with straw samples and put on the bottom platform of Instron Testing Machine. When the testing started, the upper plunger stayed its position, and the bottom platform rose with the die at a speed of 30 mm/min. After applied pressure reached preset value, the die stopped and maintained in its position for 240 s to observe the relaxation behavior. Then the compressed briquette sample was removed out of the die and weighed. The data of displacement, density, and pressure with time were recorded by the computer.

Data analysis The experimental data was analyzed using Microsoft Excel 2013 (Microsoft Corp., Redmond, WA) and fitted to the models using SPSS software 21.0 (IBM Corp., Armonk, New York, NY).

Relaxation models The basic stress relaxation can be expressed as the percent average relaxation (Eq. 1) (Johnson et al., 2013; Talebi et al., 2011).

$$Y(t) = \frac{\sigma_0 - \sigma_t}{\sigma_0} \times 100\% \tag{1}$$

Where,
$Y(t)$ =decaying parameter, showed the decay of the stress at the time *t*, %;
σ_0 =initial stress, MPa;
σ_t =the stress at time *t*, MPa.

Peleg and Moreyra (1979) developed a model to describe the relaxation characteristics of solid foods.

$$\frac{F_0 \cdot t}{F_0 - F(t)} = k_1 + k_2 \cdot t \tag{2}$$

Where,
F_0 =initial relaxation force, kN;
$F(t)$ =relaxation force at time, kN;
t =time, s;
k_1, k_2 =constants.

Then, they (Moreyra and Yeleg, 1980; Scoville and Peleg, 1981) modified the Eq. 2 and indicated that the slope can be used to determine the asymptotic modulus of food powders and solid foods. The asymptotic modulus is the residual stress in the Peleg's relaxation model and can be defined as the ability of the compressed material to sustain un-relaxed stresses.

$$E_A = \frac{F_0}{A_a \varepsilon}(1 - \frac{1}{k}) \tag{3}$$

Where,
E_A =asymptotic modulus, MPa;
ε =strain;
A_a =cross-sectional area, m^2;
k =constants.

RESULTS AND DISCUSSION

Physical properties of chopped straw The initial moisture content of canola and wheat straw samples were 7.89 and 6.46%, respectively. The geometric mean particle size of chopped canola and wheat straw samples using the hammer mill screen size of 19.05, 25.40, and 31.75 mm are listed in Table 1. Fig. 1 shows the particle size distribution of ground straw samples that are similar with previous reports (Adapa et al., 2009; Sudhagar et al., 2004).

Table 1. Mean particle size of selected straw chopped with a hammer mill using screen sizes of 19.05, 25.40, and 31.75mm

Straw	Screen size (mm)		
	19.05	25.40	31.75
Canola	3.57 ±2.21[a]	3.71 ±2.27	3.94 ±2.23
Wheat	3.84 ±2.27	4.14 ±2.51	4.33 ±2.31

[a] Geometric mean size ±geometric standard deviation, n=3.

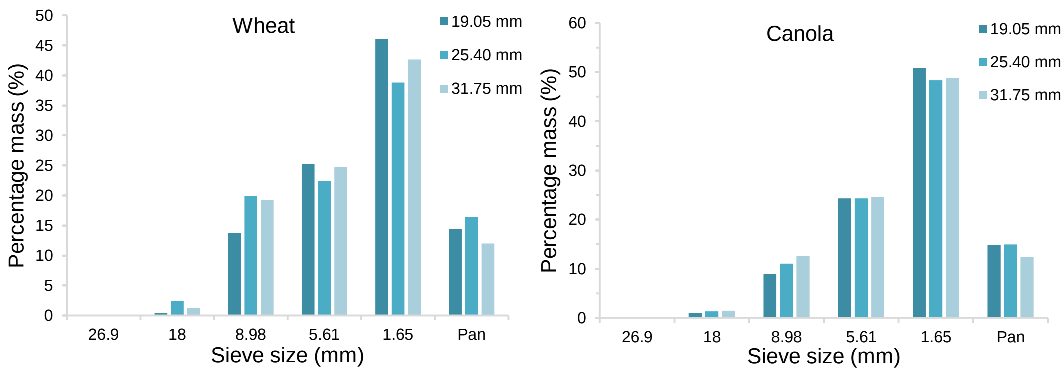

Figure 1. The distribution of selected straw chops ground using three different hammer mill screen size of 19.05, 25.40, and 31.75 mm.

Density analysis Appendix A shows that the density of compressed straw samples is significantly affected by the moisture content, hammer mill screen size, and pressure that has been reported in previous studies (Adapa et al., 2009; Mani et al., 2003).

Fig. 2 shows the typical curves of density with the compression and relaxation time at different applied pressure for chopped canola straw, which was similar to chopped wheat straw samples. It shows that the density obviously increased with increasing pressure and the four curves are almost coincident before each one reached its preset load, and the final density kept its value because the testing set stopped and maintained its position when the preset load reached (actual applied pressures were a little higher).

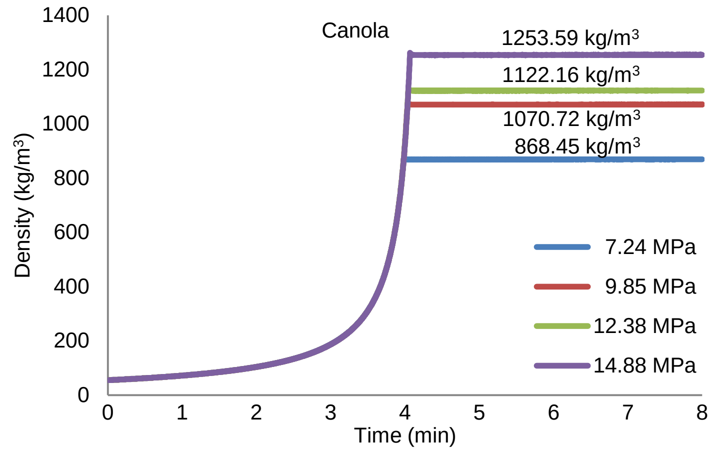

Figure 2. Typical curves of density with the compression and relaxation time at four levels of applied pressure for chopped canola straw at the screen size of 19.05 mm and moisture content of 15% (w.b.).

The moisture content has a positive influence on the density. High moisture content significantly resulted in high density that was also reported by previous studies (Talebi et al., 2011; Watts and Bilanski, 1991). Fig. 3 shows common examples from chopped canola and wheat straw samples compressed at different moisture content and preset load. It is observed that high moisture content of the sample consistently resulted in a high density when the preset load increased from 30 to 60 kN.

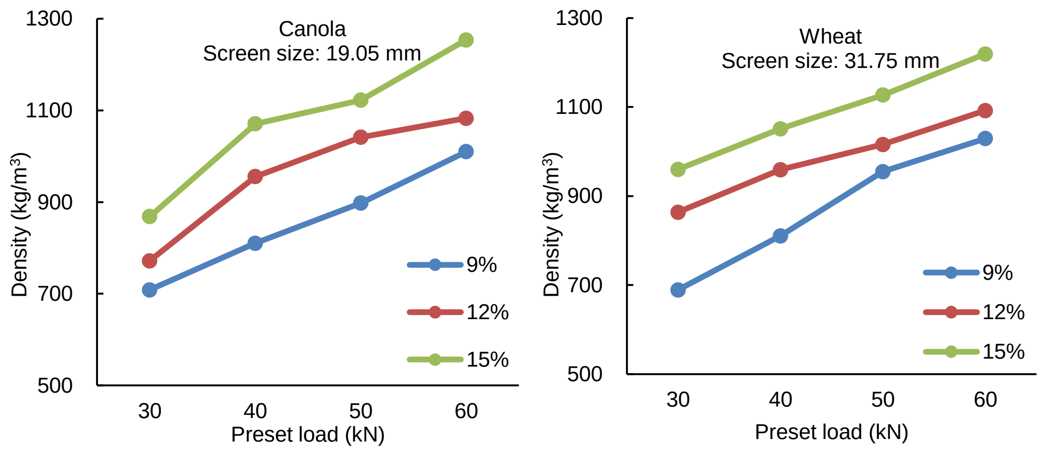

Figure 3. Density of compressed canola samples (hammer mill screen size: 19.05 mm) and wheat samples (hammer mill screen size: 31.75 mm) at moisture content of 9, 12, and 15% and preset load of 30, 40, 50, and 60 kN.

The screen size of the hammer mill has a negative effect which was also detected from the pelleting of grasses at three levels of screen sizes (3.2, 1.6 and 0.8 mm) in the study of Mani et al. (2006). High density resulted from the straw chopped using small hammer mill screen size. Fig. 4 shows the density-preset load relationship for chopped canola and wheat straw samples compressed at different particle size. It shows that smaller hammer mill screen size resulted in a high density when the preset load increased from 30 to 60 kN.

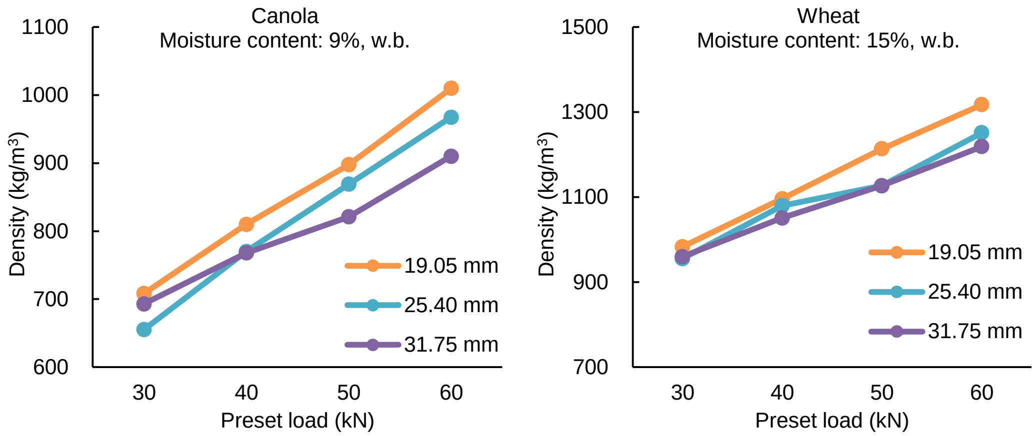

Figure 4. Density of compressed canola samples (moisture content: 9%) and wheat samples (moisture content: 15%) at hammer mill screen size of 19.05, 25.40, and 31.75 mm and preset load of 30, 40, 50, and 60 kN.

Stress relaxation characteristics After applied pressure reached a preset value, the compression die stopped and maintained its position for 240 s and the stress relaxation of compressed biomass samples was investigated (pressure vs. time at fixed strain). The stress relaxation curve of the selected biomass samples showed the same decaying pattern, which was also observed by Talebi et al. (2011). Figure 5 shows the typical relaxation curves for the biomass materials from chopped canola straw samples. The stress relaxation curves were affected by the initial preset applied loads. The higher maximum applied load, the more residual stress was left in the compressed sample; this was also observed during the compaction of ground alfalfa and chopped timothy samples by (Tabil and Sokhansanj, 1997; Talebi et al., 2011), respectively.

Figure 5 also shows that the residual stress decreased with the time. The relaxation process immediately occurred at the end of the compaction process. At the first phase of relaxation curves, the residual stress sharply decayed in a few minutes, with more than 85% of decayed stress occuring within 1 min (Appendix A). At the second phase, stress slowly declined to a relatively stable value with time. Since all the applied stresses were not recovered, the two selected biomass materials had exhibited non-linear viscoelastic behavior.

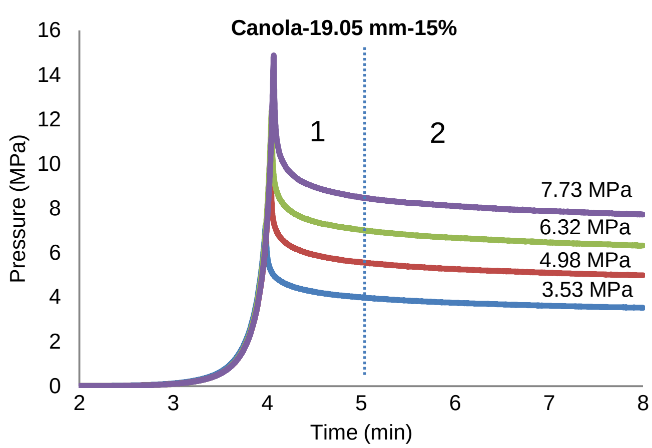

Figure 5. Stress-relaxation vs. time curves for canola straw samples compressed at the combination of smallest particle size (ground using hammer mill screen size of 19.05 mm) and largest moisture content (15%, w.b.).

Appendix A shows the maximum applied pressure has a negative effect on the percentage relaxation. Larger applied pressure may result in more energy to be converted to binding force between particles. With increasing of biomass moisture content, the percent relaxation also increased for the selected biomass materials, while it was not evidently affected by the particle size of samples (chopped using different hammer mill screen sizes). This trend of results was similarly observed for chopped timothy hay (Talebi et al., 2011). The percent relaxation values ranged from 40.00% to 51.33% for chopped canola straw and 37.86% to 46.40% for chopped wheat straw samples.

The linear regression analysis was performed for the second phase of stress relaxation to determine the relaxation speed as the followed formula. The parameters of linear regression analysis are showed in Appendix B. Results showed that higher applied stress can result in a higher relaxation speed and moisture content has a positive on the relaxation speed.

$$\sigma(t) = k_1 \cdot t + k_2$$

Where,

k1, k2 =constants.

CONCLUSIONS The following conclusions can be drawn out from this study:

1) The density of selected compressed chopped straw obviously increased with increase in applied pressure and moisture content; the hammer mill screen size has a negative effect on the density of compressed chopped straw.

2) At the first phase of relaxation, the residual stress sharply decayed in few minutes, with more than 85% of decayed stress occuring within 1 min; at the second phase, stress slowly declined to a relative stable value with time, the stress was linear related with respect to time.

3) Higher applied stress can result in a higher relaxation speed; moisture content has a positive on the relaxation speed.

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References

Adapa, P., L. Tabil, and G. Schoenau. 2009. Compaction characteristics of barley, canola, oat and wheat straw. Biosystems Engineering 104(3):335-344.

Adapa, P., L. Tabil, and G. Schoenau. 2011. Grinding performance and physical properties of non-treated and steam exploded barley, canola, oat and wheat straw. Biomass and Bioenergy 35(1):549-561.

ASABE.2008.S358.2: Moisture Measurement-Forages. MI (USA): American Society of Agricultural and Biological Engineers: St. Joseph.

ASABE.2012.S424.1: Method of Determining and Expressing Particle Size of Chopped Forage Materials by Screening MI (USA): American Society of Agricultural and Biological Engineers: St. Joseph.

Cooper, A. R., and L. E. Eaton. 1962. Compaction behavior of several ceramic powders. Journal of the American Ceramic Society 45(3):97-101.

Faborode, M. O., and J. R. O'Callaghan. 1987. Optimizing the compression/briquetting of fibrous agricultural materials. Journal of Agricultural Engineering Research 38(4):245-262.

Faborode, M. O., and J. R. O'Callaghan. 1989. A rheological model for the compaction of fibrous

agricultural materials. Journal of Agricultural Engineering Research 42(3):165-178.
Heckel, R. W. 1961. Analysis of Powder Compaction Phenomenon. Transactions of the Metallurgical Society of AIME(221):1001-1008.
Johnson, P., S. Cenkowski, and J. Paliwal. 2013. Compaction and relaxation characteristics of single compacts produced from distiller's spent grain. Journal of Food Engineering 116(2):260-266.
Jones, W. D. 1960. Fundamental principles of powder metallurgy. Edward Arnold Publishers Ltd., London, UK.
Kaliyan, N., and R. V. Morey. 2009. Constitutive model for densification of corn stover and switchgrass. Biosystems Engineering 104(1):47-63.
Mani, S., S. Sokhansanj, X. Bi, and L. Tabil. 2004a. Compaction of corn stover. In ASAE Annual International Meeting 2004. American Society of Agricultural Engineers.
Mani, S., L. Tabil, and S. Sokhansanj. 2003. An overview of compaction of biomass grinds. Powder Handling and Process 15(3):160-168.
Mani, S., L. G. Tabil, and S. Sokhansanj. 2002. Compaction behavior of some biomass grinds. AIC 2002 Meeting, CSAE/SCGR Program, Saskatoon, Saskatchewan AIC Paper No. 02-305.
Mani, S., L. G. Tabil, and S. Sokhansanj. 2004b. Evaluation of compaction equations applied to four biomass species. Canadian Biosystems Engineering 46(3):55-61.
Mani, S., L. G. Tabil, and S. Sokhansanj. 2006. Effects of compressive force, particle size and moisture content on mechanical properties of biomass pellets from grasses. Biomass and Bioenergy 30(7):648-654.
Moreyra, R., and M. Yeleg. 1980. Compressive deformation patterns of selected food powders. Journal of Food Science 45(4):866-868.
Ndiema, C., P. Manga, and C. Ruttoh. 2002. Influence of die pressure on relaxation characteristics of briquetted biomass. Energy Conversion and Management 43(16):2157-2161.
Nona, K. D., B. Lenaerts, E. Kayacan, and W. Saeys. 2014. Bulk compression characteristics of straw and hay. Biosystems Engineering 118:194-202.
Panelli, R., and F. A. Filho. 2001. A study of a new phenomenological compacting equation. Powder Technology 114(1–3):255-261.
Peleg, M., and R. Moreyra. 1979. Effect of moisture on the stress relaxation pattern of compacted powders. Powder Technology 23(2):277-279.
Scoville, E., and M. Peleg. 1981. Evaluation of the effects of liquid bridges on the bulk properties of model powders. Journal of Food Science 46(1):174-177.
Sudhagar, M., L. G. Tabil, and S. Sokhansanj. 2004. Grinding performance and physical properties of wheat and barley straws, corn stover and switchgrass. Biomass and Bioenergy 27(4):339-352.
Tabil, L. G. 1996. Binding and pelleting characteristics of alfalfa. Unpublished Ph.D. Thesis. University of Saskatchewan, Department of Agricultural and Bioresource Engineering, Saskatoon, SK
Tabil, L. G., and S. Sokhansanj. 1997. Bulk properties of alfalfa grind in relation to its compaction characteristics. Applied Engineering in Agriculture 13(4).
Talebi, S., L. Tabil, A. Opoku, and M. Shaw. 2011. Compression and relaxation properties of timothy hay. Int J Agric & Biol Eng. 4(3):69-78.
Tumuluru, J. S., L. G. Tabil, Y. Song, K. L. Iroba, and V. Meda. 2014. Grinding energy and physical properties of chopped and hammer-milled barley, wheat, oat, and canola straws. Biomass and Bioenergy 60(0):58-67.
Walker, E. E. 1923. The properties of powders. Part VI. The compressibility of powders. Trans. Faraday Soc. 19(July):73-82.
Watts, K. C., and W. K. Bilanski. 1991. Stress relaxation of alfalfa under constant displacement. Transactions of the ASAE (USA).

Appendix A. Density of compressed biomass, relaxed stress, percentage relaxation, and relaxation rate at t= 1 min.

Biomass	Hammer mill screen size (mm)	Moisture content (%)	Applied stress (MPa)	Density (kg/m^3)	Relaxed stress (MPa)	Percentage relaxation (%)	Relaxation rate at t= 1 min (%)
Canola	19.05	9	7.27	708.42	4.21	42.10	86.90
			9.71	810.18	5.74	40.92	89.13
			12.15	897.63	7.22	40.56	90.33
			14.63	1010.12	8.69	40.61	91.31
		12	7.29	771.86	3.87	47.01	88.11
			9.78	955.62	5.30	45.88	89.80
			12.31	1041.53	6.76	45.13	90.09
			14.87	1082.85	8.22	44.75	90.63
		15	7.24	868.45	3.53	51.33	87.26
			9.85	1070.72	4.98	49.42	88.26
			12.38	1122.16	6.32	48.92	88.82
			14.88	1253.59	7.73	48.09	89.86
	25.40	9	7.19	655.22	4.16	42.10	87.83
			9.73	770.08	5.72	41.23	89.27
			12.20	869.02	7.26	40.52	90.84
			14.44	967.52	8.66	40.00	90.96
		12	7.27	776.75	3.88	46.67	88.65
			9.76	824.30	5.31	45.53	88.83
			12.35	981.09	6.61	46.47	89.49
			14.60	1060.84	7.96	45.44	89.95
		15	7.41	871.59	3.72	49.72	88.41
			9.80	1004.54	4.99	49.03	88.37
			12.52	1084.58	6.60	47.31	89.50
			15.03	1133.20	8.02	46.63	89.38
	31.75	9	7.24	692.93	4.22	41.72	88.40
			9.67	767.90	5.70	41.05	89.35
			12.14	821.14	7.18	40.86	91.15
			14.66	910.12	8.71	40.58	90.86
		12	7.25	725.40	3.97	45.28	88.78
			9.64	840.84	5.33	44.73	89.22
			12.26	928.68	6.84	44.22	90.17

			14.87	1023.74	8.36	43.78	90.77
		15	7.26	828.85	3.70	49.13	88.33
			9.83	938.82	5.09	48.27	88.73
			12.51	1004.34	6.57	47.48	88.83
			14.94	1102.02	8.02	46.31	89.90
Wheat	19.05	9	7.42	815.97	4.25	42.77	89.45
			10.12	927.25	5.98	40.90	90.83
			12.71	1113.53	7.55	40.56	91.35
			15.56	1157.57	9.64	38.04	92.27
		12	7.53	945.59	4.25	43.60	89.13
			10.05	1073.52	5.82	42.11	89.37
			12.76	1201.04	7.30	42.81	89.75
			15.62	1295.00	9.27	40.68	90.08
		15	7.80	983.44	4.18	46.40	88.02
			10.29	1096.30	5.75	44.07	88.69
			13.39	1213.96	7.65	42.85	89.53
			15.75	1317.75	9.03	42.66	89.07
	25.40	9	7.45	761.61	4.32	42.01	89.55
			10.02	884.47	6.02	39.86	90.17
			12.68	1008.14	7.72	39.10	91.17
			15.34	1076.48	9.51	38.00	92.69
		12	7.47	860.39	4.17	44.16	88.85
			10.16	1007.56	5.89	42.04	89.96
			13.16	1040.18	7.76	41.04	90.51
			15.69	1150.76	9.43	39.89	90.42
		15	7.63	955.73	4.09	46.40	88.33
			10.09	1080.16	5.58	44.65	88.96
			12.97	1126.97	7.30	43.75	89.44
			16.26	1251.41	9.18	43.53	89.01
	31.75	9	7.41	689.21	4.34	41.48	89.79
			10.01	810.50	6.01	40.00	90.64
			12.79	954.71	7.82	38.85	91.71
			15.66	1029.23	9.73	37.86	91.94
		12	7.52	863.50	4.18	44.40	88.17
			10.07	959.31	5.83	42.12	89.96
			13.02	1015.92	7.68	41.01	90.81

		15.34	1091.92	9.20	40.04	91.10
	15	7.58	959.98	4.14	45.30	88.25
		10.47	1050.98	5.89	43.77	88.86
		12.79	1126.93	7.33	42.67	89.78
		15.99	1219.06	9.19	42.52	89.31

Appendix B. Parameters of linear regression at the phase 2 of stress relaxation.

Biomass	Hammer mill screen size (mm)	Moisture content (%)	Applied stress (MPa)	Phase 2			
				k_1	k_2	R^2	SSE
Canola	19.05	9	7.27	-0.115	5.100	0.964	0.019
			9.71	-0.135	6.773	0.972	0.020
			12.15	-0.144	8.340	0.967	0.023
			14.63	-0.161	9.938	0.964	0.027
		12	7.29	-0.123	4.816	0.968	0.020
			9.78	-0.151	6.462	0.964	0.025
			12.31	-0.173	8.091	0.967	0.027
			14.87	-0.201	9.773	0.969	0.031
		15	7.24	-0.145	4.638	0.962	0.025
			9.85	-0.182	6.383	0.964	0.031
			12.38	-0.218	8.004	0.971	0.033
			14.88	-0.238	9.558	0.966	0.039
	25.40	9	7.19	-0.104	4.963	0.963	0.017
			9.73	-0.128	6.707	0.967	0.020
			12.20	-0.138	8.327	0.968	0.022
			14.44	-0.162	9.917	0.968	0.026
		12	7.27	-0.113	4.752	0.963	0.019
			9.76	-0.149	6.470	0.967	0.024
			12.35	-0.186	8.046	0.962	0.032
			14.60	-0.209	9.582	0.968	0.033
		15	7.41	-0.132	4.746	0.972	0.019
			9.80	-0.176	6.352	0.966	0.029
			12.52	-0.200	8.144	0.968	0.031
			15.03	-0.235	9.842	0.968	0.037
	31.75	9	7.24	-0.102	5.006	0.969	0.016
			9.67	-0.125	6.669	0.969	0.019
			12.14	-0.136	8.233	0.969	0.021
			14.66	-0.169	10.019	0.969	0.026
		12	7.25	-0.106	4.788	0.963	0.018
			9.64	-0.142	6.436	0.976	0.019
			12.26	-0.161	8.090	0.973	0.023
			14.87	-0.185	9.791	0.964	0.031
		15	7.26	-0.125	4.665	0.964	0.021
			9.83	-0.166	6.372	0.965	0.027
			12.51	-0.211	8.202	0.971	0.032
			14.94	-0.227	9.772	0.969	0.035
Wheat	19.05	9	7.42	-0.108	5.085	0.968	0.017
			10.12	-0.127	6.951	0.965	0.021
			12.71	-0.149	8.705	0.966	0.024
			15.56	-0.159	10.849	0.954	0.030
		12	7.53	-0.119	5.164	0.969	0.018
			10.05	-0.147	6.963	0.974	0.021

		12.76	-0.191	8.773	0.959	0.034
		15.62	-0.212	10.894	0.959	0.038
	15	7.80	-0.143	5.285	0.963	0.024
		10.29	-0.171	7.084	0.967	0.027
		13.39	-0.203	9.200	0.954	0.039
		15.75	-0.247	10.975	0.977	0.033
25.40	9	7.45	-0.107	5.151	0.970	0.016
		10.02	-0.126	6.992	0.940	0.028
		12.68	-0.147	8.854	0.970	0.022
		15.34	-0.142	10.616	0.961	0.025
	12	7.47	-0.121	5.107	0.966	0.020
		10.16	-0.141	6.974	0.961	0.025
		13.16	-0.175	9.111	0.965	0.029
		15.69	-0.203	11.003	0.962	0.035
	15	7.63	-0.141	5.170	0.958	0.025
		10.09	-0.169	6.880	0.959	0.030
		12.97	-0.203	8.878	0.975	0.028
		16.26	-0.260	11.188	0.960	0.046
31.75	9	7.41	-0.098	5.098	0.958	0.018
		10.01	-0.124	6.969	0.971	0.019
		12.79	-0.127	8.808	0.949	0.025
		15.66	-0.158	10.956	0.960	0.028
	12	7.52	-0.132	5.200	0.970	0.020
		10.07	-0.141	6.908	0.953	0.027
		13.02	-0.168	8.974	0.965	0.028
		15.34	-0.186	10.639	0.973	0.027
	15	7.58	-0.133	5.167	0.964	0.022
		10.47	-0.171	7.215	0.977	0.023
		12.79	-0.187	8.779	0.967	0.030
		15.99	-0.250	11.122	0.968	0.039