UTILIZATION OF RHEOLOGICAL MODEL FOR DESCRIPTION OF MECHANICAL BEHAVIOUR OF RAPE BULK SEEDS UNDER COMPRESSION LOADING

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Abstract
The article is focused on the description of mechanical behavior of rape bulk seeds under compression loading with aid of simple rheological model. A single pressing vessel with inner diameter 80 mm with initial pressing height 80 mm of bulk rape seeds were used for determination of deformation characteristics under compression loading up to 100 kN. Determined mechanical behavior of rape bulk seeds was described by rheological model with one branch and rheological model with two branches. Based on this study it follows that model with two branches more precisely described the compressive stress and time response than the model with one branch.

Key words: *viscosity; modulus; elasticity; strain; stress; time.*

INTRODUCTION
For optimal design of technology for oil seeds pressing it is necessary to fully understand to the inner processes occur during compression of bulk seeds as well as mathematically describe dependency between compressive force and bulk seeds deformation (*Karaj, & Muller, 2011*). There are several already published methods which can be used for description of deformation curve (*Herak, Kabutey, & Sigalingging, 2016; Kabutey, Herak, Choteborsky, et al., 2013; Rajabipour, Zariefard, Dodd, & Norris, 2004*). However these methods are mostly based on tangent curve utilization, using reciprocal slope transformation or application of Darcy laws. Unfortunately these methods don't respect viscoelasticity behavior of pressed bulk seeds which currently comes to the fore especially in oil processing models for example based on finite element method used in industrial engineering (*Petru, Novak, Herak, & Simanjuntak, 2012; Saeidirad, Rohani, & Zarinfneshat, 2013*). Mechanical behavior of rape bulk seeds under compression loading was deeply investigated in already published studies and gained knowledge is widely used in industrial practice (*Divisova, Herak, Kabutey, et al., 2014; Mohsenin, 1970*). Nevertheless the lack of information about viscoelasticity properties of rape bulk seeds still exists and they are highly desirable for mathematical models development. Thus the aim of this study is to describe mechanical behavior of rape bulk seeds under compression loading with aid of simple rheological model.

MATERIALS AND METHODS
Samples of bulk Rape seeds (*Brassica napus* L.) obtained from Czech Republic were used for the experiment. The general physical properties of the oilseed crop are given in Tab. 1. To determine the relationship between compressive force and deformation characteristic curves, a compression device (Labortech, model 50, Czech Republic) was used to record the course of deformation function. A single pressing vessel with inner diameter D = 80 mm (Fig. 1) was used. Initial pressing height H = 80 mm of bulk seeds were tested with a compression speed v = 1 mm·s^{-1} under temperature of 20 °C. The compressive force F was between 0 and 100 kN. The experiment was repeated three times. The measured characteristics between compressive force F (kN) and deformation x (mm) were transformed into dependency between compressive stress σ (MPa) and strain ε (-).

Tab. 1 Physical properties of bulk rapeseeds; data in the table are means ± SD

Moisture content (%)	Mass (g)	Porosity (%)	Coefficient of variation of compressive force (%)
6.9 ± 0.1	269± 0.4	42.85 ± 0.49	8.0 ± 0.3

Description of the mechanical behavior of rape bulk seeds was carried out by applying rheological model with one branch and rheological model with two branches presented in Fig. 1. One branch model was assembled as serial linked spring and dashpot, where spring was loaded by compression loading and dashpot by tension loading. Compressive speed was assumed as a constant and deformation rate γ (s^{-1}) was calculated by eq. (1).

$$\gamma = \frac{v}{H} \quad (1)$$

Mechanical behavior of one branch rheological model was described by general differential equation eq. (2).

$$\dot{\varepsilon} = \gamma = \frac{\dot{\sigma}}{\eta} - \frac{\sigma}{E} \quad (2)$$

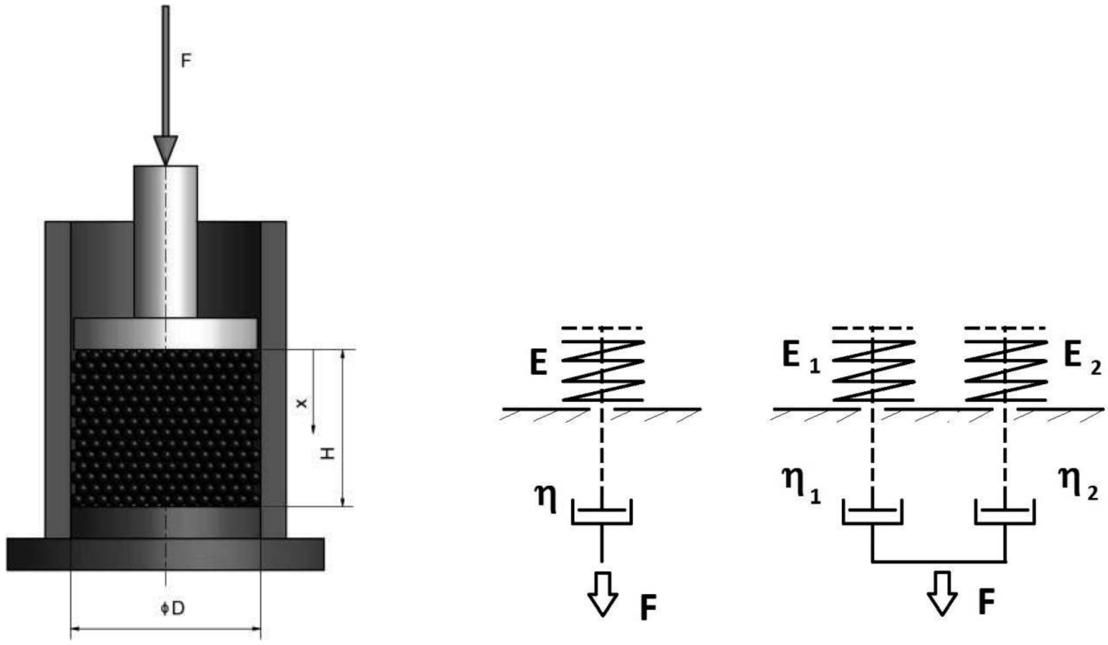
where E (MPa) is moduli of elasticity and η ($MPa \cdot s^{-1}$) is coefficients of dynamic viscosity. Formula for description dependency between compressive stress and time (3) was determined by solving eq. (2) with consideration of boundary conditions (σ = 0 MPa; t = 0 s) that in zero time is also zero compression stress.

$$\sigma_I = \gamma \cdot \eta \cdot (e^{\frac{E}{\eta} \cdot t} - 1) \quad (3)$$

Two branch model (Fig. 1) was also derived from eq. (3) and it is described by eq. (4),

$$\sigma_{II} = \gamma \cdot \eta_1 \cdot \left(e^{\frac{E_1}{\eta_1} \cdot t} - 1\right) + \gamma \cdot \eta_2 \cdot (e^{\frac{E_2}{\eta_2} \cdot t} - 1) \quad (4)$$

where E_1 (MPa), E_2 (MPa) are moduli of elasticity for the models branches; η_1 ($MPa \cdot s^{-1}$) and η_2 ($MPa \cdot s^{-1}$), are coefficients of dynamic viscosity of the models branches, t (s) is time of compression; σ_I (MPa), σ_{II} (MPa) are compressive stress. The stress strain characteristics for rheological models was analyzed using Mathcad 14 Software (MathCAD 14, PTC Software, Needham, MA, USA), which uses the Levenberg-Marquardt algorithm for data fitting (*Marquardt, 1963*).



a) **b)** **c)**

Fig. 1 a) Scheme of pressing equipment; b) Scheme of one branch model; c) Scheme of two branches model

RESULTS AND DISCUSSION

The amounts determined from individual experiments are shown in Fig. 2. Measured amounts were fitted by one branch model (3) and two branches model (4) whose coefficients are shown in Tab. 2. Graphical displaying of measured amounts and fitted functions are also displayed in Fig. 2. From the determined coefficients of determination it was found that fitted functions described the measured amounts accurately. The amounts of the coefficients of determination in all experiments were close to one (Tab. 3). From analysis of the images of individual experiments it was clear that the fitted curves (3 and 4) described accurately measured amounts over the whole range of deformation. From the statistical analysis ANOVA which was calculated for the level of significance 0.05, it was seen (Tab. 3) that the values of F_{crit} (critical value compares a pair of models) were higher than F_{ratio} values (value of the F-test) for all measured experiments and amounts of P_{value} (significance level at which it can be rejected by the hypothesis of equality of models) were higher than significance level 0.05. This shows that one branch model as well as two branches model are statistically significant as measured data and models (3 and 4) can be used for fitting of measured amounts

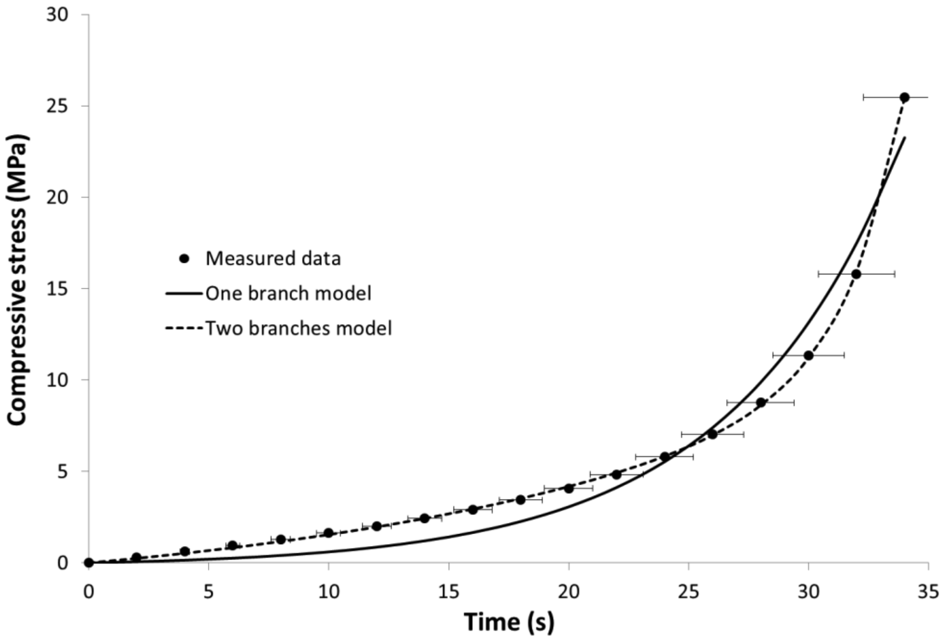


Fig. 2 Dependency between compressive stress and strain

Tab. 2 Determined coefficients of rheological models

One branch model		**Two branches model**			
***E* (MPa)**	**η (MPa·s^{-1})**	**E_1 (MPa)**	**η_1 (MPa·s^{-1})**	**E_2 (MPa)**	**η_2 (MPa·s^{-1})**
2.196	15.583	9.455	183.637	$3.737 \cdot 10^{-4}$	$9.033 \cdot 10^{-4}$

Tab. 3 Coefficients of statistical analysis

	F_{ratio} (-)	**P_{value} (-)**	**F_{crit} (-)**	**R^2 (-)**
One branch model	0.0345	0.854	4.1491	0.92
Two branches model	0.0005	0.994	4.1491	0.99

Based on the variability of rape bulk seeds which was confirmed by the coefficient of variation values (Tab. 1), the model with two branches (4) more precisely described the compressive stress and time response (Fig. 2) than the model with two branches (3), which showed deviation of the deformation curve as confirmed by the coefficient of variation values (Fig. 2). From this conducted study it follows that the determined curves using rheological models were in accordance with results of already published studies and that the obtained values of viscoelasticity properties of rape bulk seeds can be used as background for development of further models (*Herak, Kabutey, Divisova, & Simanjuntak, 2013; Blahovec, 1996.; Petru, Novak, Herak, & Simanjuntak, 2012; Rajabipour, Zariefard, Dodd, & Norris, 2004*) and it is clear that determined rheological model can be also used for description of mechanical behaviour of other oil bulk seeds.

CONCLUSIONS

- Mechanical behavior of rape bulk seeds under compression loading was determined in this study.
- With aid of two simple rheological models based on serial linked spring and dashpot deformation characteristic of rape bulk seeds was mathematically described.
- Rheological models were compared to each other and based on this study it follows that model with two branches more precisely described the compressive stress and time response than the model with one branch.

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