Abstract: Biogas production occurs during methane fermentation from organic substrates and the mass remaining after fermentation, containing organic matter and valuable minerals having regard to plant nutrition, forms the digestate, which could be useful for fertilizing purposes and very beneficial in the case of the fertilization of rapeseeds. This paper focuses on the use of two forms of fertilization of rapeseeds—digestate and mineral fertilizers—in order to reduce the compressive strength of rapeseeds. The object presents results of compressive strength tests of three rape varieties (Bios, Feliks, Markus). The uniaxial compression tests between two parallel planes were made using a Zwick/Roell Z005 testing machine. Comparative analyses for the analyzed variables were carried out applying parametric and non-parametric statistical tests. On the basis of the conducted research, it was found that the distribution of the increase in the force crushing Bios and Feliks rapeseed varieties in both forms of cultivation was proportional to the increase in their mass. However, with a relatively comparable mass of Bios cv. seeds, in the case of the digestate use, a stronger correlation was found between the seed pressing force and its mass than for the multi-component fertilizer, understanding the need to apply more force to crush the seeds for this form of cultivation. In the conducted tests, the average size of rapeseed diameters of all varieties and forms of cultivation ranged from 1.81–1.95 mm, which indicates their good suitability for industrial purposes.

Keywords: digestate; biomass; rapeseed; compression force; static strength

1. Introduction

Methane fermentation from organic substrates, which may be natural fertilizers, plant biomass, or products of the agri-food industry, contributes to the production of biogas. During this process conducted under controlled conditions in an agricultural biogas plant, the organic matter decomposes with the production of biogas, the main component of which is methane [1]. In Poland, the annual efficiency of installations for the production of agricultural biogas is 391,328,847.8 m³/year, giving a total electric power of 101.093 MW. However, in the Lublin province, 36,100,000 m³/year is acquired [2]. The mass remaining after fermentation, containing organic matter and valuable minerals from the point of view of plant nutrition, forms the named digestate. The basic direction of digestate management after taking into account its physicochemical properties should be fertilizer use. A biogas plant located...
in agricultural areas should receive from farmers organic products created on their farms, natural fertilizers, or intentionally cultivated plants. On the other hand, farmers, taking care of the quality of the soil on their farms should take away from the biogas plant the resulting digestate and use it for fertilization purposes [2]. Possible use of the resulting digestate for fertilizing purposes could be very beneficial for the fertilization of rapeseeds. Indeed, the size and strength of rapeseeds are factors that can affect their suitability for storage and processing.

Mineral fertilizers and fertilizers of animal origin are used in traditional rape cultivation. Recently, there has been a growing interest in the management of digestate sludge, and, consequently, the use of the digestate for fertilizing purposes. The mineral matter remaining after fermentation, containing organic matter and minerals valuable from the point of view of plant nutrition [1], contains significant amounts of nitrogen, phosphorus, and potassium. In terms of the action speed (uptake of nutrients by plants), it is similar to mineral fertilizers, because N, P, and K components are easily available to plants. The digestate also contains a part of the organic matter that has a positive effect on the physicochemical properties of the fertilized soils [1,3]. The digestate used as a fertilizer improves soil fertility, quality, and resistance of plants to biotic and abiotic factors. Kouřimská et al. in their study found that the use of digestate improves the quality and yield of vegetables [4]. A negative impact of digestate on the soil was found by Odlare et al. and Comparetti et al. [5,6]. Montemurro reported that digestate does not contain heavy metals and, therefore, it can be used as a mineral fertilizer, which promotes environmental protection [7].

Storage of rapeseeds has a higher risk than storing cereal grains [8,9]. The chemical composition of seeds plays an important role, which can cause uncontrolled and unfavorable reactions [10]. The most influential factor on the spoilage of rapeseeds during storage is moisture [11,12], which should be 6–9% [13]. Rapeseeds require a post-harvest treatment during which they are provided with forced drying, which affects the quality of the obtained oil [14–17]. Significant differences in the physical characteristics of rapeseeds compared to cereal grains must be taken into account when adapting or relying on storage arrangements for cereal grains [11,18–20].

Studies on the impact of rapeseed storage conditions on their dynamic or static strength properties [21] are generally limited to controlling laboratory conditions. In designing silos for storing the seeds, the mechanical properties of seeds that have not experienced stress related to changing conditions practically prevailing in the silo are taken into consideration [16,22–24]. The size and strength of rapeseeds are factors that can affect their suitability for storage and processing [25]. Mechanical properties of whole seeds depend mainly on their coating composition [22,23,26]. The degree of mechanical damage of individual rapeseeds is determined by their strength properties that are associated with a variety of features (e.g., color of seeds), growing conditions, degree of ripeness, moisture content of seeds, seed temperature, as well as combined harvest and post-harvest treatment, e.g., level and type of dynamic load, spatial orientation of seeds during loading, drying technology and conditions, and time of seed storage [11,12,23,26–30].

There are few studies describing the properties of seed strength compared to the size or form of the crop, although Szot and Kutzbach found that the size of the seeds does not affect the degree of their damage by dynamic load. However, Tys and Szwed showed that small seeds are more susceptible to mechanical damage, especially at higher crushing forces [21,31]. Taking into account the strength indices, research by Herak, among others, has shown that the hysteresis value and the deformation index are not dependent on the maximum compressive force, which results in the non-linear behavior of oil seeds during mechanical pressing by means of an extruder [32]. In Kabutey’s studies on the compression behavior of bulk rapeseed with variable heat treatment force and speed, it was shown that the maximum deformation, deformation energy, and oil yield increased with an increase in force and heat treatment temperature, while that of speed showed a downward trend [33]. A plot of the amount of force and deformation displayed a smooth and serration curve characteristic. In turn, Mizera proved that the maximum oil recovery efficiency (82.6%) was found at the lowest screw speed (screw rotation speed 10, 20, 30, 40, 55, and 65 rpm was used) [34]. When storing the rapeseeds, it was
also observed that after some time, seeds with a certain moisture content at a constant temperature and under constant load begin to change their strength to dynamic loads [21]. It was also noted on the basis of the measurement of airflow resistance in seeds that during storage, rapeseeds are permanently deformed, especially at higher moisture content (11%) [35]. Although Figiel indicated that the storage of rapeseeds in a silo for 16 weeks in industrial conditions does not have a direct impact on their strength properties, the observation was made using quasi-static speeds [36]. In addition, it was also found that the increase in the seed moisture contributed to the reduction in the strength of individual seeds and an increase in the elastic modulus of the seeds.

The aim of this study was to undertake research determining the static strength of rapeseeds fertilized in a traditional manner (with the use of mineral fertilizers) compared with the use of digestate.

2. Materials and Methods

2.1. Experimental Material

Three varieties of spring rapeseed (Bios, Feliks and Markus) from the Plant Cultivation Station Strzelce Sp. zoo. were subjected to tests. The seeds were sown on experimental plots in south-eastern Poland in Lublin province in 2015–2016. The aforementioned varieties of spring rape were subjected to plot growing in three variants. The first one used natural fertilizer (digestate) originating from a biogas plant (Biogas-Tech, Sp. zoo., Lublin, Poland) in Piaski, Lublin province. Digestate was spilled onto the plots in an amount of 97 L per 27 m² (Biogas-Tech, Sp. zoo., Lublin, Poland) in Piaski, Lublin province. The uniaxial compression tests between two parallel planes were made using a Zwick/Roell Z005 testing machine equipped with a compression head with a maximum force of 50 N. During testing, the speed of the moving plate was constant and amounted to 3 mm/min. Measurements were carried out until the seeds ruptured, recording the changes in a loading force as a function of the measuring head displacement.

The cracking point corresponding to a clear decrease in the pressure force on the load-deformation characteristics was determined automatically using Zwick’s TestXpertII.V3.5 software. The force (CF) at which the seeds cracked was accepted as the granule breaking force.

2.2. Determining the Compressive Force

The uniaxial compression tests between two parallel planes were made using a Zwick/Roell Z005 testing machine equipped with a compression head with a maximum force of 50 N. During testing, the speed of the moving plate was constant and amounted to 3 mm/min. Measurements were carried out until the seeds ruptured, recording the changes in a loading force as a function of the measuring head displacement.

The cracking point corresponding to a clear decrease in the pressure force on the load-deformation characteristics was determined automatically using Zwick’s TestXpertII.V3.5 software. The force (CF) at which the seeds cracked was accepted as the granule breaking force.

2.3. Statistical Analysis

While processing the obtained results, the following software was used: MS Office 2007 package, and Statistica version 13.1 by StatSoft. Results are presented using basic elements of descriptive
statistics: mean value, median, standard deviation, minimum and maximum values. On the other hand, the compliance of the normal distribution was verified by means of the Shapiro–Wilk test and the homogeneity of the variance by the Brown–Forsyth test. Comparative analysis for the analyzed variables was carried out applying non-parametric by the Kruskal–Wallis tests. Correlation tests were used to assess simple relationships between single parameters. For continuous variables with normal distributions, the Spearman’s rank correlation non-parametric test was used. The observed dependencies were considered statistically significant at $\alpha < 0.05$.

3. Results and Discussion

Weather conditions that prevailed during the research period are presented in Table 1. They concerned the period from March to September in 2015 and 2016 and were recorded by IMGW-PiB from Lublin Radawiec Station.

| Month  | Year 2015 | Year 2016 |
|--------|-----------|-----------|
|        | Pressure (hPa) | Temperature (°C) | Rainfall (mm H$_2$O) | Pressure (hPa) | Temperature (°C) | Rainfall (mm H$_2$O) |
| March  | 991.41      | 4.70       | 1.31 | 985.26      | 3.46       | 2.04 |
| April  | 986.86      | 7.75       | 1.20 | 983.69      | 8.91       | 1.20 |
| May    | 986.75      | 12.37      | 2.20 | 985.82      | 14.44      | 1.09 |
| June   | 989.60      | 26.63      | 0.63 | 986.30      | 18.34      | 1.78 |
| July   | 986.81      | 21.40      | 1.42 | 987.12      | 18.91      | 4.49 |
| August | 990.38      | 25.15      | 0.30 | 990.73      | 18.07      | 1.52 |
| September | 989.19     | 14.63      | 3.02 | 990.73      | 15.15      | 0.47 |

The macronutrient and heavy metal contents in the digestate used were also tested (Table 2). Laboratory tests were carried out at the District Chemical-Agricultural Station in Lublin in accordance with KQ/PB-17-76-77: 2012 [37]. Maize silage, whey, and green waste matter were used as a feedstock in the biogas plant for the production of the biogas and digestate.

| Element     | Unit   | Content |
|-------------|--------|---------|
| Nitrogen    | (g·L$^{-1}$) | 0.119   |
| Phosphorus  | (g·L$^{-1}$) | 0.12    |
| Potassium   | (g·L$^{-1}$) | 5.37    |
| Calcium     | (g·L$^{-1}$) | 0.28    |
| Magnesium   | (g·L$^{-1}$) | 0.07    |
| Cadmium     | (mg·L$^{-1}$) | <0.43   |
| Lead        | (mg·L$^{-1}$) | <0.43   |
| Nickel      | (mg·L$^{-1}$) | <0.43   |
| Chromium    | (mg·L$^{-1}$) | <0.43   |
| Cooper      | (mg·L$^{-1}$) | 0.43    |
| Zink        | (mg·L$^{-1}$) | 2.00    |
| Manganese   | (mg·L$^{-1}$) | 2.26    |
| Iron        | (mg·L$^{-1}$) | 70.82   |

Table 3 presents the results of the research on the content of the macroelements in the soil before the application of selected fertilizers and after the harvest of plants, which were carried out at the District Chemical-Agricultural Station in Lublin. Soil samples were tested for the content of bioavailable components regarding phosphorus and potassium in accordance with the applicable standards for the above-mentioned components PN-R-04024: 1997, and magnesium in mg per 100 g soil according to PN-ISO 10390: 1997 [38,39]. Soil acidity, pH in KCl, and possible liming needs were taken into account.
while the lowest was found for Markus cv. (4.44 mg) in the control crop. Of all the rapeseed varieties, Table 4. Sustainability 2019 ranging from 16.53 N to the largest 23.67 N in Bios cv. In the same cultivation, the largest difference in the static strength of their seeds in relation to the control combination. The highest compressive strength value was recorded for Bios cv. (29.81 N) and the smallest value was 5.63 N (for Feliks cv.). When cultivating using the digestate, the range of compressive strength values for seeds also had the smallest differentiation in the Markus variety ranging from 16.53 N to the largest 23.67 N in Bios cv. In the same cultivation, the largest difference in

Table 3. Content of bioavailable ingredients and acidity of the soil.

| Experimental Variant | Kind of Field | pH in KCl | Reaction | Liming Needs | Content of Bioavailable Ingredients (mg 100 g⁻¹) |
|----------------------|---------------|-----------|----------|--------------|---------------------------------------------|
|                      | Before sieve  |           |          |              |                                             |
| Digestate            | Control       | 6.97      | neutral  | redundant    | 23.8 a                                      |
|                      | Experimental plot | 7.22    | alkaline | redundant    | 42.17 b                                    |
| NPK                  | Control       | 7.06      | alkaline | redundant    | 21.1 c                                      |
|                      | Experimental plot | 5.51    | acidic   | necessary    | 23.37 a                                    |
| Digestate            | Control       | 6.99      | neutral  | redundant    | 25.1 d                                      |
|                      | Experimental plot | 7.52    | alkaline | redundant    | 64.5 b                                      |
| NPK                  | Control       | 7.06      | alkaline | redundant    | 21.6 c                                      |
|                      | Experimental plot | 5.37    | acidic   | necessary    | 26.5 d                                      |
|                      | After harvest |           |          |              |                                             |

a, b, c, d, e—average values marked with the same letter are not statistically different (p < 0.05), NPK—mineral fertilizer.

Application of the fertilization method affected the change in the weight of seeds. The highest significant mean weight was found for the Feliks cv. (4.91 mg) in the cultivation using digestate, while the lowest was found for Markus cv. (4.44 mg) in the control crop. Of all the rapeseed varieties, the highest average weight was obtained by seeds when using the digestate (4.76 mg), whereas in traditional cultivation it was 4.69 mg and on control plots (4.61 mg). Considering the rapeseed type, the highest average weight was obtained for seeds of the Feliks variety (4.79 mg), although Bios cv. had a very similar value of 4.78 mg. Markus cv. Were the lightest seeds (4.49 mg). The total average weight of all tested seeds was 4.69 mg (Figure 2). However, statistical analysis using the Kruskal–Wallis test showed no effect of fertilization on the mass of rapeseeds.

![Figure 2. Effect of fertilization on the weight of rapeseeds (NPK—mineral fertilizer).](image_url)

In the conducted research, three forms of fertilization for individual rape varieties were used. Results of spring rapeseed strength tests and values of the variability coefficients are presented in Table 4.

Based on Table 4, it can be observed that the use of digestate in the cultivation of rape for both Bios and Feliks varieties contributed to an increase in the static strength of their seeds in relation to the control combination. The highest compressive strength value was recorded for Bios cv. (29.81 N) and the smallest value was 5.63 N (for Feliks cv.). When cultivating using the digestate, the range of compressive strength values for seeds also had the smallest differentiation in the Markus variety ranging from 16.53 N to the largest 23.67 N in Bios cv. In the same cultivation, the largest difference in
average seed strength, occurring between the highest and the lowest average value of the force, was also observed, which amounted to 4.91 N.

Table 4. Compressive strength and size of tested spring rapeseeds.

| Variety | Kind of Cultivar | Mean Value (N) | Standard Deviation (N) | Minimum Value (N) | Maximum Value (N) | CV (%) | Mean Diameter of Seeds (mm) |
|---------|------------------|----------------|------------------------|-------------------|-------------------|--------|-----------------------------|
| Bios    | Control          | 13.34          | 6.05                   | 3.99              | 25.49             | 45.35  | 1.95 ± 0.149                |
|         | NPK              | 14.75          | 5.46                   | 6.31              | 26.71             | 37.02  | 1.89 ± 0.126                |
|         | Digestate        | 16.40          | 5.14                   | 6.14              | 29.81             | 31.34  | 1.89 ± 0.144                |
| Feliks  | Control          | 12.95          | 4.95                   | 3.89              | 22.33             | 38.22  | 1.91 ± 0.151                |
|         | NPK              | 16.25          | 5.12                   | 3.86              | 26.45             | 31.51  | 1.85 ± 0.181                |
|         | Digestate        | 18.53          | 5.11                   | 5.63              | 27.72             | 27.58  | 1.90 ± 0.158                |
| Markus  | Control          | 12.50          | 5.67                   | 3.19              | 24.40             | 45.36  | 1.89 ± 0.152                |
|         | NPK              | 13.27          | 6.06                   | 4.34              | 24.77             | 45.67  | 1.81 ± 0.158                |
|         | Digestate        | 13.62          | 4.20                   | 8.96              | 25.49             | 30.84  | 1.81 ± 0.145                |

In the case of crops using the mineral fertilizer, the lowest value of the force required to crush the rapeseeds was 3.86 N for the Feliks variety and the highest was 26.7 N for Bios cv. In this cultivation, the compressive strength range was from 20.36 N for Markus cv. to 22.54 N for Feliks. On the other hand, the difference in mean seed strength occurring between the highest and lowest average strength value was 2.98 N, which was smaller than for the variant with the digestate.

Considering the case with the absence of any form of fertilization, it was observed that in all varieties of rape, the average compressive strength was the lowest. The minimum compressive strength was recorded for the Markus variety, which reached a value of 3.19 N and it was the lowest of all seeds tested. However, the highest strength was achieved by Bios cv. at the level of 25.49 N. In the control combinations, the range of compression strength for rapeseeds was also not very different and ranged from 18.31 N for Feliks variety to 21.41 N for Bios cv. However, it was more than half the value when compared to the digestate cultivation variant. In turn, the difference in average seed strength occurring between the highest and the lowest average strength value amounted to 0.84 N, which was the smallest of all forms of rape cultivation.

When assessing the variability coefficient for the compressive force of the rapeseeds, the lowest values were reached with cultivations using the digestate, 29.92% on average. This indicates greater uniformity in the size of rapeseeds compared to other forms of cultivation. The highest value of this coefficient was obtained for cultivation using a multi-component fertilizer (45.67%—Markus variety). Elevated values in all cases indicate high variability in the size of the rapeseeds in the samples tested.

Considering the size of the seeds, Lamb and Jahnson showed that seeds with a diameter below 1.8 mm have lower agricultural usefulness as well as lower technological and nutritional value [40]. It is a consequence of relatively small kernels in smaller seeds with a small amount of reserve compounds [41]. In the tests carried out, the range of medium-sized rapeseed diameters ranged from 1.81 to 1.95 mm, which indicates their good suitability for the food industry. Seeds above 2 mm in diameter (with larger weight) are the source of the best oil in terms of quality. Unfortunately, oil is produced from the smallest seeds, which causes its deterioration through higher oxidation and hydrolysis processes [29]. In addition, Tańska et al. showed that the strength properties of seeds are dependent on the size of the seeds and correlated with the equivalent diameter of seeds [26]. All measured strength indices showed that seeds with larger diameters were significantly resistant. This was confirmed by the study of Szwed and Tys, which suggest that in bulk mass, small seeds are the main cause of seed spoilage [42].

The statistical analysis using the Kruskal–Wallis test showed with a probability \( p = 0.638 \) that the fertilization variants used did not significantly affect the compressive force. Only for the Bios and Feliks cv. was the static strength of the seeds more varied. In the Bios variant, there was a probability \( p = 0.101 \) with stronger dependence observed in the homogeneous group NPK-digestate (\( p = 0.767 \)). However, for the Feliks cv., a significant effect of the fertilization variants on the compressive force was found with the probability \( p = 0.001 \), with one homogeneous group NPK-digestate \( p = 0.308 \) (Table 5).
Table 5. Statistical analysis calculated by the Kruskal–Wallis test.

| Variety | Parameter          | Code   | Valid N | Sum of Ranks | Mean of Rank | p       |
|---------|--------------------|--------|---------|--------------|--------------|---------|
| Bios    | Compressive force (N) | Control | 100     | 1586.000     | 52.866       | 0.101   |
|         |                    | NPK    | 100     | 1356.000     | 45.200       |         |
|         |                    | Digestate | 100    | 1153.000     | 38.433       |         |
|         | Mass (mg)          | Control | 100     | 1311.500     | 43.716       | 0.881   |
|         |                    | NPK    | 100     | 1372.000     | 45.733       |         |
|         |                    | Digestate | 100    | 1411.500     | 47.050       |         |
| Feliks  | Compressive force (N) | NPK    | 100     | 1407.500     | 46.916       | 0.001   |
|         | Digestate          | 100     | 950.000 | 31.666       | 0.638       |
|         | Mass (mg)          | Control | 100     | 1311.500     | 43.716       | 0.181   |
|         | Digestate          | 100     | 1195.000 | 39.833       |            |
| Markus  | Compressive force (N) | NPK    | 100     | 1386.500     | 46.216       | 0.638   |
|         | Digestate          | 100     | 1488.500 | 48.283       |            |
|         | Mass (mg)          | Control | 100     | 1311.500     | 43.716       | 0.360   |
|         | Digestate          | 100     | 1200.500 | 40.016       |            |

To assess the simple relationships between seed compression force and mass, Spearman’s rank correlation tests were used at the significance level $\alpha = 0.05$ (Table 6) for variables with a normal distribution.

Table 6. Spearman rank correlations at a significance level of $p < 0.05$ for dependence of compressive force and seed weight.

| Group | Interdependence                     | Spearman’s Rank Correlation Coefficient (Rs) | Level of Significance P |
|-------|-------------------------------------|-----------------------------------------------|-------------------------|
| Bios  | CF/CONTROL and M/CONTROL            | 0.158                                         | 0.403                   |
|       | CF/CONTROL and M/NPK                | 0.009                                         | 0.963                   |
|       | CF/CONTROL and M/DIGESTATE          | −0.123                                        | 0.518                   |
|       | CF/NPK and M/CONTROL                | 0.327                                         | 0.078                   |
|       | CF/NPK and M/DIGESTATE              | 0.448                                         | 0.014                   |
|       | CF/DIGESTATE and M/CONTROL          | 0.175                                         | 0.355                   |
|       | CF/DIGESTATE and M/NPK              | 0.184                                         | 0.331                   |
|       | CF/DIGESTATE and M/DIGESTATE        | 0.140                                         | 0.463                   |
|       | CF/CONTROL and M/DIGESTATE          | −0.303                                        | 0.103                   |
|       | CF/NPK and M/DIGESTATE              | −0.270                                        | 0.149                   |
|       | CF/NPK and M/NPK                    | 0.370                                         | 0.044                   |
|       | CF/DIGESTATE and M/NPK              | 0.144                                         | 0.012                   |
|       | CF/DIGESTATE and M/DIGESTATE        | −0.265                                        | 0.156                   |
|       | CF/CONTROL and M/CONTROL            | −0.379                                        | 0.038                   |
|       | CF/CONTROL and M/DIGESTATE          | −0.012                                        | 0.948                   |
|       | CF/DIGESTATE and M/NPK              | 0.119                                         | 0.529                   |
|       | CF/DIGESTATE and M/DIGESTATE        | 0.379                                         | 0.038                   |
|       | CF/CONTROL and M/DIGESTATE          | 0.023                                         | 0.902                   |
|       | CF/NPK and M/DIGESTATE              | 0.053                                         | 0.303                   |
|       | CF/DIGESTATE and M/NPK              | 0.197                                         | 0.298                   |
|       | CF/DIGESTATE and M/DIGESTATE        | 0.105                                         | 0.588                   |
|       | CF/CONTROL and M/DIGESTATE          | −0.279                                        | 0.135                   |
|       | CF/DIGESTATE and M/NPK              | 0.208                                         | 0.270                   |
|       | CF/DIGESTATE and M/DIGESTATE        | 0.293                                         | 0.115                   |
| Markus| CF/CONTROL and M/CONTROL            | 0.069                                         | 0.717                   |
|       | CF/CONTROL and M/NPK                | 0.221                                         | 0.239                   |
|       | CF/DIGESTATE and M/NPK              | 0.023                                         | 0.902                   |
|       | CF/NPK and M/CONTROL                | 0.197                                         | 0.298                   |
|       | CF/NPK and M/DIGESTATE              | 0.103                                         | 0.588                   |
|       | CF/DIGESTATE and M/NPK              | 0.208                                         | 0.270                   |

In the case of Bios variety, there was a relation between the mass and size of the rapeseeds vs. the compressive force. It was noticed that when the seed mass increased, the force needed to crush it was greater. This phenomenon was observed in the case of seeds that were fertilized with both digestate and mineral fertilizer. It is also worth noting that when using the digestate, this correlation
was stronger (Rs = 0.621) than for the multi-component fertilizer (Rs = 0.448). This proves that with a relatively comparable mass of seeds in both types of cultivation, greater seed crushing force should be used in the case of cultivation with the digestate.

Considering Feliks cv., a similar relationship can be seen. It applies to all three cases where without any form of fertilization, increased compressive forces were needed with increasing seed mass. Looking at the correlation coefficients from Table 5, it can be seen that at the significance level of \( p < 0.05 \), their values were very close to each other (0.370, 0.377, 0.379). Thus, in this case again, with the increasing mass of seeds, it was necessary to use a greater crushing force.

Taking into consideration Markus cv., no significant correlations were found between the weight of seeds and the compressive force for each type of crop. This may be due to the individual properties of seeds of this rape variety.

Comparing the results of the present research to those by Táňska and Konopka in which the digestate was not used, the value of the rapeseed strength in view of their size was in the range from 10 to 18 N, with large seeds (of larger weight) showing much less elastic deformation than medium seeds [26]. Referring to the conducted research, values obtained with the use of a multi-component fertilizer were similar and were in the range of 7–21 N in three of the considered cases. Rapeseeds maintained their compressive properties in a similar range in a treated crop, the values of which were between 7 and 24 N. It can, therefore, be concluded that the compression strength ranges are similar to each other in the considered cultivations. This was confirmed by statistical analyses in two cases for the Bios and Feliks varieties, which showed that the strength of seeds increases with increasing weight. Considering that in the current literature the research on the strength of rapeseeds does not take into account cultivations using the digestate, it is necessary to undertake further study in this field.

4. Conclusions

In cultivations using the digestate, the largest difference in mean seed strength was observed between the highest and lowest mean strength values, which was 4.91 N, while the smallest was recorded for the control combination (0.84 N). Digestate fertilization for cultivation of the Bios and Feliks varieties contributed to an increase in the static strength of their seeds in relation to the control combination and statistical analysis pointed to NPK-digestate homogeneous groups. It was found that the distribution of the increase in the crushing force for Bios and Feliks rapeseed varieties in both forms of cultivation was proportional to the increase in their mass. However, with a relatively comparable mass of seeds of Bios cv., a stronger correlation was observed with the use of the digestate than with a multi-component fertilizer. This shows that seeds from this form of cultivation need a larger force to crush. In the conducted tests, the average rapeseed diameters of all varieties and forms of cultivation ranged from 1.81 to 1.95 mm, which indicates their good suitability for industrial purposes. Of all the varieties of rapeseed, the highest average weight was obtained in cultivation using the digestate (4.76 mg), while in traditional cultivation, it was 4.69 mg and in control combinations it was 4.61 mg.

Author Contributions: The study was designed by A.P., M.K. (Magdalena Kachel), M.K. (Milan Koszel), A.K. and A.S.A. Investigation: A.P., K.M., M.K. (Milan Koszel), N.L., and A.K. Methodology: A.P., M.K. (Magdalena Kachel), and M.K. (Milan Koszel). Formal analysis: A.P., A.S.A., and M.K. (Milan Koszel). Writing: A.P., M.K. (Magdalena Kachel), and M.K. (Milan Koszel). Statistical analysis: A.S.A., A.P., and A.K.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kowalczyk-Jusko, A.; Szymańska, M. Poferment Nawozem dla Rolnictwa; FnRRPR: Warszawa, Poland, 2015.
2. Krajowy Ośrodek Wsparcia Rolnictwa-Rejestr wytwórców biogazu rolniczego z dnia 05.01.2018 r. Available online: http://www.kowr.gov.pl/uploads/piliki/oe/biogaz/7.%20Rejestr%20wytw%C3%B3rc%C3%B3w%20biogazu%20rolniczego%20z%20dnia%2005.01.2018%20r.pdf (accessed on 1 February 2019).
3. Alburquerque, J.A.; Fuente, C.; Ferrer-Costa, A.; Carrasco, L.; Abdad, M.; Bernal, M.P. Assessment of the Fertilizer Potential of Digestates from Farm and Agroindustrial Residues. *Biomass Bioenergy* 2012, 40, 181–189. [CrossRef]

4. Kouřimská, L.; Pouštková, I.; Babička, L. The use of digestate as a replacement of mineral fertilizers for vegetables growing. *Sci. Agric. Bohem.* 2012, 43, 121–126. [CrossRef]

5. Odlare, M.; Pell, M.; Svensson, K. Changes in soil chemical and microbiological properties during 4 years of application of various organic residues. *Waste Manag.* 2008, 28, 1246–1253. [CrossRef]

6. Comparetti, A.; Febo, P.; Greco, C.; Orlando, S. Current state and future of biogas and digestate production. *Bulg. J. Agric. Sci.* 2013, 19, 1–14.

7. Montemurro, F.; Vitti, C.; Diacono, M.; Canali, S.; Tittarello, F.; Ferri, D. A three-year field anaerobic digestates application: Effects on fodder crops performance and soil properties. *Fresenius Environ. Bull.* 2010, 19, 2087–2093.

8. Kwede, A.; Schulze, D.; Schwedes, J. Determination of the stress ratio in uniaxial compression tests—Part 1. *Powder Handl.* Process. 1994, 6, 61–65.

9. Kwede, A.; Schulze, D.; Schwedes, J. Determination of the stress ratio in uniaxial compression tests—Part 2. *Powder Handl.* Process. 1994, 6, 199–203.

10. Bojanowska, M. Changes in chemical composition of rapeseed meal during storage, influencing nutritional value of its protein and lipid fractions. *J. Anim. Feed Sci.* 2017, 26, 157–164. [CrossRef]

11. Izli, N.; Unal, H.; Sincik, M. Physical and mechanical properties of rapeseed at different moisture content. *Int. Agrophys.* 2009, 23, 137–145.

12. Szwed, G.; Tys, J. Susceptibility of rapeseeds to dynamic depending on moisture and storage time. *Zes. Probl. Postepow Nauk Rol.* 1995, 427, 87–90.

13. Niewiadomski, H. Technologia Nasion Rzepaku; PWN: Warszawa, Poland, 1983.

14. Brooker, D.B.; Baaker-Arkema, F.W.; Hall, C.W. *Drying and Storage of Grains and Oilseeds*; Van Nostrand Reinhold: New York, NY, USA, 1992.

15. Stepniowski, A.; Sztot, B.; Sosnowski, S. Uszkodzenia Nasion Rzepaku w Pozbiorowym Procesie Obróbki. *Acta Agrophys.* 2003, 2, 195–203.

16. Sukumaran, C.R.; Sing, B.P.N. Compression of a bed of rapeseeds: The oil-point. *J. Agric. Eng. Res.* 1989, 42, 77–84. [CrossRef]

17. Unal, H.; Sincik, M.; Izli, N. Comparison of some engineering properties of rapeseed cultivars. *Ind. Crop. Prod.* 2009, 30, 131–136. [CrossRef]

18. Calisir, S.; Marakoglu, T.; Ogit, H.; Ozturk, O. Physical properties of rapeseed (*Brassica napus oleifera* L.). *J. Food Eng.* 2005, 69, 61–66. [CrossRef]

19. Molenda, M.; Horabik, J. *Mechanical Properties of Granular Agro-Materials and Food Powders for Industrial Practice: Characterization of Mechanical Properties of Particulate Solids for Storage and Handling—Part 1*; Institute of Agrophysics Polish Academy of Sciences: Lublin, Poland, 2005.

20. Rusinek, R.; Molenda, M.; Sykut, J.; Pits, N.; Tys, J. Uniaxial compression of rapeseed using apparatus with cuboid chamber. *Acta Agrophys.* 2007, 10, 677–685.

21. Calisir, S.; Marakoglu, T.; Ogit, H.; Ozturk, O. Physical properties of rapeseed (*Brassica napus oleifera* L.). *J. Food Eng.* 2005, 69, 61–66. [CrossRef]

22. Laskowska, J.; ysiak, G.; Skonecki, S. *Mechanical Properties of Granular Agro-Materials and Food Powders for Industrial Practice: Material Properties in Grinding and Agglomeration—Part 2*; Institute of Agrophysics Polish Academy of Sciences: Lublin, Poland, 2005.
27. Kuotsu, K.; Das, A.; Lal, R.; Munda, G.C.; Ghosh, P.K.; Ngachan, S.V. Land forming and tillage effects on soil properties and productivity of rainfed groundnut (Arachis hypogaea L.)–rapeseed (Brassica campestris L.) cropping system in northeastern India. *Soil Tillage Res.* 2014, 142, 15–24. [CrossRef]

28. Obchodzki, P.; Żebrowski, J.; Piotrowska, A. Studies on seed mechanical properties of recent Polish rapeseed cultivars. In Proceedings of the 11th International Rapeseed Congress, Copenhagen, Denmark, 6–10 July 2003; Volume 2, pp. 681–684.

29. Taniška, M.; Rotkiewicz, D. Technological value of rapeseed seed fractions after one year storage. *Rośliny Oleiste (Oilseed Crop.)* 2003, 24, 709–716.

30. Tys, J.; Sobczuk, H.; Rybacki, R. Influence of drying temperature on mechanical properties for seeds of oilseed rape. *Rośliny Oleiste (Oilseed Crop.)* 2002, 23, 417–426.

31. Szołt, B.; Kutzbach, H.D. Rapeseed damage as influenced by the dynamic load. *Int. Agrophys.* 1992, 6, 103–115.

32. Herak, D.; Słeger, V.; Mizera, C.; Siedlacek, A. Mechanical behavior of bulk rapeseeds under quasi dynamic compression loading. *Eng. Rural Dev. Jelgava* 2015, 20, 28–32.

33. Kabutey, A.; Herak, D.; Chotebrosky, R.; Dajbach, O.; Sigalingging, R.; Akabgbe, O.L. Compression behaviour of bulk rapeseed: Effects of heat treatment, force, and speed. *Int. J. Food Prop.* 2017, 20, 654–662. [CrossRef]

34. Mizera, C.; Herak, D.; Hrabe, P.; Kabutey, A. Extraction of oil from rapeseed using duo screw press. *Agron. Res.* 2018, 16, 1118–1123. [CrossRef]

35. Szwed, G.; Tys, J.; Strobel, W. Zmiana właściwości mechanicznych nasion rzepaku wywołana warunkami oraz czasem przechowywania. *Inżynieria Rolnicza* 2000, 6, 289–294.

36. Figiel, A.; Stępień, B.; Janowicz, L. Wybrane właściwości wytrzymałościowe nasion rzepaku. *Inżynieria Rolnicza* 2006, 2, 285–292.

37. KQR/BP-17-76-77: 2012. ver. 04 from 02.07.12. Gleby mineralne, organiczne, ogrodnicze. Zawartość metali Cu, Mn, Zn, Fe, Cd, Pb, Ni, Cr. Polskie Centrum Akredytacji. Zakres akredytacji laboratorium badawczego Nr AB 1186. Available online: www.pca.gov.pl/akredytowane-podmioty/akredytacje-aktywne/laboratoria-badawcze/AB-29733,podmiot.html (accessed on 1 March 2015).

38. PN-R-04024: 1997. Analiza chemiczno-rolnicza gleby—Oznaczanie zawartości przyswajalnego fosforu, potasu, magnezu i manganu w glebach organicznych. Available online: http://sklep.pkn.pl/pn-r-04024-1997p.html (accessed on 1 March 2015).

39. PN-ISO 10390: 1997. Jakość gleby—Oznaczanie pH. Available online: http://sklep.pkn.pl/pn-iso-10390-1997p.html (accessed on 1 March 2015).

40. Lamb, K.E.; Johnson, B.L. Seed size and seeding depth influence on canola emergence and performance in the Northern Great Plants. *Agron. J.* 2004, 96, 454–461. [CrossRef]

41. Mińskowski, K. Influence of variety and size of winter rapeseed on content and chemical composition of hull and embryo. *Rośliny Oleiste (Oilseed Crop.)* 2000, 21, 156–166.

42. Szwed, G.; Tys, J. Resistance of rape seeds to the impact of dynamic forces. *Zesz. Probl. Postępów Nauk Rol.* 1995, 427, 83–86.

© 2019 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).