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The Influence of Digestate on the Static Strength of Spring Rapeseeds (*Brassica napus* var. *arvensis*)

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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 m^3/year, giving a total electric power of 101.093 MW. However, in the Lublin province, 36,100,000 m^3/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 m^2 (36,000 L ha^{-1}). The pH value of the digestate used for rapeseed cultivation was 8.73. In the second variant, a multi-component mineral fertilizer Yara NPK 5-14-28 (5% N, 14% P, 28% K, 12.5% SO_3, and 3% CaO) in the amount of 0.405 kg/plot (150 kg·ha^{-1}) was used. Doses of each fertilizer were selected based on the manufacturer's recommendations. In the third case, a control plot was used, in which no form of fertilization was applied. After harvesting, the seeds were cleaned and then left for one month under laboratory conditions at 20 °C, under conditions of approx. 70% humidity to equilibrate the moisture content (Figure 1).

Figure 1. Experimental procedure.

The moisture content of the tested seeds was 7%. Depending on the type of cultivation, 100 seeds were randomly selected from each variety and weighed with an accuracy of 0.1 mg using the scales (Max 50/1/WH). After preparing the raw material, the rapeseeds were subjected to tests to determine the compression 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.

Table 1. Weather conditions in 2015 and 2016.

Month	Year 2015			Year 2016		
	Pressure (hPa)	Temperature (°C)	Rainfall (mm H_2O)	Pressure (hPa)	Temperature (°C)	Rainfall (mm H_2O)
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	21.60	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.

Table 2. Content of macronutrients and selected heavy metals in the digestate used for the cultivation of spring rape.

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

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

Experimental Variant	Kind of Field	Acidity		Liming Needs	Content of Bioavailable Ingredients (mg 100 g^{-1})		
		pH in KCl	Reaction		P_2O_3	K_2O	Mg
Before sieve							
Digestate	Control	6.97	neutral	redundant	23.8 ^{a}	16.3 ^{a}	10.3 ^{a}
	Experimental plot	7.22	alkaline	redundant	42.17 ^{b}	53.17 ^{b}	13.75 ^{b}
NPK	Control	7.06	alkaline	redundant	21.1 ^{c}	15.7 ^{a}	9.5 ^{a}
	Experimental plot	5.51	acidic	necessary	23.57 ^{a}	20.55 ^{c}	14.05 ^{b}
After harvest							
Digestate	Control	6,99	neutral	redundant	25.1 ^{d}	20.04 ^{c}	9.6 ^{a}
	Experimental plot	7.52	alkaline	redundant	64.5 ^{e}	60.5 ^{e}	21.8 ^{c}
NPK	Control	7.06	alkaline	redundant	21.6 ^{c}	16.7 ^{a}	9.55 ^{a}
	Experimental plot	5.37	acidic	necessary	26.5 ^{d}	23.3 ^{d}	17.2 ^{b}

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.

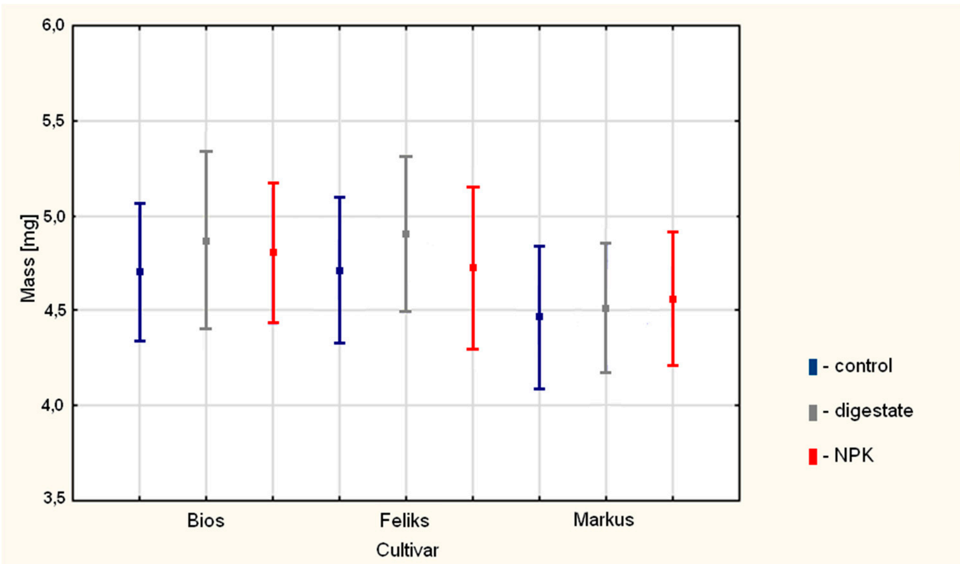

Figure 2. Effect of fertilization on the weight of rapeseeds (NPK—mineral fertilizer).

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	22.23	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)**	Control	100	1737.500	57.916	0.001
		NPK	100	1407.500	46.916	
		Digestate	100	950.000	31.666	
	Mass (mg)	Control	100	1561.000	52.033	0.181
		NPK	100	1195.000	39.833	
		Digestate	100	1339.000	44.633	
Markus	**Compressive force (N)**	Control	100	1260.000	42.000	0.638
		NPK	100	1386.500	46.216	
		Digestate	100	1448.500	48.283	
	Mass (mg)	Control	100	1468.500	48.950	0.360
		NPK	100	1426.000	47.533	
		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/NPK	0.448	0.014
	CF/NPK and M/DIGESTATE	0.175	0.355
	CF/DIGESTATE and M/CONTROL	0.184	0.331
	CF/DIGESTATE and M/NPK	0.140	0.463
	CF/DIGESTATE and M/DIGESTATE	0.621	0.001
Feliks	CF/CONTROL and M/CONTROL	0.377	0.040
	CF/CONTROL and M/NPK	0.197	0.298
	CF/CONTROL and M/DIGESTATE	−0.303	0.103
	CF/NPK and M/CONTROL	−0.270	0.149
	CF/NPK and M/NPK	0.370	0.044
	CF/NPK and M/DIGESTATE	−0.265	0.156
	CF/DIGESTATE and M/CONTROL	−0.012	0.948
	CF/DIGESTATE and M/NPK	0.119	0.529
	CF/DIGESTATE and M/DIGESTATE	0.379	0.038
Markus	CF/CONTROL and M/CONTROL	0.069	0.717
	CF/CONTROL and M/NPK	0.221	0.239
	CF/CONTROL and M/DIGESTATE	0.023	0.902
	CF/NPK and M/CONTROL	−0.178	0.346
	CF/NPK and M/NPK	0.103	0.588
	CF/NPK and M/DIGESTATE	−0.279	0.135
	CF/DIGESTATE and M/CONTROL	0.208	0.270
	CF/DIGESTATE and M/NPK	0.040	0.833
	CF/DIGESTATE and M/DIGESTATE	0.293	0.115

CF—compressive force (N), M—mass (m).

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 Tańska 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.

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