Monika SŁUPSKA[1], Roman STOPA[1], Krzysztof KAWA[2]
[1] Uniwersytet Przyrodniczy we Wrocławiu, Instytut Inżynierii Rolniczej
ul. Chełmońskiego 37/41, 51-630 Wrocław, Poland
[2] Uniwersytet Przyrodniczy we Wrocławiu, Instytut Kształtowania i Ochrony Środowiska
pl. Grunwaldzki 24, 50-363 Wrocław, Poland
e-mail: roman.stopa@upwr.edu.pl, monika.slupska.95@gmail.com, krzysztof.kawa@upwr.edu.pl

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AN ANALYSIS OF USEFULNESS OF RASPBERRY STALKS FOR BRIQUETTE PRODUCTION

Summary

The paper presents research on the strength properties of raspberry stems from cuttings and their suitability for the production of briquettes. For this purpose, the cutting resistance, Charpy impact and bending stiffness of raspberry stalks were determined. Then briquettes were made to define their mechanical strength for different moisture contents. After that the heat of combustion of the briquettes was checked.
Keywords: *bending stiffness, biomass, briquettes, Charpy impact test, cutting resistance, impact strength, raspberry stalks, renewable energy sources*

ANALIZA MOŻLIWOŚCI ZASTOSOWANIA ŁODYG MALIN DO PRODUKCJI BRYKIETÓW

Streszczenie

Praca przedstawia badania dotyczące właściowości wytrzymałościowych łodyg malin pochodzących z przycinki krzewów oraz ich przydatności do produkcji brykietów. W tym celu określno opory cięcia, udarność i sztywność na zginanie łodyg malin. Następnie wykonano z nich brykiety, określono ich wytrzymałośc mechaniczną dla różnych zawartości wilgoci oraz sprawdzono ciepło spalania.
Słowa kluczowe*: sztywność zginania, biomasa, brykiety, próba Charpy'ego, opory cięcia, udarność, łodygi malin, odnawialne źródła energii*

1. Introduction

Poland is the second largest producer of raspberries in the world right after Russia. The cultivated area of raspberries in Poland is 30 thousand hectares and the annual raspberry production is 120 thousand tons per year [1]. Every year, growers burn raspberry stalks after pruning bushes in order to limit diseases that could contribute to the reduction of crops or plantation diseases. Due to the fact that the use of biomass for energy production was supported by the Agriculture Committee and Rural Development of the European Parliament, at the same time placing the condition of the lack of competitiveness of energy crops for the agri-food market [2]. Therefore, the best solution may be to promote the use of waste biomass for energy production in order to prevent competitiveness of both sectors, therefore the use of raspberry stems for energy purposes could be a profitable solution for the renewable energy market [3, 4, 5, 6].

Strength tests of plants enable obtaining information necessary for the better effectiveness of their processing. The results contribute to the optimization of equipment operation and methods of proceeding in harvesting and processing [7]. One of the strength characteristics that can be determined when carrying out research on biological material are: cutting resistance, impact strength and modulus of elasticity. The method of determining each of the abovementioned features depends on the characteristics of the material, structure, geometry and the measuring instruments used [8, 9, 10].

2. Object, purpose and course of research

The purpose of this study was to determine the strength properties of raspberry stems and determine their suitability for the production of briquettes. For this purpose, the cutting resistance, impact strength and stiffness on bending of the stems were measured. Moreover, sieve analysis was performed after knife grinding at different rotational speeds of the blades. The mechanical strength of briquettes was checked for different material moisture, depending on the moment of harvesting the stems from the field and these tests were performed for stems characterized by moisture content enabling the production of briquettes.

2.1. Cutting resistance

The measuring stand for cutting resistance test was designed (Fig. 1A), and then the research stand (Fig. 1B) was constructed at the Department of Fundamentals of Technology at the Wrocław University of Environmental and Life Sciences. The model shown in Fig. 1 was made using the Autodesk Inventor Professional 2015 program.

The cutting resistance tests were carried out for three different speeds of the knife crusher, successively: 4200, 3200 and 2200 RPM. A laser tachometer was used to measure the drop in rotational speed. In order to check the effect of cutting surface on torque, a fragmentation analysis for three, five and eight stems in nine replications was made. As the material had different dimensions, the diameter of each sample was measured with a caliper, and then the shear surface was determined.

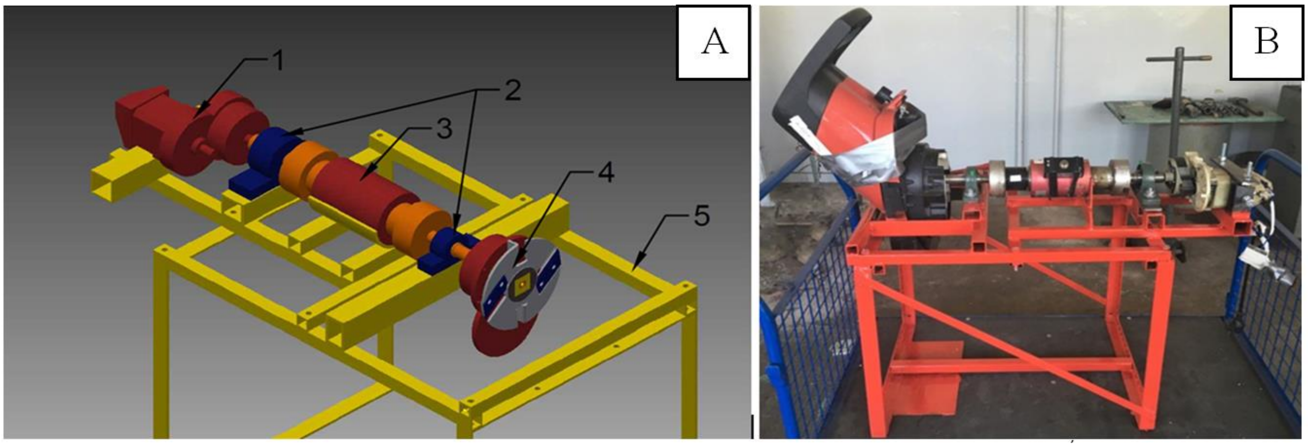

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Fig. 1. A - Design of the test stand for testing the torque required in the grinding process with a set of cutting knives: 1 – electric motor, 2 – bearing, 3 – torque gauge, 4 – cutting set, 5 – frame; B – measuring stand

Rys. 1. A - Projekt stanowiska badawczego do badania momentu obrotowego potrzebnego w procesie rozdrabniania zestawem noży tnących: 1 – silnik elektryczny, 2 – łożysko, 3 – momentomierz, 4 – zestaw tnący, 5 – rama; B – stanowisko pomiarowe

2.2. Charpy impact test

Impact tests using the Charpy method were carried out in the Wrocław University of Science and Technology research stand at the Department of Strength of Materials.

The measurement method was mainly based on the current PN-EN ISO 148-1:2017-02 standard [11]. Sample preparation required circumvention of certain standards contained in the standard due to the heterogeneity of material construction and its unique entrance dimensions. The normalized dimensions of the sample are presented at Fig. 2B, whereas Fig. 2A shows how the samples are measured (dimensions b and h) and the dimensions for which the standards have been retained: the length and manner of scoring. The tests were carried out in five replications.

To calculate the impact strength of the stalks, formulas 1 and 2 were used.

$$Ku = K1 - K2 \tag{1}$$

where:

Ku - Energy absorbed, [J]

K1 - The first potential energy, [J]

K2 – The second potential energy, [J]

$$K = \frac{Ku}{A} \tag{2}$$

K - Impact resistance, [$J \cdot cm^{-2}$]

A - Sectional area, [cm^2]

2.3. Bending stiffness

The machine for testing the strength properties of Instron 5566, on which the bending force was measured as a function of displacement shows Fig. 3.

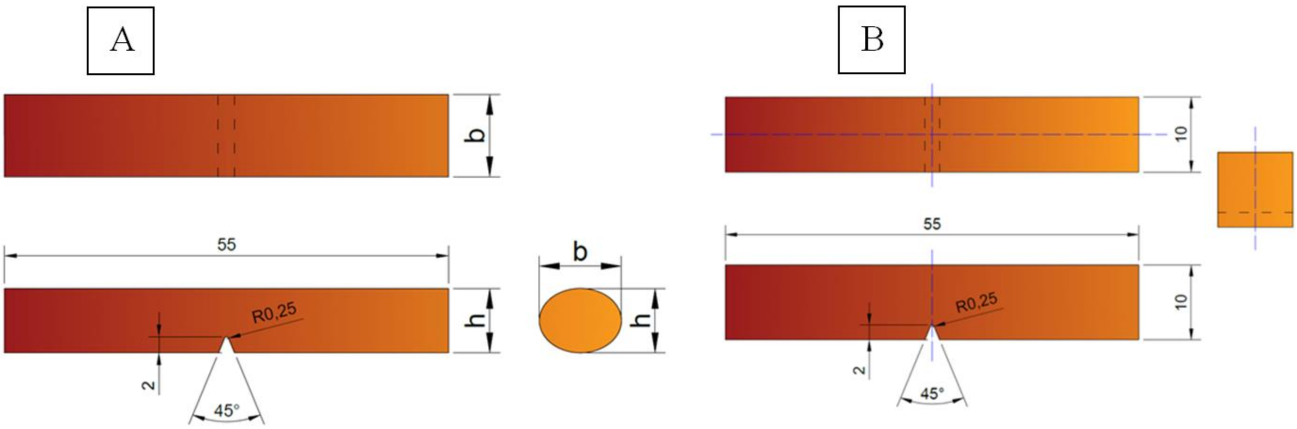

Fig. 2. Preparation and dimensions of samples: A – non-standardized sample, B – normalized sample [11]

Rys. 2. Przygotowanie i wymiary próbek: A – próbka niestandardowa, B – próbka znormalizowana:[11]

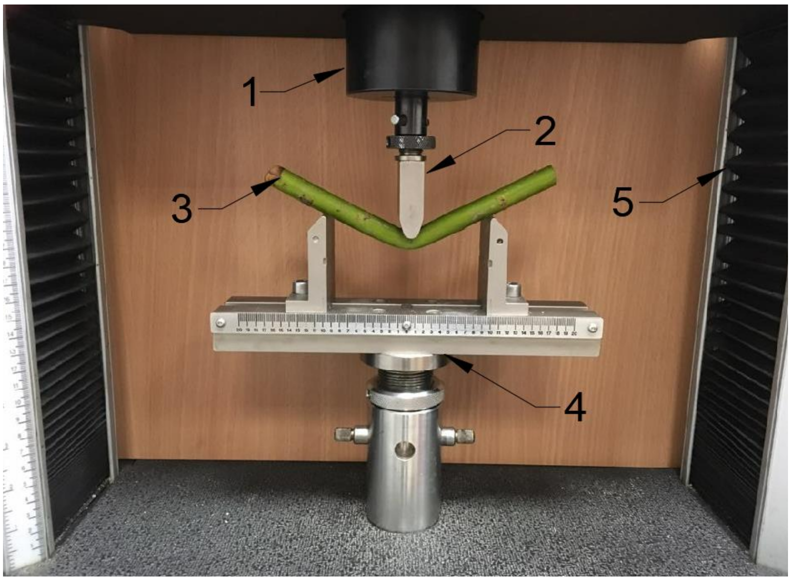

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Fig. 3. Scheme of the measurement station: 1 – measuring head, 2 – measuring adapter, 3 – sample, 4 – support, 5 – guide
Rys. 3. Schemat stanowiska pomiarowego: 1 – głowica pomiarowa, 2 – przystawka pomiarowa, 3 – próbka, 4 – podpora, 5 – prowadnica

Due to the differences in the mechanical properties of individual parts of the material, the stems were divided into three measurement zones: apex, middle and lower part. Before each measurement, the diameter of the sample had to be measured in order to determine the moment of inertia and the index on bending. The samples were subjected to a bending load using an Instron 5566 testing machine with a measuring range up to 1 kN. The measuring stand consisted of a head equipped with a sample loading attachment in its central point and a bottom plate, to which an element constituting a two-point support for the material subjected to bending test was fixed (Fig. 3). Loads were made using different displacement speeds (1.8, 30, 100 and 500 $mm \cdot min^{-1}$). On the basis of the analysis of the peak value of the bending force in the displacement function, the modulus of elasticity, stress and stiffness on bending for the stalks were determined.

2.4. Mechanical strength of briquette

The briquettes (Fig. 4A) were made at the Department of Low Carbon Energy Sources and Waste Management of the Wrocław University of Environmental and Life Sciences. For this purpose, the POR Junior 5.5 kW hydraulic briquetting machine was used. In order to measure briquette strength according to PN-EN 15210-2, a T809 laboratory stand made by Łukomet (Fig. 4B) was used. The samples were made on a material with different moisture contents.

2.5. Briquette LHV and HHV

The heat of combustion test was carried out in 5 replications, for briquettes characterized by the highest mechanical strength using calorimetric bomb IKA C200. The formula 3 was used to calculate the heating value of the briquettes.

$$LHV = HHV \cdot (1 - MC) - (r \cdot MC) \quad (3)$$

where:

LHV – Low heating value, [$MJ \cdot kg^{-1}$]

HHV – High heating value, [$MJ \cdot kg^{-1}$]

MC – Moisture content, [%]

r – Heat of vaporization, [$MJ \cdot kg^{-1}$]

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Fig. 4. A - briquette made of raspberry stalks, B - machine Łukomet T809 for testing the strength of briquettes
Rys. 4. A - brykiet z łodyg malinowych, B - maszyna do badania wytrzymałości brykietów Łukomet T809

3. Measurement results

3.1. Cutting resistance

During the tests, it turned out that the value of 2200 RPM (forced by the voltage drop of the motor) was too low and did not give representative results. When loading the machine with material, the drop in rotation was too high and prevented further measurements.

Fig. 5 shows the measurement results for stem cutting resistance.

The reduction of the initial speed as well as the increase of the wall surface cause an increase in the torque due to the increase of material resistance. The cutting force increases proportionally to the cutting surface area (Fig. 5). In addition, the increasing torque results in a reduction of the rotational speed of the disc under load (Fig. 6), which results in an increase in the shear force. The power increases with force until the drop in rotational speed resulting from the load does not exceed 1500 RPM. Then, the rotational speed is too small to fragment the material by shearing, with a selected apex angle of 30°.

3.2. Charpy impact test

The impact test performed did not give unambiguous results. For similar sections of the samples, the impact measurements measured 26-40 $J \cdot cm^{-2}$ The average impact strength of the raspberry stem was 32 $J \cdot cm^{-2}$.

3.3. Bending stiffness

Figs 7 and 8 show the influence of Young's modulus, diameter, velocity and measuring zone on bending stiffness.

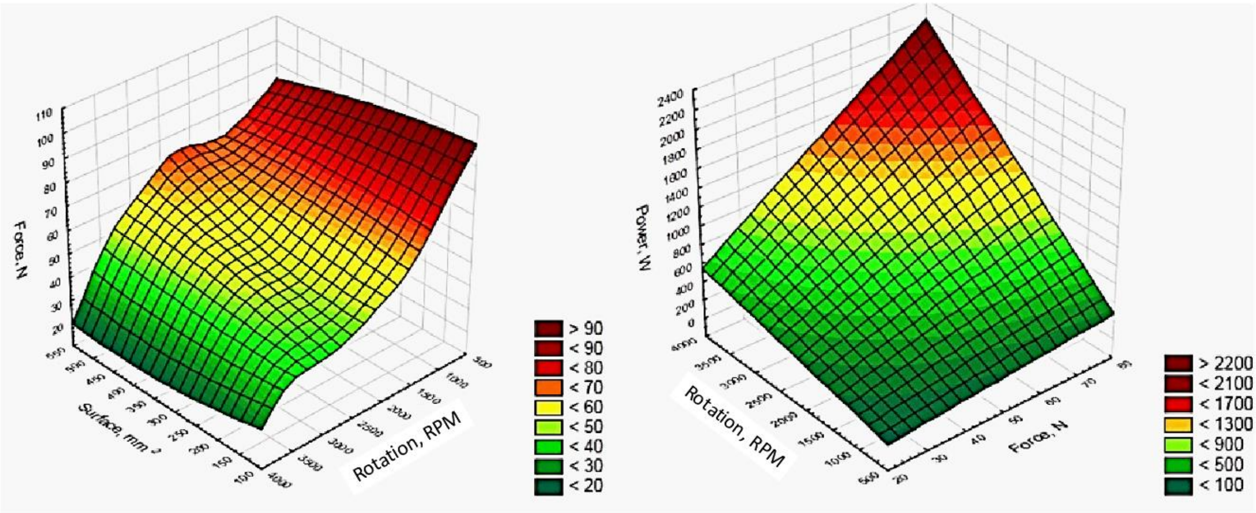

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Fig. 5. The dependence between surface, force, rotations and power during the grinding process

Rys. 5. Zależność między powierzchnią, siłą, obrotami i mocą podczas procesu rozdrabniania

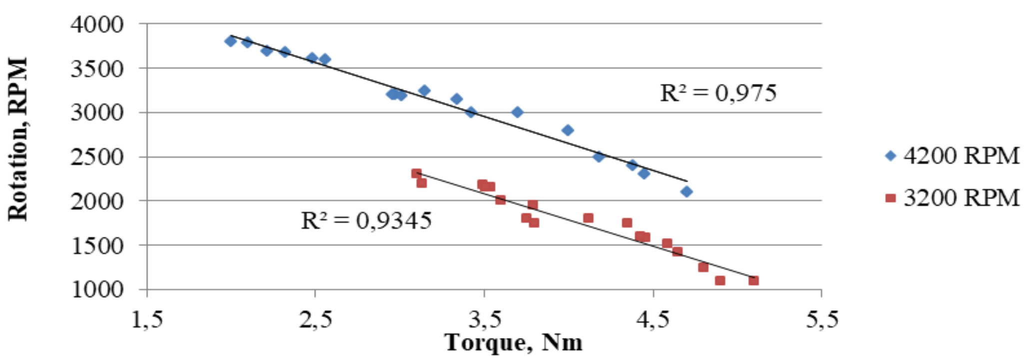

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Fig. 6. Decrease in rotations as a function of torque

Rys. 6. Spadek obrotów w funkcji momentu obrotowego

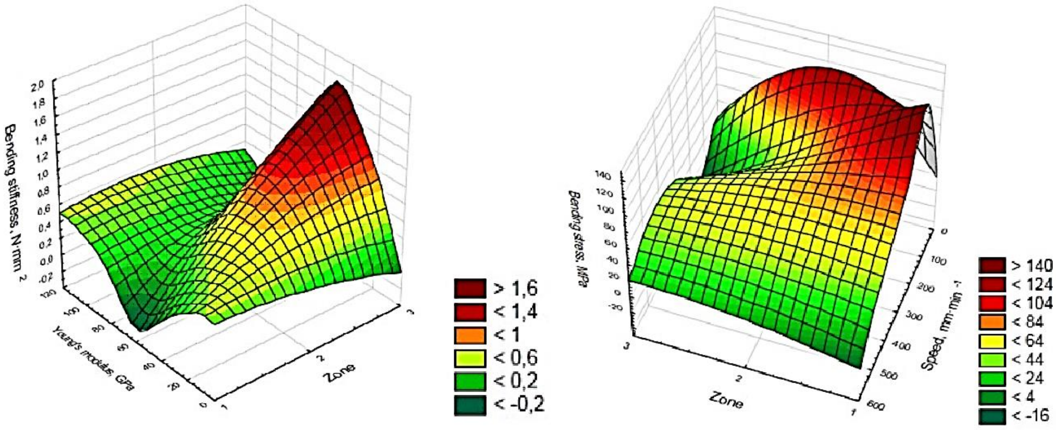

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Fig. 7. The influence of Young's modulus, zone and measuring speed on bending stiffness
Rys. 7. Wpływ modułu Younga, strefy oraz prędkości pomiarowej na sztywność na zginanie

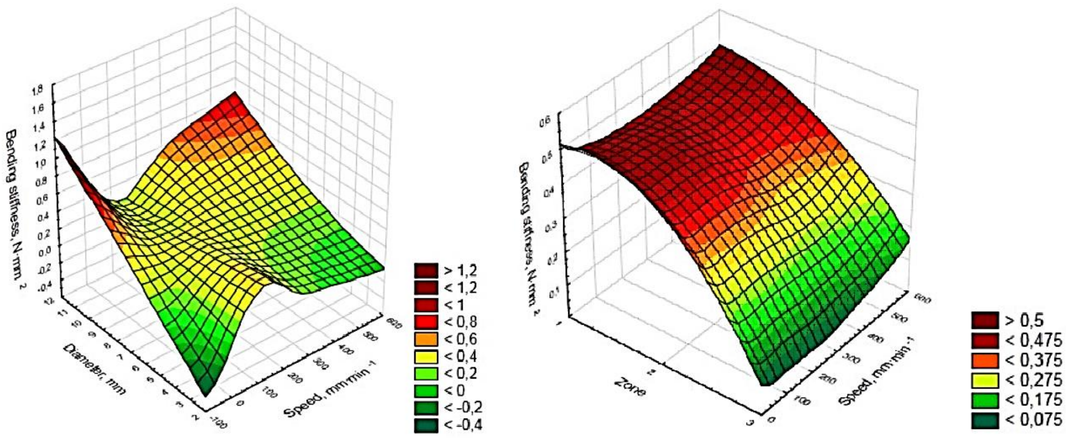

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Fig. 8. The influence of diameter, zone and measuring speed on bending stiffness
Rys. 8. Wpływ średnicy, strefy oraz prędkości pomiarowej na sztywność na zginanie

The diameter of the stems and their collection zone affect their value of the elastic modulus (Figs 7, 9). As the stem diameter increases (closer to the lower zone), its modulus of elasticity decreases as a result of the increase of the reinforcing tissue and stone cells found in it (Fig. 10). Bending stresses, on the other hand, reach the highest value in the apical zone (Fig. 11). Medium (zone 2) and lower (zone 1) assume approximate values with a little predominance of the lower zone. Bending stiffness increased with the approximation to the root zone and reached the highest values at the lowest and highest speed of movement (Fig. 8).

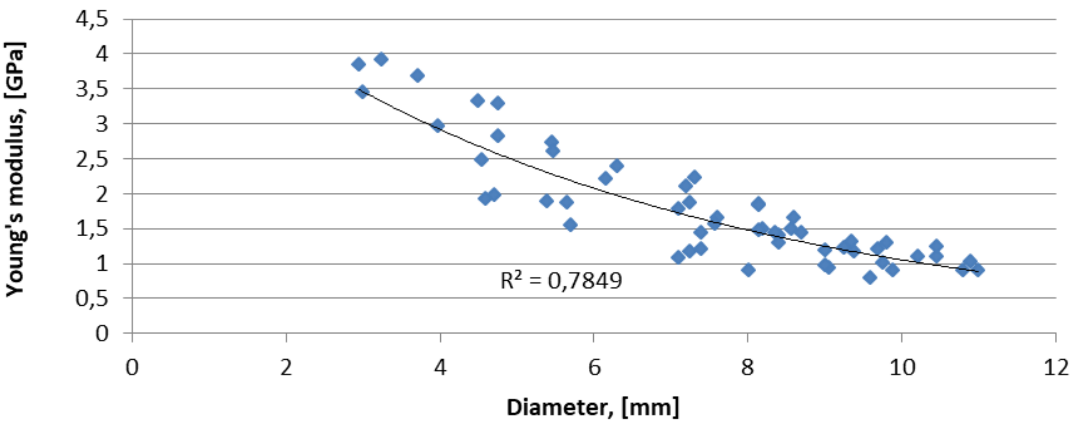

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Fig. 9. Diagram of the relationship between the diameter of the stems and their modulus of elasticity
Rys. 9. Zależność między średnicą łodyg a ich modułem sprężystości

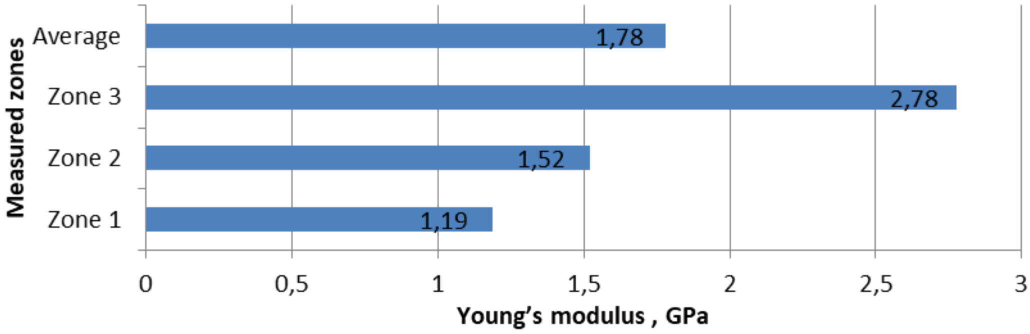

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Fig. 10. Average values of the Young's modulus of given measurment zones
Rys. 10. Średnie wartości modułu Younga dla zadanych stref pomiarowych

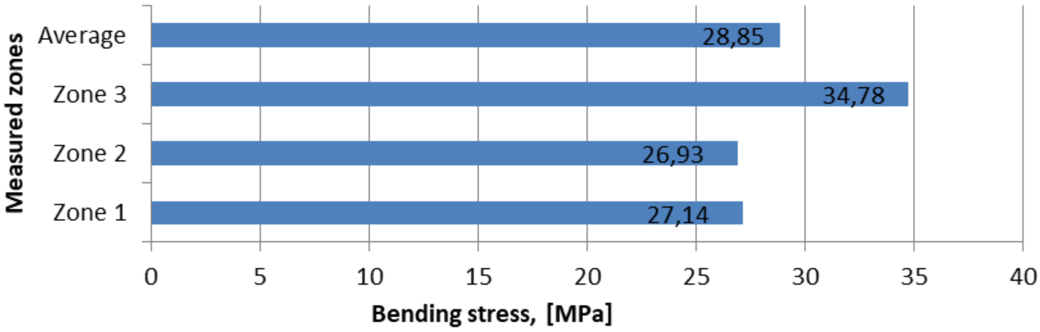

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Fig. 11. Average values of the bending stress of given measurment zones
Rys. 11. Średnie wartości naprężeń dla zadanych stref pomiarowych

3.4. Mechanical strength of briquette

Fig. 12 shows the effect of humidity on the mechanical strength of briquettes.

The material with a moisture content of 23.71% achieved the best mechanical strength (Fig. 12). This parameter influenced the performance of other strength tests, which were carried out at the above-mentioned humidity of raspberry stems. On this basis, the most optimal moment of harvesting of stems in the investigated period (January - March) was also determined.

3.5. Briquette LHV and HHV

Briquettes obtained from raspberry stalks achieved satisfactory parameters for the production of an alternative energy source. The average heat of combustion of the produced briquettes was 17.3 $MJ \cdot kg^{-1}$. However, in order to obtain information on the actual energy potential of the stalks, their calorific value of 12.8 $MJ \cdot kg^{-1}$ was calculated.

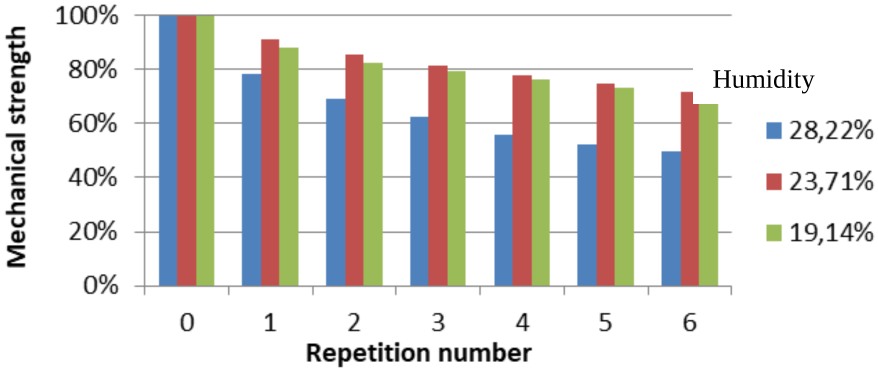

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Fig. 12. Mechanical strength of briquettes at variable humidity values
Rys. 12. Wytrzymałość mechaniczna brykietów przy zmiennych wartościach wilgotności

4. Conclusions

– The management of waste from raspberry plantations for energy purposes contributes to the improvement of the natural environment.
– The rotational speed of 2200 RPM was too low to cut the raspberry stalks.
– With the increase in torque, the speed of the shredder decreased, while the strength and power increased.
- The average impact strength of the raspberry stem was 32 $J \cdot cm^{-2}$.
– The highest value of Young's modulus and bending stress achieved zone 3 (apical).
- Young's module decreases along with the approximation to the root zone.
– Raspberry stem briquettes have the highest mechanical strength at a moisture content of 23.7%.
– The heat of stalk burning is 17.3 $MJ \cdot kg^{-1}$, while the calorific value is 12.8 $MJ \cdot kg^{-1}$.

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