# MOISTURE CONDITIONING OF BULK RAPESEEDS AND DETERMINATION OF MECHANICAL PROPERTIES AND PERCENTAGE OIL YIELD UNDER UNIAXIAL COMPRESSION LOADING

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***Abstract***
*This study described the mechanical properties and estimation of the percentage oil yield of bulk rapeseeds samples at different moisture content under compression loading. The initial moisture content was determined to be 4.879 % w.b. The moisture content levels of 6.615, 7.144, 8.325 and 9.375 % w.b. were determined using the moisture conditioning oven at different relative humidity levels from 60 to 75 % with 5% interval. The mass of the samples was kept constant at 111.69 g repressing an initial pressing height of 60 mm using the vessel diameter of 60 mm. The samples were compressed at a the maximum force of 100 kN and a speed of 5 mm/min. The observed parameters were deformation, oil yield, oil expression efficiency, hardness and deformation energy. Based on the correlation analysis, it was found that all the observed parameters negatively correlated significantly (P < 0.05) with moisture content. The correlation values were between -0.933 and -0.983. The model parameter estimates were also described from the simple linear regression analysis. The moisture content of 4.875 % w.b. was established to be optimum for a higher oil yield of 14.849 ± 2.475 %, oil expression efficiency of 46.593 ± 7.767 %, deformation energy of 447.375 ± 22.710 J, deformation of 30.7 ± 0.410 mm and hardness of 3257.62 ± 43.519 N/mm.*

**Key words:** *moisture content, percentage oil yield, strength properties, deformation energy, regression models.*

## INTRODUCTION
Moisture content is one of the most important factors to consider in the processing and handling of agricultural products (*Mamman & Umar, 2005; Burubai, Akor, Igoni & Puyate, 2007*). In the literature, considerable studies have been conducted on the effect of moisture content on the mechanical properties and loading orientations of seeds/kernels/nuts which are not limited to the following authors (*Baumler, Cuniberti, Nolasco & Riccobene, 2006; Burubai, Akor, Igoni & Puyate, 2007; Lzli, Unal & Sincik, 2009; Carcel et al., 2012; Adejumo, Inaede & Adamu, 2013*). Under the uniaxial compression loading, the mechanical/strength properties of agricultural products include the rupture force, deformation to rupture point, failure stress and strain, Young's modulus, toughness, hardness and strain energy (*Sirisomboon, Kitchaiya, Pholpho & Mahuttanyavanitch, 2007; Chakespari, Rajabipour & Mobli, 2010; Carcel et al., 2012*). In particular, *Burubai, Akor, Igoni & Puyate (2007)* reported the mechanical properties namely compressive force, deformation, failure stress, strain energy and Young's modulus of African nutmeg (Monodora myristica) in the moisture content range of 8.0 to 28.7 % d.b. The authors indicated that compressive force, failure stress and Young's modulus decreased with an increase in moisture content whiles deformation and strain energy increased with an increase in moisture content. *Lzli, Unal & Sincik (2009)* also studied the physical and mechanical properties of rapeseed at different moisture levels in the range of 7.3 to 27.4 % d.b. for three varieties of rapeseeds. Regarding the mechanical properties, the authors reported only the rupture force for the mechanical properties which decreased as a function of moisture content. Most importantly, for oil yield, *Adejumo, Inaede & Adamu (2013)* studied the effect of moisture content on the yield and characteristics of oil from *Moringa oleifera* seeds. The authors found a decrease in oil yield with the increase in moisture

content from 7.28 to 20 % d.b. *Orhevba, Chukwu, Osunde & Ogwuagwu (2013)* also reported a decrease in oil yield of neem seed kernel in the moisture content values from 6.3 to 16.6 % w.b. In our previously published studies on bulk rapeseeds under compression loading, single moisture content was considered to examine the mechanical properties, force-deformation characteristic curves, oil yield and optimum operating factors (*Divišova et al., 2014; Demirel et al., 2021; Demirel et al., 2022*). Moisture dependence on mechanical properties and percentage oil yield of bulk rapeseeds is not adequate in the literature. Therefore, this present study aims to add to the literature the information on the compressive force, deformation, energy, hardness, oil yield and oil expression efficiency of bulk rapeseeds at different moisture content under compression loading.

## MATERIALS AND METHODS

A bag of 25 kg of rapeseeds was obtained from Česká Skalice, Czech Republic and kept in the laboratory. The initial moisture content of the sample of 4.879 (% w.b.) was determined using the standard oven method at 105 ºC and drying time of 17 h (*ISI, 1996*). The oil content of the sample of 31.87±0.01% by the Soxhlet extraction procedure as reported in our previously published study (*Demirel et al., 2021*) was used in the calculation of the oil expression efficiency. The moisture conditioning of the samples was done using the hot oven (MEMMERT GmbH+Co.KG, Schwabach, Germany) equipped with a distilled water container placed atop. The relative humidity was set in the range between 60 and 75% with a 5% interval. For each sample, the minimum and maximum temperatures were set at 48 ºC and 52 ºC respectively and the actual temperature was set at 50 ºC where the moisture conditioning for each sample was run for 24 h. The electronic balance (Kern 440-35, Kern & Sohn GmbH, Balingen, Germany) was used to measure the mass of the samples. To determine the moisture content at each relative humidity, the samples after 24 h conditioning were further put into the standard oven method. The moisture content of the sample was calculated using equation (1) (*Blahovec, 2008*).

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

where $m_b$ and $m_a$ represent the masses of rapeseed samples before and after oven drying (g).

**Tab. 1** Calculated moisture content at different relative humidity

| Relative humidity (%) | Moisture content (% w.b.) |
|---|---|
| 47* | 4.879 |
| 60** | 6.615 |
| 65** | 7.144 |
| 70** | 8.325 |
| 75** | 9.375 |

* Laboratory condition ** Moisture conditioning

The universal compression machine (ZDM 50, Czech Republic) and the pressing vessel diameter of 60 mm with a plunger were used to describe the force-deformation curves of the samples at a maximum force of 100 kN and speed of 5 mm/min. The initial pressing height of the sample was measured at 60 mm corresponding to a mass of 111.69 g. The compression tests with the moisture levels are shown in Fig. 1. The tests were repeated twice, and averaged values were used in further analyses.

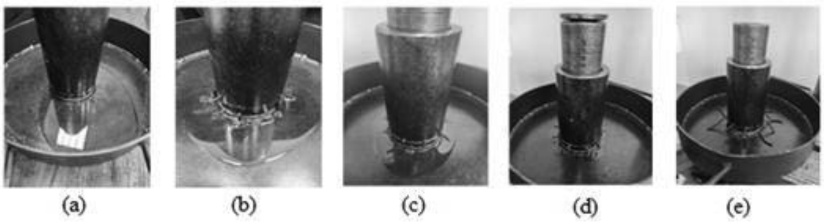


**Fig. 1** Compression test of rapeseed samples at different moisture levels (a) 4.879 % w.b. (b) 6.615 % w.b. (c) 7.144 % w.b. (d) 8.325 % w.b. and (e) 9.375 % w.b showing the output oil and seedcake ejection.

Deformation values were obtained directly from the compression test for each sample. Oil yield and oil expression efficiency were determined according to equations (2) and (3) (*Deli et al., 2011; Demirel et al., 2021*).

$$OY = \left(\frac{M_O}{M_S}\right) \cdot 100 \tag{2}$$

$$OEE = \left(\frac{OY}{O_C}\right) \cdot 100 \tag{3}$$

where $OY$ is the oil yield (%), $M_O$ is the mass of oil (g), $M_S$ is the mass of sample seeds (g), $OEE$ is the oil expression efficiency (%) and $O_C$ is the oil content (%) by the Soxhlet extraction the Soxhlet extraction procedure (*Niu, Li, Chen & Xu 2014*). The energy is the area under the force-deformation curve which was calculated using equation (4) (*Gupta and Das, 2000; Lysiak, 2007; Karaj and Muller, 2010*).

$$EN = \sum_{n=0}^{n=i=1} \left[\frac{F_{n+1} + F_N}{2} . X_{n+1} - X_n\right] \tag{4}$$

where $EN$ is the energy (J), $F$ is the compressive force (N), and $X$ is the deformation (mm), which was converted to meters during the calculation. The hardness was calculated using equation (5) (*Chakespari, Rajabipour & Mobli, 2010*).

$$HD = \frac{F}{X} \tag{5}$$

where $HD$ is the hardness (N/mm), $F$ is the compressive force (N) and $X$ is the deformation (mm). The data were analyzed using Statistica software (*Statsoft, 2013*) by employing correlation and simple regression techniques.

## RESULTS AND DISCUSSION

The obtained data are given in Tabs. 1 to 3 and Fig. 2. It can be seen Tab. 1 that the increment in moisture content linearly decreased the amounts of oil yield, oil expression efficiency, deformation energy, deformation and hardness. For the moisture content range of 4.879 to 9.375 (% w.b.); the oil yield ranged from 14.849±2.475 to 3.446±0.998 %; oil expression efficiency ranged from 46.593±7.767 to 10.811±3.130 %; deformation energy ranged from 447.375±22.710 to 180.041±14.271 J; deformation ranged from 30.7±0.410 to 25.48±0.156 mm and the hardness ranged from 3257.62±43.519 to 2188.074±27.234 N/mm. All the parameters negatively correlated significantly ($P < 0.05$) with moisture content increment with high correlation values between -0.936 and -0.983 (Tab. 2). The simple regression analysis (Tab. 2) also proved significant (F value > F critical or P value < 0.05) where the values of the coefficient of determination ($R^2$) were high within the range of 0.876 to 0.966. The simple regression models for all the parameters are given in Tab.3. The intercept and moisture content coefficient were significant ($P < 0.05$) indicating the adequacy of the determined models. The force-deformation curves for each moisture content value are shown in Fig. 2. The area under the curve is the deformation energy (*Gupta and Das, 2000; Lysiak, 2007; Karaj and Muller, 2010*). The control moisture content of 4.879 % w.b. showed a smooth curve compared to the moisture content value of 6.615% w.b. which indicated a serration effect being characterized by the ejection of the seedcake through the holes of the pressing vessel (*Divišova et al., 2014*). Based on this observation, the compression test for the other moisture content values was stopped at the limit force without the serration effect. The serration effect was also observed in our published study on jatropha seeds at moisture levels of 32 % w.b. and 37 % w.b. (*Kabutey, Herak & Sedlacek, 2011*). It is relevant to indicate that the serration effect is not only attributed to the high moisture content but also to the combination of high pressure and speed and diameter of the pressing vessel (*Divišova et al., 2014; Kabutey, Herak, Mizera & Wasserbauer, 2018*). The limit or rupture force values for the above-mentioned moisture content values were 100 kN, 86 kN, 79 kN, 66 kN and 57 kN respectively. It was found that the limit force decreased linearly with moisture content. Similar results were indicated by *Lzli, Unal & Sincik (2009)* for rapeseed varieties as a function of moisture content, and then *Gupta and Das (2000)* on sunflower seed and kernel. The results also confirm the study by *Burubai, Akor, Igoni & Puyate, (2007)* on African nutmeg. In this present study, oil yield decreased with the increase in moisture content. The optimum moisture content was observed at 4.879 % w.b. *Adejumo, Inaede & Adamu (2013)* reported a decrease in oil yield for Moringa oleifera seeds in the moisture content range of 7.28 to 20 % d.b. The authors further indicated that the oil yield of moringa seeds decreased with moisture content above 10 % d.b. *Orhevba, Chukwu, Osunde & Ogwuagwu (2013)* also found a decrease in neem kernel oil yield from 24.86 to 15.62 % in the moisture content range of 6.3 to 16.6 % w.b. The authors mentioned that the optimum moisture content was between 6.3 and 8.1 % d.b.

**Tab. 1** Calculated parameters at different moisture levels of bulk rapeseed samples

| Moisture content (% w.b.) | Oil Yield *OY* (%) | Oil Expression Efficiency *OEE* (%) | Deformation Energy *EN* (J) | Deformation *X* (mm) | Hardness *HD* (N/mm) |
|---|---|---|---|---|---|
| 4.879 | 14.849±2.475 | 46.593±7.767 | 447.375±22.710 | 30.7±0.410 | 3257.62±43.519 |
| 6.615 | 9.813±1.151 | 30.790±3.611 | 364.214±6.771 | 28.28±0.198 | 3182.619±22.244 |
| 7.144 | 8.361±1.686 | 26.235±5.289 | 313.112±22.766 | 26.52±0.665 | 2979.152±21.341 |
| 8.325 | 4.075±0.964 | 12.788±3.023 | 217.7412±13.200 | 25.235±0.064 | 2536.169±6.396 |
| 9.375 | 3.446±0.998 | 10.811±3.130 | 180.041±14.271 | 25.48±0.156 | 2188.074±27.234 |

**Tab. 2** Results of correlation and simple regression with the effect of moisture content

| Correlation | | | Simple regression | | |
|---|---|---|---|---|---|
| Calculated parameters | R | $R^2$ | F-value | F-critical | P-value |
| *OY* (%) | -0.952 | 0.907 | 77.667 | 5.318 | < 0.05 |
| *OEE* (%) | -0.952 | 0.907 | 77.667 | 5.318 | < 0.05 |
| *EN* (J) | -0.983 | 0.966 | 229.845 | 5.318 | < 0.05 |
| *X* (mm) | -0.936 | 0.876 | 56.464 | 5.318 | < 0.05 |
| *HD* (N/mm) | -0.941 | 0.886 | 62.209 | 5.318 | < 0.05 |

R: Correlation; $R^2$: Coefficient of determination; F-value > F-critical or P-value < 0.05 is significant.

**Tab. 3** Model estimates under the effect of moisture content

| Effect | Model *OY* (%) | Standard Error | t-value | P-value |
|---|---|---|---|---|
| Intercept | 27.563 | 2.256 | 12.218 | < 0.05 |
| Moisture content (% w.b.) | -2.677 | 0.304 | -8.813 | < 0.05 |
| Effect | Model *OEE* (%) | Standard Error | t-value | P-value |
| Intercept | 86.487 | 7.078 | 12.218 | < 0.05 |
| Moisture content (% w.b.) | -8.399 | 0.953 | -8.813 | < 0.05 |
| Effect | Model *EN* (J) | Standard Error | t-value | P-value |
| Intercept | 761.029 | 30.773 | 24.731 | < 0.05 |
| Moisture content (% w.b.) | -62.818 | 4.143 | -15.161 | < 0.05 |
| Effect | Model *X* (mm) | Standard Error | t-value | P-value |
| Intercept | 36.35924 | 1.239785 | 36.35924 | < 0.05 |
| Moisture content (% w.b.) | -1.25437 | 0.166931 | -1.25437 | < 0.05 |
| Effect | Model *HD* (N/mm) | Standard Error | t-value | P-value |
| Intercept | 4649.978 | 235.9717 | 19.70566 | < 0.05 |
| Moisture content (% w.b.) | -250.599 | 31.7725 | -7.88729 | < 0.05 |

*OY*: Oil Yield (%); *OEE*: Oil Expression Efficiency (%); *EN*: Deformation Energy (J); *X*: Deformation (mm) and *HD*: Hardness (N/mm).

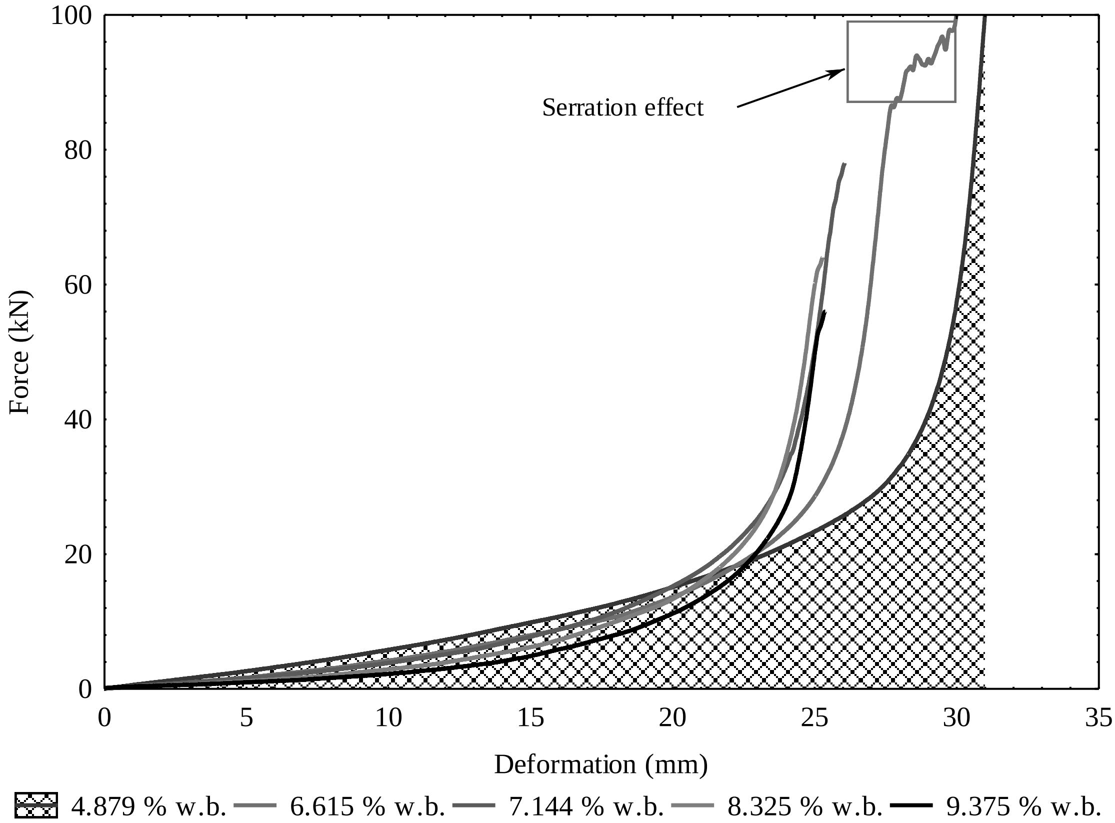


**Fig. 2** Force-deformation curves of bulk rapeseed samples at different moisture levels with the serration effect.

## CONCLUSIONS

The moisture content value of 4.879 % w.b. obtained the highest oil yield of 14.849±2.475 % and oil expression efficiency of 46.593±7.767. The corresponding deformation energy was 447.375±22.710 J. The increase in moisture content decreased the oil yield, oil expression efficiency, deformation energy, deformation and hardness of the rapeseed samples. Under the uniaxial compression loading, the moisture content of 4.879 % w.b. of the rapeseeds sample was found to be optimum for a higher percentage oil yield. In a future study, the mechanical screw press Farmet Duo would be used to validate the observed optimum moisture content for oil recovery efficiency, throughput, energy input, specific energy, temperature and oil residue in press cake.

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