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# Determination of mechanical properties of poppy waste pellets

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**Abstract.** The work deals with evaluation of mechanical properties three types of pellet samples produced from poppy waste. The pellets were submitted to compressive loading. The compressive loading curves of dependencies of force on strain and force on time were realised. Certain mechanical parameters were determined, namely the diameter of the sample, length of the sample, force at 10% of strain, force in the first maximum of the force – strain curve, strain in the first maximum of the force – strain curve, modulus of elasticity, force in the inflex point of the force – time and force – strain curves and strain and stress in the inflex point of the force – time and force – strain curves. The work lists correlations of mechanical parameters of individual pellet types. The pellet type 1 made only of ground poppy head mass has shown the best results, the pellet type 3 consisting of ground poppy heads after harvest and waste from sieving of poppy seeds in mass proportion 1 : 1 has shown the worst results.

**Key words:** compression loading, modulus of elasticity, force, strain.

## INTRODUCTION

Pellet biomass is currently utilized as a fuel in energetics, bedding and feed for livestock, as well as a fertilizer in primary agricultural production. The most common material for pellet production is wood, however, the usage of biomass from agricultural production and waste biomass, potential of which is considerable, is becoming more and more prominent. Due to this, the aim of the paper is to determine the mechanical properties of poppy waste pellets.

Duncan (2010), Obenberger & Thek (2010), Macák et al. (2015), Spirchez et al. (2016) and others deal with pellet quality in their research papers and works.

Pellet mechanical properties evaluation by compressive loading test began to receive increased attention in the last decade. Our research and experiments are based on the results of studies carried out by Oloso & Clarke (1993), Vursavuş & Özgüven (2004), Kubík et al. (2016). Pellet quality is usually evaluated by means of their density and durability. Low pellet durability is undesirable, as it can result in malfunctions of feeding system, dust emissions, and increased risk of explosion and fire during handling and storage (Zafari & Kianmehr, 2012).

Mechanical durability of pellets is influenced by many factors, including force and temperature of compression, particle size and chemical properties of input biomass (Kaliyan & Morey, 2009). Križan (2014) states that fraction content significantly influences the compressed material quality when evaluating the pellet mechanical properties crucial in terms of handling and storage.

## MATERIALS AND METHODS

The evaluated pellets are made of ground poppy heads and waste from sieving of poppy seeds (that is, small impurities and oilseed of poppy (*Papaver somniferum*) with smaller diameters, not captured in sieving). The poppy heads were ground using hammer mill. Pellet type 1 was made solely of ground poppy heads; pellet type 2 was made of material consisting of ground poppy heads and waste from sieving of poppy seeds in mass ratio 2 : 1; pellet type 3 was made of material consisting of ground poppy heads and waste from sieving of poppy seeds in mass ratio 1 : 1.

The pellets were made by the granulating machine MGL 200 (output 50–150 kg per hour for alternative pellets, power 8.85 kW, weight 310 kg, maximum height 2,230 mm). In the production of the pellets no binding agent was used, except for water. The moisture of pellets 1 was 8.89%, the moisture of pellets 2 was 8.75% and the moisture of pellets 3 was 9.77%. The density of pellets 1 was 796.3 kg m$^{-3}$, the density of pellets 2 was 776.33 kg m$^{-3}$ and the density of pellets 3 was 655.98 kg m$^{-3}$. The difference in density was caused by the differences in sample composition.

Material fraction size (Feret diameter) of pellets is listed in Table 1. Materials of pellet type 1 and 3 are shown Figs 1 and 2.

**Table 1.** Material fraction size of pellets, percentage

| Fraction, mm | 0.0–1.5 | 1.5–3.0 | 3.0–4.5 |
|---|---|---|---|
| Pellet type 1 | 70.83 | 18.75 | 10.42 |
| Pellet type 2 | 75.00 | 16.67 | 8.33 |
| Pellet type 3 | 86.42 | 11.31 | 2.27 |

**Figure 1.** Material of pellet type 1.

**Figure 2.** Material of pellet type 3.

The pellets were subjected to the compressive loading. The strength of the pellets was evaluated via the quasi static compression test. Ten compression tests were carried out for each pellet type. The result of the single test is the compression curve, that is, the dependence between compression force $F$ and compressive strain $\varepsilon$ of the pellet. The basis for the determination of compressive strain is the initial length of the pellet $L_0$. The pellets were compressed in the axial direction. The upper steel plate of the Andilog Stentor 1000 test stand, compressed the cylinder at a speed of 10 mm min$^{-1}$, until failure was observed. The compression curves were determined as the dependences $F(\varepsilon)$ and the dependences $F(t)$. Time of compression was calculated from the speed of the test stand (10 mm min$^{-1}$), the elongation $\Delta L$ was also measured by the stand.

The cubic regression equations of the dependence $F(\varepsilon)$ were evaluated on the intervals $(0, F_m)$:

$$F = a\varepsilon^3 + b\varepsilon^2 + c\varepsilon + d \qquad (1)$$

where $F$ – compression force, N; $\varepsilon$ – compressive strain, mm mm$^{-1}$; $a$, $b$, $c$, $d$ –regression coefficients, N.

The cubic regression equations were evaluated also on the intervals $(0, F_m)$ and the inflection points were determined for the dependencies $F(t)$:

$$F = et^3 + ft^2 + gt + h \qquad (2)$$

where $F$ – compression force, N; $t$ – time of compression, s; $e$ – regression coefficient, N s$^{-3}$; $f$ – regression coefficient, N s$^{-2}$; $g$ – regression coefficient, N s$^{-1}$; $h$ – regression coefficient, N.

Several mechanical parameters of the pellets were enumerated on the basis of the dependence of force on time and strain and on the basis of the inflection points of the compression curves. The compressive strain in the first maximum of the compression curves was enumerated from the equation:

$$\varepsilon_m = \frac{v\, t_m}{L_0} \qquad (3)$$

where $\varepsilon_m$ – compressive strain in the first maximum of the compression curve $F(\varepsilon)$, mm mm$^{-1}$; $v$ – speed of deformation, mm min$^{-1}$; $t_m$ – time in the first maximum, min; $l_0$ – original length of the sample, mm.

The compressive stress in the first maximum of the compression curves was enumerated from the equation:

$$\sigma_m = \frac{4\, F_m}{\pi\, d^2}(1 - \varepsilon_m) \qquad (4)$$

where $\sigma_m$ – compressive stress in the first maximum of the compression curve $\sigma(\varepsilon)$, MPa; $\varepsilon_m$ – compressive strain in the first maximum of the compression curve $F(\varepsilon)$, mm mm$^{-1}$; $F_m$ – force in the first maximum of the compression curve $F(\varepsilon)$, N; $d$ – original diameter of the sample, mm.

The compressive stresses $\sigma_{mp}$ were also evaluated from the first maximum of the compression loading curves of the dependence $F(\varepsilon)$.

Time $t_m$ was determined in the first maximum of the compression loading curves of the dependence $F(t)$. The compressive strains $\varepsilon_{mp}$ were also evaluated from the first maximum of the compression loading curves of the dependence $F(\varepsilon)$. The inflection point ($F_{inf}$, $\varepsilon_{inf}$) of the compression curve was determined. The times $t_{inf}$ and forces $F_{inf}$ were determined in the inflection points on the curves $F(t)$. Compressive strains $\varepsilon_{inf}$ and compressive stresses $\sigma_{inf}$ in the inflection points of the compression curves and compressive strains $\varepsilon_m$ and stresses $\sigma_m$ in the first maximum of the compression curves were also enumerated. The initial firmness of the pellets was determined as the force $F_{10}$ at the 10% of the compressive strain on the compression curve. The second parameter of the firmness was the force $F_{inf}$ in the inflection point of the compression curve at the compressive strain $\varepsilon_{inf}$ . The third parameter of the firmness of the pellets was the force $F_m$ at the first maximum at the $\varepsilon_m$ compressive strain on the compression curve.

The compressive strain in the inflection point of the compressive curves was enumerated from the equation:

$$\varepsilon_{inf} = \frac{v\ t_{inf}}{L_0} \tag{5}$$

where $\varepsilon_{inf}$ – compressive strain in the inflection point of the compression curve $F(\varepsilon)$, mm mm$^{-1}$; $v$ – deformation speed, mm min$^{-1}$; $t_{inf}$ – time in the inflection point, min; $L_0$ – original length of the sample, mm.

The compressive stress in the inflection point of the compression curves was enumerated from the equation:

$$\sigma_{inf} = \frac{4\ F_{inf}}{\pi\ d^2}\left(1 - \varepsilon_{inf}\right) \tag{6}$$

where $\sigma_{inf}$ – compressive stress in the inflection point of the compression curve $\sigma(\varepsilon)$, MPa; $\varepsilon_{inf}$ – compressive strain in the inflection point of the compression curve $F(\varepsilon)$, mm mm$^{-1}$; $F_m$ – force in the inflection point of the compression curve $F(\varepsilon)$, N; $d$ – original diameter of the sample, mm.

Young's modulus of elasticity was calculated from the equation:

$$E = \frac{4\ \Delta F\ L_0}{v\ \Delta t\ \pi\ d^2} \tag{7}$$

where $E$ – Young's modulus of elasticity, MPa; $\Delta F/\Delta t$ – the slope of the linear part of dependences the compression curve $F(t)$, N s$^{-1}$; $v$ – speed of deformation, mm s$^{-1}$, $L_0$ – original height of the sample, mm; $d$ – original diameter of the sample, mm.

## RESULTS AND DISCUSSION

For each pellet type, ten pellet samples were subjected to measuring.

The Fig. 3 depicts the compression diagrams of pellet type 1; these are dependencies $F(\varepsilon)$. The slope is almost all the diagrams is the same. In the diagrams for samples 4, 6 and 10, it is clearly visible that in the beginning of the test, significant sample compression took place even at small values of compression force, reaching the deformation rate of 6%. In sample 6, after the reaching of the first maximum – after which the sample was not yet destroyed – an increase of density, paired with the increase of compression force, took place, with the sample being destroyed only at reaching the second maximum of force.

The Fig. 4 shows dependencies $F(t)$ of pellet type 1. Time necessary for reaching of the first maximum was in the range of 7 to 10 s; the lowest time was observed for sample 3 and the highest time was observed for sample 10.

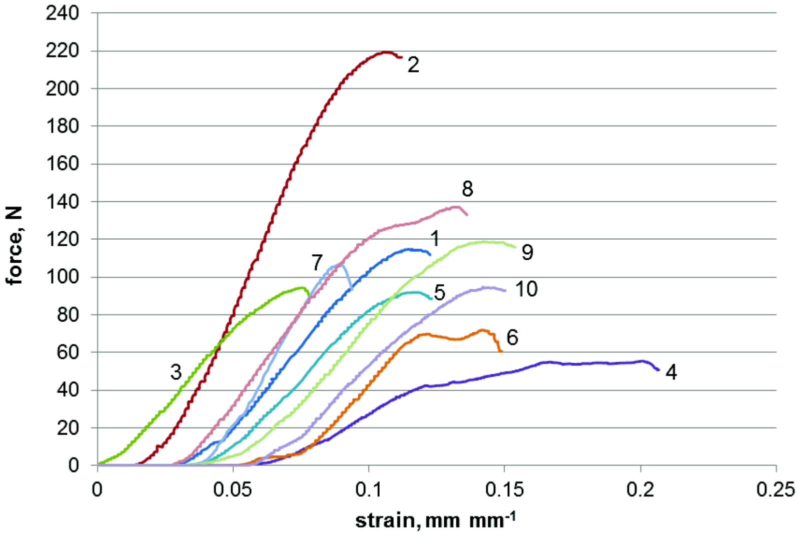

**Figure 3.** Compression diagrams of pellet type 1 – dependence *F*(*ε*).

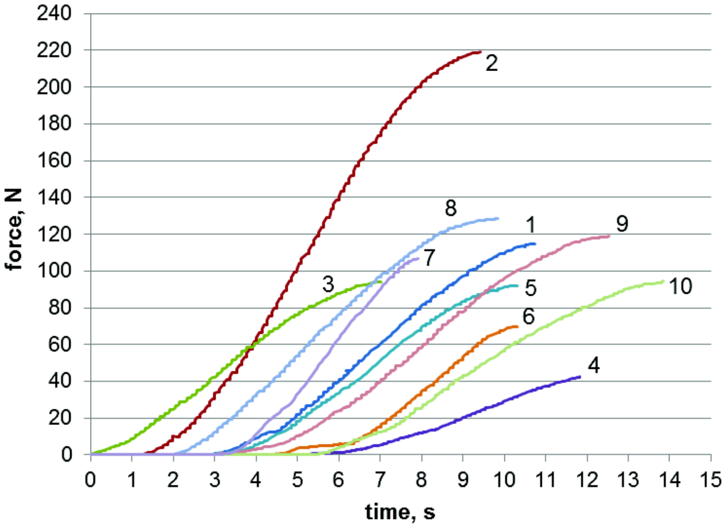

**Figure 4.** Compression diagrams of pellet type 1 – dependence *F*(*t*).

Fig. 5 shows the compression diagrams observed at compressive loading test of pellet type 2, these are dependencies *F*(*ε*).

All the compression diagrams have approximately the same slope. On the slopes of samples 1, 5 and 8, it can be observed that, after reaching the first maximum of the compression force, increase in pellet density takes place, resulting in the increase of compression force to the second maximum. On the slopes of samples 7 and 8, non-linearity of dependence *F*(*ε*) was observed. The compression diagrams *F*(*t*) depicted in Fig. 6 shows that time necessary for reaching of the first maximum of the loading force $F_m$ was in the range of 6.8 to 16.3 s; the lowest time was measured for sample 5 and the highest time was measured for sample 9.

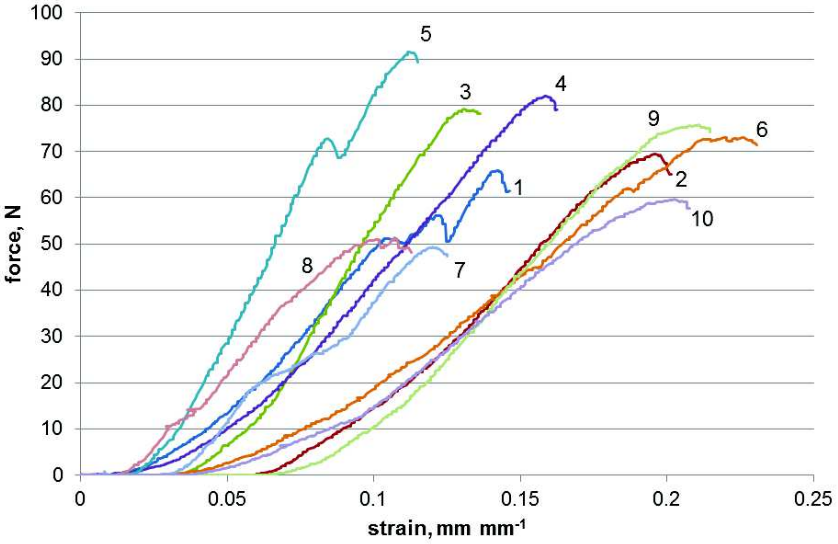

**Figure 5.** Compression diagrams of pellet type 2 – dependence *F*(ε).

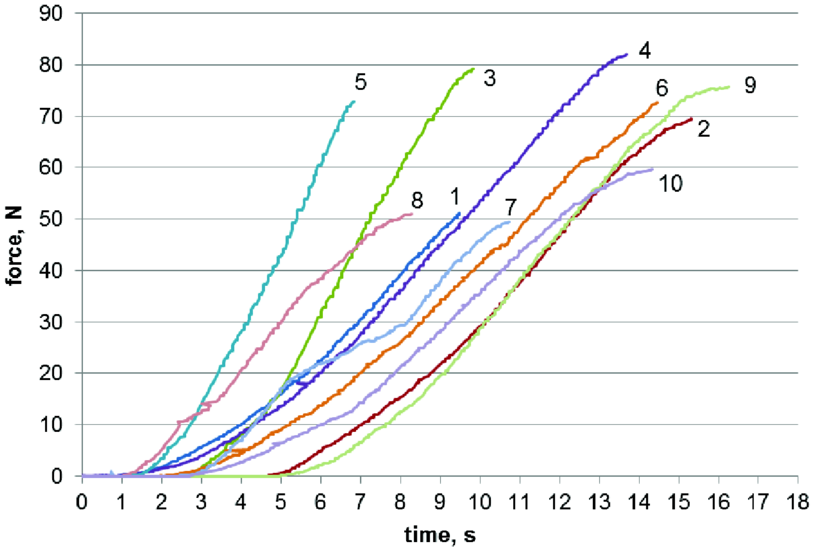

**Figure 6.** Compression diagrams of pellet type 2 – dependence *F*(*t*).

Fig. 7 depicts the compression diagrams of dependence *F*(ε) obtained from compression loading test of pellet type 3.

Behaviour of individual pellets during the compression test differs. The values of compression force in the first maximum and strain of pellets have a high variance.

Development of the force on pellet 5 is nonlinear, pellets 3 and 7 have a more prominent yield point, typical for brittle materials. Diagrams for pellets 8 and 10 show properties typical for materials without prominent yield point. This signifies that, with increase in the amount of poppy waste from sieving added to the base ground poppy head mass, the mechanical properties of pellets, produced by same means as pellet type 1 and 2, become significantly imbalanced.

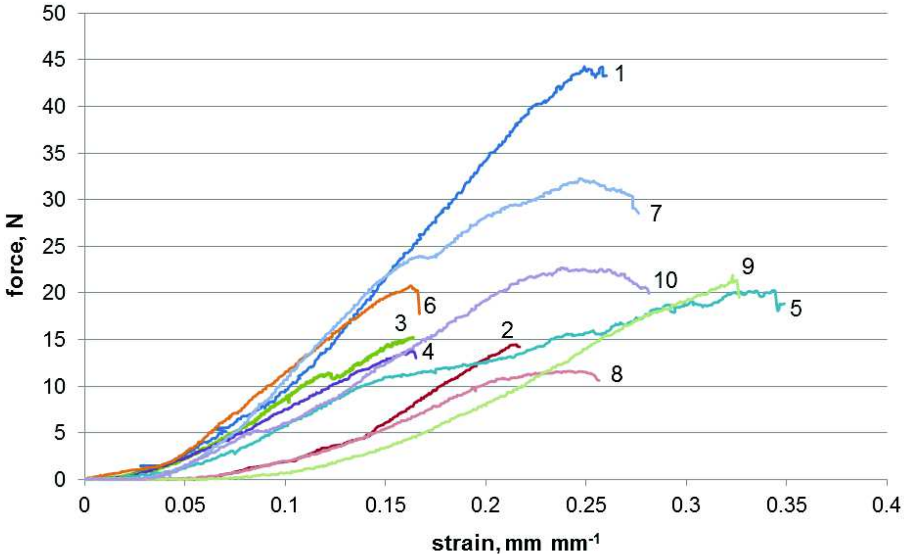

**Figure 7.** Compression diagrams of pellet type 3 – dependence *F*(ε).

The Fig. 8 shows the compression diagrams *F*(*t*) of pellet type 3.

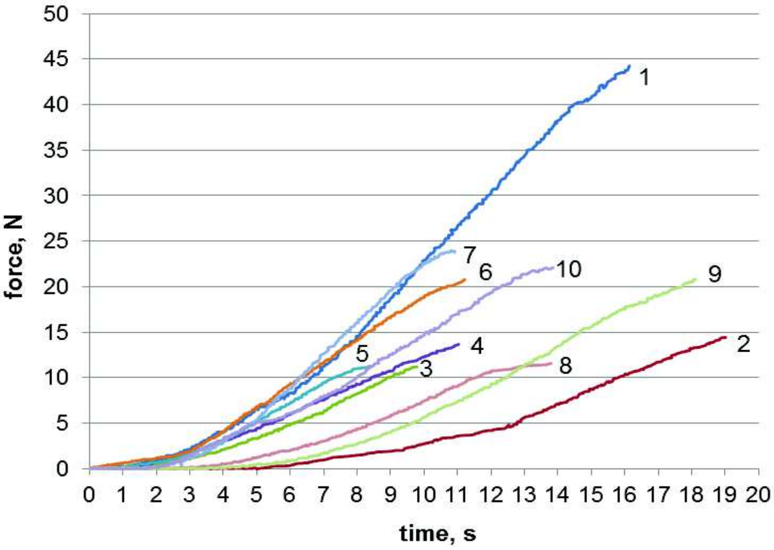

**Figure 8.** Compression diagrams of pellet type 3 – dependence *F*(*t*).

The geometrical parameters and mechanical properties of the pellets are shown in Table 2.

**Table 2.** Geometrical parameters and mechanical properties of observed pellets

| | Pellets | 1 | 2 | 3 |
|---|---|---|---|---|
| | x̄ | 6.29 | 6.33 | 6.50 |
| | S | 0.13 | 0.18 | 0.07 |
| | s (%) | 2.14 | 2.92 | 1.06 |
| | x̄ | 15.19 | 13.36 | 11.11 |
| | S | 0.64 | 1.22 | 1.81 |
| | s (%) | 4.21 | 9.12 | 16.26 |
| | x̄ | 107.96 | 66.31 | 19.40 |
| | S | 44.08 | 11.78 | 9.50 |
| | s (%) | 40.83 | 17.76 | 48.97 |
| | x̄ | 0.12 | 0.15 | 0.20 |
| | S | 0.02 | 0.05 | 0.06 |
| | s (%) | 15.78 | 32.10 | 27.81 |
| | x̄ | 3.52 | 2.11 | 0.62 |
| | S | 1.51 | 0.40 | 0.30 |
| | s (%) | 42.98 | 18.81 | 48.26 |
| | x̄ | 0.11 | 0.15 | 0.20 |
| | S | 0.02 | 0.05 | 0.06 |
| | s (%) | 17.50 | 32.10 | 27.81 |
| | x̄ | 3.13 | 1.79 | 0.46 |
| | S | 1.36 | 0.35 | 0.22 |
| | s (%) | 43.50 | 19.71 | 46.88 |
| | x̄ | 56.72 | 24.48 | 4.80 |
| | S | 20.58 | 8.89 | 1.67 |
| | s (%) | 36.28 | 36.32 | 34.77 |
| | x̄ | 79.67 | 37.36 | 6.37 |
| | S | 55.96 | 21.70 | 3.62 |
| | s (%) | 70.24 | 58.09 | 56.91 |
| | x̄ | 64.04 | 45.18 | 13.22 |
| | S | 21.32 | 11.25 | 6.33 |
| | s (%) | 33.29 | 24.90 | 47.89 |
| | x̄ | 0.09 | 0.12 | 0.15 |
| | S | 0.04 | 0.04 | 0.06 |
| | s (%) | 44.44 | 34.15 | 39.01 |
| | x̄ | 1.91 | 1.27 | 0.33 |
| | S | 0.67 | 0.32 | 0.15 |
| | s (%) | 34.90 | 24.89 | 46.17 |

The diameter of all pellets was of similar values – this is also proven by statistical evaluation.

Small deviations from the mean value for strain compression $\varepsilon_{mp}$ observed form diagrams (Fig. 1) and strain compression $\varepsilon_m$ calculated according to relation (3) were observed. Similar deviations from the mean were detected for the values of mechanical compression stress $\sigma_{\mathrm{mp}}$ observed by means of diagrams and values of $\sigma_{\mathrm{m}}$ calculated by means of relation (4) and also at values of compressive strain and mechanical stress in the inflexion point. The greatest deviations from the mean were observed in the initial durability of pellets $F_{10}$.

The values of mechanical properties of the pellet type 2 show only small deviations from the mean values. However, the variability of measured and calculated values is higher; the greatest variability can be seen in the initial durability of pellets $F_{10}$. Its values are in the range of 10.52 N to 82.22 N.

All the quantity values observed in pellet type 3 showed very small or small deviations from the mean values. However, the variability of measured and calculated values is higher for all quantities, except the diameter and length of the pellets. The initial durability of the pellets $F_{10}$ varies the most; its values are within the range of 0.68 N to 11.53 N.

The mean value of the modulus of elasticity of the pellet type 1 was 56.72 MPa. The mean value of the modulus of elasticity of the pellet type 2 was 24.48 MPa, what is 2.3 times lower than the value of modulus of elasticity of the pellet type 1, made solely of ground poppy heads. The mean value of the modulus of elasticity of the pellet type 3 was 4.8 MPa, what is 11.8 times lower than the value of modulus of elasticity of the pellet type 1.

It can be seen that the values of compressive strain $\varepsilon_{mp}$ and $\varepsilon_m$ in pellet type 3 are nearly twice as high as pellet type 1 and 1.3 times higher than those of pellet type 2.

It can be therefore concluded that with increasing addition of the waste from the sieving of poppy seeds to the pellet content, pellets become softer, what is reflected in their mechanical properties. The values of modulus of elasticity, initial durability and force in the first maximum are the lowest for pellet type 3.

Experiments show that differences can be observed even in the pellets of the same type, meaning that pelletization of the given material under operational conditions does not result in the pellets with the same mechanical properties,. In addition to this, with increasing amount of poppy waste from sieving, the differences in pellet properties also grow, this material type therefore negatively affects the particle integration in pelletization.

The Table 3 provides the correlation coefficients for mechanical properties of the pellet type 1, absolute value of which is higher than 0.5. Coefficients with absolute value higher than 0.8, signifying a high degree of linear dependence between quantities, are highlighted. The greatest degree of dependence – the coefficient value almost equals 1 – is between quantities $\sigma_m - \sigma_{mp}$, $F_m - \sigma_{mp}$ and $F_m - \sigma_m$.

**Table 3.** Value of correlation coefficients for the quantities evaluated in the compression test of pellet type 1

| | $d$ | $L_0$ | $F_{10}$ | $F_m$ | $\varepsilon_{mp}$ | $\sigma_{mp}$ | $\varepsilon_m$ | $\sigma_m$ | $E$ | $F_{inf}$ | $\varepsilon_{inf}$ | $\sigma_{inf}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $d$ | 1 | | | | | | | | | | | |
| $L_0$ | | 1 | | | | | | | | | | |
| $F_{10}$ | | | 1 | | | | | | | | | |
| $F_m$ | -0.55 | | **0.90** | 1 | | | | | | | | |
| $\varepsilon_{mp}$ | | | | | 1 | | | | | | | |
| $\sigma_{mp}$ | -0.61 | | **0.91** | **1.00** | | 1 | | | | | | |
| $\varepsilon_m$ | | | | | **0.98** | | 1 | | | | | |
| $\sigma_m$ | -0.62 | | **0.89** | **0.99** | | **1.00** | | 1 | | | | |
| $E$ | -0.66 | | **0.86** | **0.96** | | **0.97** | | **0.97** | 1 | | | |
| $F_{inf}$ | | | 0.73 | 0.77 | | 0.73 | | 0.70 | 0.63 | 1 | | |
| $\varepsilon_{inf}$ | | | | | | | | | | | 1 | |
| $\sigma_{inf}$ | | | **0.80** | **0.84** | | **0.82** | | **0.80** | 0.73 | **0.98** | | 1 |

Only correlation coefficients with the absolute value higher than 0.5 are provided.

The correlation coefficients for mechanical properties of the pellet type 2 are shown in Table 4. Correlation coefficient of $\varepsilon_m - \varepsilon_{mp}$ reaches the value of 1; the values of compressive strain obtained from the dependence $F(\varepsilon)$ are corresponding with values of compression strain calculated by means of relation (3). For the pellet type 2, there occurs a significant degree of linear dependence between diameter and $F_{10}$, $\varepsilon_{mp}$, $\varepsilon_m$ and $E$.

**Table 4.** Values of correlation coefficients for the quantities evaluated in the compression test of pellet type 2

| | $d$ | $L_0$ | $F_{10}$ | $F_m$ | $\varepsilon_{mp}$ | $\sigma_{mp}$ | $\varepsilon_m$ | $\sigma_m$ | $E$ | $F_{inf}$ | $\varepsilon_{inf}$ | $\sigma_{inf}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $d$ | 1 | | | | | | | | | | | |
| $L_0$ | | 1 | | | | | | | | | | |
| $F_{10}$ | **-0.87** | | 1 | | | | | | | | | |
| $F_m$ | | | | 1 | | | | | | | | |
| $\varepsilon_{mp}$ | **0.81** | -0.66 | **-0.91** | | 1 | | | | | | | |
| $\sigma_{mp}$ | | | | **0.94** | | 1 | | | | | | |
| $\varepsilon_m$ | **0.81** | -0.66 | **-0.91** | | **1.00** | | 1 | | | | | |
| $\sigma_m$ | -0.54 | | 0.52 | **0.82** | | **0.96** | | 1 | | | | |
| $E$ | **-0.87** | | **0.88** | | -0.79 | | -0.79 | 0.71 | 1 | | | |
| $F_{inf}$ | | | | 0.70 | | 0.64 | | 0.54 | | 1 | | |
| $\varepsilon_{inf}$ | 0.79 | -0.51 | **-0.85** | | **0.91** | | **0.91** | | | 0.54 | 1 | |
| $\sigma_{inf}$ | | | | | | 0.74 | | 0.75 | | **0.91** | | 1 |

The correlation coefficients of the observed values obtained from the test of the pellet type 3 are given in Table 5. The diameter, initial length and durability of the pellets do not show any degree of dependence with other quantities that would be worth of consideration. $\varepsilon_m - \varepsilon_{mp}$ have correlation coefficient equal to 1. High degree of correlation was discovered for the couples of quantities $\sigma_{mp} - F_m$, $\sigma_m - F_m$, $\sigma_{mp} - \sigma_m$, $\sigma_{inf} - F_{inf}$.

**Table 5.** Value of correlation coefficients for the quantities evaluated in the compression test of pellet type 3

| | $d$ | $L_0$ | $F_{10}$ | $F_m$ | $\varepsilon_{mp}$ | $\sigma_{mp}$ | $\varepsilon_m$ | $\sigma_m$ | $E$ | $F_{inf}$ | $\varepsilon_{inf}$ | $\sigma_{inf}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $d$ | 1 | | | | | | | | | | | |
| $L_0$ | | 1 | | | | | | | | | | |
| $F_{10}$ | | | 1 | | | | | | | | | |
| $F_m$ | | | | 1 | | | | | | | | |
| $\varepsilon_{mp}$ | | | -0.61 | | 1 | | | | | | | |
| $\sigma_{mp}$ | -0.54 | | | **0.99** | | 1 | | | | | | |
| $\varepsilon_m$ | | | -0.61 | | **1.00** | | 1 | | | | | |
| $\sigma_m$ | | | 0.51 | **0.99** | | **0.99** | | 1 | | | | |
| $E$ | -0.66 | | 0.65 | 0.77 | | **0.82** | | **0.84** | 1 | | | |
| $F_{inf}$ | -0.52 | | | **0.94** | 0.58 | **0.93** | 0.58 | **0.89** | 0.62 | 1 | | |
| $\varepsilon_{inf}$ | | | -0.71 | | 0.76 | | **0.97** | | | | 1 | |
| $\sigma_{inf}$ | -0.55 | | | **0.98** | | **0.97** | | **0.95** | 0.73 | **0.99** | | 1 |

The issue of influence of fraction size on compressed material was investigated by Kaliyan & Morey (2009). The fact that structure of input material has an impact on the properties of the compressed material is also proven by this evaluation of the mechanical properties of the pellets made of poppy waste. The pellet type 1 made only from ground poppy heads shows the best mechanical properties. This is due to the fact that the crushed poppy mass has a high proportion of fine fraction. This result proves the observations of Križan (2014) that if the material contains a larger amount of fine particles, the compression to pellet form is easier.

According to Gil et al. (2010), the usage of several raw materials can also have adverse effects on the final compression of the product.

Swietochovski et al. (2016) also focused on the determination of the mechanical properties of the pellets and carried out compression tests for the pellets that had identical diameter as those observed here, with feed speed of the loading plate of the testing device also the same as in experiments presented here. In their study on force bondings in pellets made of wood and agricultural biomass, Stelte et al. (2011) performed a compressive loading test that is comparable to compressive loading test carried out by testing device Stentor Andilog 1000 in terms of technical parameters and conditions. The dependence course of compression force on deformation corresponds with the compression diagrams obtained in testing of pellets presented here. The force necessary for mechanical damaging of the pellet integrity was slightly higher than the observed values.

Mechanical properties of the evaluated pellets prove high variability of behaviour of the pellets in the fields of elastic and plastic deformation. This conclusion was also reached by Stelte et al. (2011) and Miao et al. (2015). The compression diagrams are very similar to compression testing of biological materials presented by Shirmohammadi et al. (2011), proving that the observed pellets show behaviour typical for biological materials in general.

## CONCLUSION

The paper provides an examination and evaluation of three pellet types, differing in composition of the input material. The pellet mechanical properties were changing with the alternations in the material composition. With increasing proportion of waste from sieving of poppy seeds to the basic matter, the values of the mechanical properties were worsening.

The results show that the examined pellets differ from each other in their mechanical properties; in comparison with pellets made of dendromass, they show lower values of the observed parameters. The pellet type made only of ground poppy head mass has shown the best results, the pellet type consisting of ground poppy heads and waste from sieving of poppy seeds in mass proportion 1 : 1 has shown the worst results. Young's modulus of elasticity is equal to 56.72 MPa for pellet type 1, 24.48 MPa for pellet type 2. In pellet type 3, it amounts only to 4.8 MPa. The force in the first maximum develops in the same manner: it is 107.96 N for pellet type 1, 66.31 N for pellet type 2 and only 19.4 N for pellet type 3.

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