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PRINCIPAL COMPONENT ANALYSIS IN ASSESSMENT OF RELATIONS TO SOME PELLETED FEED CHARACTERISTICS

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Abstract. The paper describes the study of three feed mixtures, from which pelleted feed was produced. The main components of examined feed were wheat, corn and soybeans. Different proportions of components and varying degrees of fragmentation (0.6, 0.7 and 1.6 mm) enabled to obtain nine feedingstuffs, which differ in composition, degree of fragmentation, bulk and tapped density. The quality of feed pellets was determined by the pellet durability index, their average length and the amount of broken pellets. The statistical tests principal components analysis method was used. They were two principal components, which explained 91.11% of the variability of input data, with the loss of information at the level of 8.89%. Also 4 groups of feed with similar physical properties were determinated.

Key words: principal component analysis, pelleted feed, pelleter, pellet durability index

INTRODUCTION

Pelleted feed, as each product should meet certain requirements, which in this case are imposed by the purchasers. The use of pelleted feed in animal nutrition, in comparison with the meal feed, has advantages such as [Behnke 1996, Grochowicz 1996]: homogeneity, it can not delaminate, slowly loses nutritional value, is more readily eaten by animals, easier to transport and store. The disa-

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dvantages of pelleted feed include higher purchase costs compared to meal feed and high energy consumption during pelleting process.

Behnke [1996] reports that the quality of pelleted feed is affected by technical and technological parameters of pelleting process, the components used and the degree of fragmentation. The use of pelleted feed, will not give expected results, if it will be characterized by low quality.

The parameters defining the quality of pelleted feed are: pellet durability index, hardness, homogeneity of the pellets' lenght, appearance, dust content and palatability [Wood 1987, Thomas and Poel 1996, Synnøve Aas et al. 2011]. The pellet durability index is a parameter which indicate the resistance of pelleted feed to damage during transport. Audet [1995] reports that it is one of the most important features in pellet quality.

Wondra et al. [1995] studied the effect of ingredients' fragmentation degree on pellet durability index. Based on the survey they found that with increasing fragmentation degree also pellet durability index was growing. However Brzóska and Śliwinski [2011] argue that excessive fragmentation of food leads to weakening of cellulose digestion in rumen, rapid decomposition of starch and lower the pH of the rumen pH to approx. 5.5. This slows down the synthesis of bacteria and protozoa in the rumen and moving its content to the abomasum.

The aim of this study was to extract specific groups of the examined pelleted feed using principal component analysis.

MATERIAL AND METHODS

Tests were performed on DPAA Buhler pelleting press with annular matrix, horizontal axis and two working rollers. The thickness of matrix was 100 mm and diameter of holes was 4 mm. Examined feedingtuffs were labeled as Ga, Gb and Gc, their composition and percentage share is shown in Table 1. The composition varied in percentage of each component in the blend. These mixtures were the raw material for the production of pelleted feed. Their basic components were wheat, corn and soybeans. Before the pelleting process all components were shredded and mixed.

Figure 1 shows a diagram of controlled during the study physical characteristics of mixes and pelleted feed on the entrance and exit of the pelleting press.

RESEARCH METHODOLOGY

Determination of ingredients' fragmentation degree was carried out for the samples of examined feed weighting 100 g. The feed was poured into the top sieve of laboratory siever (using meshes with hole diameters: 10.0, 8.0, 6.0, 5.0,

Table 1. Percentage of components in the tested mixed feed

Tabela 1. Procentowy udział komponentów w badanych mieszankach

No. Lp.	Component, % – Komponent, %	Type of feed – Rodzaj paszy		
		Ga	Gb	Gc
1	Corn – Kukurydza	33	23	48
2	Wheat – Pszenica	33	30	15
3	Soy – Soja	23	31	23
4	Rapeseed meal, concentrate, vegetable oil Śruta rzepakowa, koncentrat, olej roślinny	11	16	14

Source: own compilation.
Źródło: opracowanie własne.

4.0, 3.0, 2.0, 1.0, 0.5, 0.2 and 0.1 mm) and sieved 3 minutes at a frequency of 100 Hz and 130 mm amplitude [in accordance with PN-89/R-64798]. After 3 minutes sieving was stopped, the sides of the frame were tapped and sieving was started again through a 1 min. After completion each fraction was weighed to the nearest 0.1 g. On this basis geometric weighted average of particle size (d_g), hereinafter referred as the fineness of particle feed, was calculated according to the formula:

$$d_g = 10^x$$

in which:

$$x = \frac{\sum_{i=1}^{n} W_i \lg d_{zi}}{\sum_{i=1}^{n} W_i}$$

where:

d_g – geometric weighted average of particle size (fineness of particle feed), mm,

W_i – weight of residue on each sieve and the bottom, g,

d_{zi} – equivalent diameter of each fraction – a constant value according to norm PN – 89/R–64798, mm,

n – the number of screens with bottom.

The bulk density of loose mixture was determined by pouring the sample into a measuring vessel of known volume. The bulk density was calculated according to the formula

$$G_{us} = \frac{m_1 - m_2}{v}$$

where:

G_{us} – bulk density, kg · m^{-3},

m_1 – mass of the vessel with meal feed, kg,

m_2 – mass of empty vessel, kg,

v – volume of the vessel, m^3.

The result was the arithmetic average of the three repetitions.

The tapped density of mixed feed was determined by pouring a sample of 500 g into a measuring container of Engelsmann's device, then tapped for 5 minutes at frequency of 150 Hz and amplitude of 10 mm. After completion volume of the sample was measured. The tapped density was calculated according to the formula:

$$G_{ut} = \frac{m}{V_p}$$

where:

G_{ut} – tapped density, kg · m^{-3},

m – sample mass, kg,

V_p – volume after tapping, m^3.

Measurement of pellet durability index was carried out using a mechanical tester ZU-05, according to norm PN-R-64834.Samples for measurements weighting at least 3 kg were prepared from primary samples. Crushed parts were sieved from general sample (using mesh with holes 1 mm smaller then pellets' diameter), then three samples of 500 g ±0.5 g were collected. Each sample was placed in a chamber chich was centrifuged for 10 minutes. After stopping – sample was sieved on a mesh with holes 1 mm smaller then the pellets' diameter, residue on the sieve was weighted. Pellet durability index was calculated according to formula:

$$P_{di} = \frac{m_i}{m} \cdot 100\%$$

where:

P_{di} – pellet durability index, %,

m_i – mass of pellets remaining on the sieve after the test of strength, g,

m – mass of the sample of examined pellets – 500 g.

Homogeneity of the pellets' length. To determine the homogeneity of the pellets' length standard deviation was determined based on the length 20 randomly

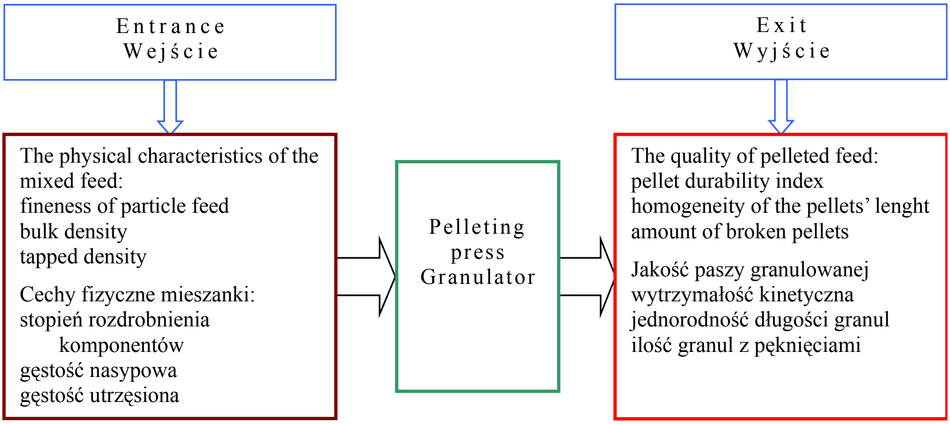

Fig. 1. The physical characteristics of the blend and pelleted feed controlled during testing on the entrance and exit of the pelleting press; source: own compilation

Rys. 1. Schemat kontrolowanych w trakcie badań cech fizycznych mieszanki i paszy granulowanej na wejściu i wyjściu granulatora; źródło: opracowanie własne.

selected pellets from a laboratory sample [Wood 1987]. Lower standard deviation indicates a more homogenous pellets' length.

The amount of broken pellets. From laboratory sample of 500 g 100 pellets were randomly selected. Then pellets with visible brokens were chosen and counted. Amount of broken pellets was calculated from the formula:

$$U_g = \frac{L_{ug}}{L_g} \cdot 100\%$$

where:

U_g – amount of broken pellets, %,

L_{ug} – number of broken pellets,

L_g – number of pellets in sample.

To determine the relations between selected features of pelleted feedingstuff statiscical analysis of principal components was used, which is classified as multivariate analysis. Principal component analysis is a statistical procedure that without significant loss of information allows to: reduce the number of variables, detect structures and general regularities in the relationships between variables [Stanisz 2007]. For this purpose, the following variables were determined: bulk and tapped density, fineness of particle feed and pellet durability index, length and amount of pellets with brokens.

As a criterion for reducing the number of variables percentage of variance explained by that component was adopted. Statistical analysis were performed in the application Statistica 12 (StatSoft, USA).

RESULTS

Table 2 shows obtained during testing parameters that characterize loose mixture (bulk and tapped density, fragmentation degree) and pelleted feedingstuff (pellet durability index, length, amount of broken pellets). The largest bulk density (688.8 kg $\cdot$ m^{-3}) obtained mixture Gc3, which main ingredients were corn (48%) and soy (23%). Its fragmentation degree obtained a value of 1.6 mm. The best result of pellet durability index (97.7%) received a Ga1 mixture, which was made from feedingstuff of 0.6 mm fragmentation degree.

Principal component analysis was performed on the results shown in Table 2 for the following variables: bulk density (G_{us}) and tapped density (G_{ut}) mixed feed, fineness of particle feed (d_g), pellet durability index (P_{di}), pellets' length (L) and the amount of broken pellets (U_g).

Table 2. The average values for each feature of tested pelleted feed

Tabela 2. Wartości średnie dla poszczególnych cech badanych pasz granulowanych

Feature Parametr	Main ingredients Skład głównych komponentów			Bulk density mixed feed Gęstość nasypowa	Tapped density mixed feed Gęstość utrzęsiona	Fineness of particle feed Stopień rozdrobnienia	Pellet durability index Wytrzymałość kinetyczna	Pellet length Długość granul	Amount of broken pellets Ilość pękniętych granul
Type of feed Rodzaj paszy	corn kukurydza	wheat pszenica	soy soja						
	K, %	P, %	S, %	G_{us}, kg $\cdot$ m^{-3}	G_{ut}, kg $\cdot$ m^{-3}	d_g, mm	P_{di}, %	L, mm	U_g, %
Ga1	33	33	23	612.4	660.2	0.6	97.7	13.8	2.3
Ga2	33	33	23	624.7	668.4	0.7	93.9	13.8	0.8
Ga3	33	33	23	655.9	688.7	1.6	85.4	10.6	2.8
Gb1	23	30	31	620.1	694.5	0.6	96.6	14.0	4.7
Gb2	23	30	31	629.4	686.1	0.7	93.6	13.0	3.2
Gb3	23	30	31	667.4	700.1	1.6	83.6	10.0	2.8
Gc1	48	15	23	636.4	700	0.6	95.5	14.9	1.7
Gc2	48	15	23	643.2	688.2	0.7	92.7	14.1	1.7
Gc3	48	15	23	688.8	712.9	1.6	79.2	9.3	6.2

Source: own compilation.
Źródło: opracowanie własne.

From Table 3 it can be stated a high negative correlation between the bulk density, G_{us}, and pellet durability index, P_{di}, (0.97), fragmentation degree of pelleted mixture, d_g, and pellet durability index, P_{di}, (–0.96) and positive correlation between bulk, G_{us}, and tapped density, G_{ut}, (0.77). Due to the presence of differentiated correlation values as shown in the above matrix, it can be assumed that there is a pattern that will have an impact on the form of principal components.

Table 3. Matrix of correlation coefficients between the variables

Tabela 3. Macierz współczynników korelacji pomiędzy zmiennymi

Variable – Zmienna	G_{us}	G_{ut}	d_g	P_{di}	L	U_g
G_{us}	1.00	0.77	0.88	–0.97	–0.86	0.51
G_{ut}	0.77	1.00	0.53	–0.64	–0.51	0.63
d_g	0.88	0.53	1.00	–0.96	–0.97	0.44
P_{di}	–0.97	–0.64	–0.96	1.00	0.95	–0.51
L	–0.86	–0.51	–0.97	0.95	1.00	–0.57
U_g	0.51	0.63	0.44	–0.51	–0.57	1.00

Source: own compilation.
Źródło: opracowanie własne.

The first component (Table 4) corresponding to the largest eigenvalue (4.63) explains 77.24% of the total variance, while the second component corresponding to the second eigenvalue (0.83) explains 13.87% of the total variance. From Table 4 it can be observed that the component 1 and 2 explains 91.11% of the total variance with the loss of information at the level of 8.89%.

Table 4. Eigenvalues of correlation matrix

Tabela 4. Wartości własne macierzy korelacji

Value number Numer wartości	Eigenvalue Wartość własna	% total variance % ogółu wariancji	Cumulative eigenvalue Skumulowana wartość własna	Cumulative % Skumulowany %
1	4.63	77.24	4.63	77.24
2	0.83	13.87	5.47	91.11
3	0.45	7.54	5.92	98.64
4	0.07	1.10	5.98	99.74
5	0.01	0.20	6.00	99.94
6	0.00	0.06	6.00	100.00

Source: own compilation.
Źródło: opracowanie własne.

In order to present the form of components, their coefficients or the eigenvectors were determined (Table 5).

Based on the Table 5 it can be assumed that sought first two principal components take the following forms:

$$Z_1 = 0.45G_{us} + 0.35Gut + 0.43d_g - 0.45P_{di} - 0.44L + 0.31U_g$$

$$Z_2 = 0.07G_{us} - 0.54G_{ut} + 0.36d_g - 0.22P_{di} - 0.26L - 0.68U_g$$

Table 5. Eigenvectors of correlation matrix

Tabela 5. Wektory własne macierzy korelacji

Variable Zmienna	Factor 1 Czynnik 1	Factor 2 Czynnik 2	Factor 3 Czynnik 3	Factor 4 Czynnik 4	Factor 5 Czynnik 5	Factor 6 Czynnik 6
G_{us}	0.45	0.07	–0.32	–0.61	0.25	0.51
G_{ut}	0.35	–0.54	–0.62	0.39	–0.21	–0.05
d_g	0.43	0.36	0.09	0.56	0.60	0.00
P_{di}	–0.45	–0.22	0.04	0.34	0.14	0.78
L	–0.44	–0.26	–0.34	–0.18	0.68	–0.35
U_g	0.31	–0.68	0.62	–0.12	0.20	–0.03

For the correct interpretation of the components' properties Table 6 shows the factor loadings that describe the correlations between variables and components. It can be noticed that the first component Z_1 is more correlated with variables because it has the most highest factor loadings. The loads for bulk density (G_{us}) was 0.96 and 0.93 for fragmentation degree of pelleted mixture (d_g). Pellet durability index (P_{di}) and pellets' length (L) affect this component in an opposite manner that the other variables. Variable of pellets with brokenss (U_g) has a high negative factor loading with the second component.

Table 6. Factor-variable correlations

Tabela 6. Ładunki czynnikowe

Variable Zmienna	Factor 1 Czynnik 1	Factor 2 Czynnik 2	Factor 3 Czynnik 3
G_{us}	0.96	0.07	–0.22
G_ut	0.76	–0.49	–0.42
d_g	0.93	0.32	0.06
P_{di}	–0.97	–0.20	0.03
L	–0.94	–0.24	–0.23
U_g	0.66	–0.62	0.42

Figure 2 shows plot of variables and distribution of six features in system of selected principal components pairs. Pellet durability index (P_{di}), the pellets' length (L), fineness of particle feed (d_g) and bulk density (G_{us}) are connected with the first principal component.

Comparing the position of pelleted feed Gc3 on Figure 3 with the principal components forms and factor loadings it can be concluded that pellets of this feed were characterized by the highest amount of brokens (U_g) and the highest tapped density (G_{ut}) of ingredients from which it was produced. Next group includes feeds Ga3 and Gb3, whose ingredients were characterized by a high fragmentation degree of pelleted mixture (d_g) and high bulk density values (G_{us}). Feeds Gb1, Gb2 and Gc1 were characterized by high pellet durability index (P_{di}) and pellets' length (L). The fourth group includes feeds Ga1, Ga2, and Gc3, which do not have common features.

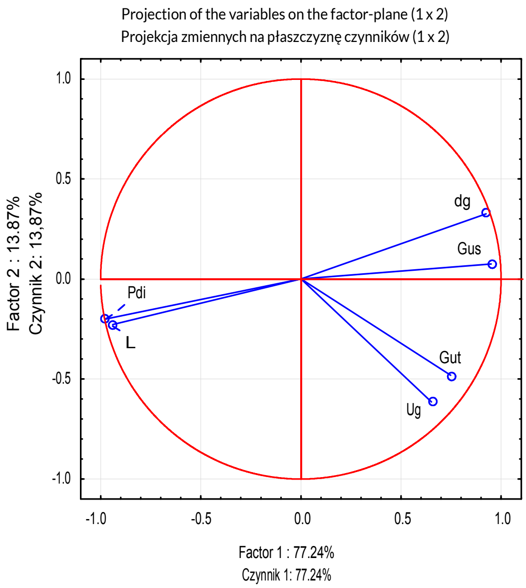

Fig. 2. Plot of variables. Location of load vectors towards two principal components

Rys. 2. Wykres współrzędnych czynnikowych zmiennych

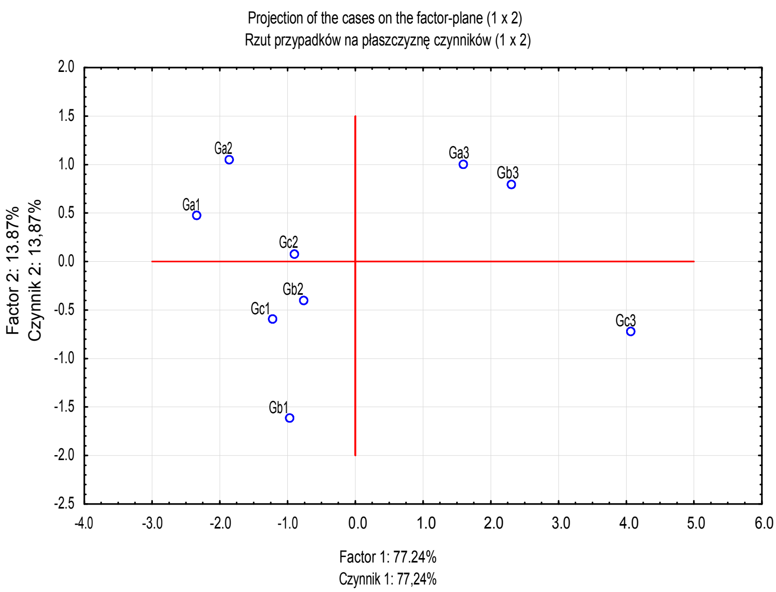

Fig. 3. Loadings graph; source: own elaboration

Rys. 3. Wykres współrzędnych czynnikowych przypadków; źródło: opracowanie własne

CONCLUSIONS

The study presents the results of research carried out on nine types of compound feed with different composition and fineness of particle feed (d_g): from 1.6 mm to 0.6 mm. Components obtained in this way were pelleted and then their quality was assessed, considering the pellet durability index, pellets' length and the amount of broken pellets.

The influence of the analyzed factors on the quality of the feed pellets was described by two principal components, which explained 91.11% of the variance of input data with the loss of information at the level of 8.89%. On the basis of principal components analysis from 9 types of tested pelleted feed 4 groups were distinguished. Group that included feeds: Gb1, Gb2 and Gc1 was characterized by high results of pellet durability index. In contrast, the group that included only feed Gc3, was characterized by the highest amount of broken pellets (6.2%) and the highest tapped density of mixed feed, from which it has been produced (700.1 $kg \cdot m^{-3}$). The third group includes feeds Ga3 and Gb3, which have the highest tapped density of mixed feed from which they were produced (G_{us}), and the smallest fineness of particle feed (d_g) – 1.6 mm. On the basis of conducted principal components analysis, it found its suitability to extract groups of pelleted feed with similar characteristics.

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STATYSTYCZNA ANALIZA SKŁADOWYCH GŁÓWNYCH W OCENIE ZALEŻNOŚCI WYBRANYCH CECH PASZY GRANULOWANEJ

Streszczenie. W pracy opisano badania trzech mieszanek paszowych, z których wytwarzano pasze granulowane. Głównymi składnikami badanych pasz była pszenica, kukurydza oraz soja. Różne proporcje komponentów oraz różny stopień ich rozdrobnienia (0,6, 0,7 i 1,6 mm) umożliwiły uzyskanie dziewięciu mieszanek paszowych różniących się składem, stopniem rozdrobnienia, gęstością nasypową i utrzęsioną. Jakość paszy granulowanej określano na podstawie wytrzymałości kinetycznej granul, ich średniej długości oraz ilości pękniętych granul. W badaniach statystycznych wykorzystano metodę analizy składowych głównych. Wyodrębniono dwie składowe główne, które wyjaśniły 91,11% zmienności danych wejściowych, przy utracie informacji na poziomie 8,89%. Wyznaczono także 4 grupy pasz charakteryzujących się podobnymi właściwościami fizycznymi.

Słowa kluczowe: analiza składowych głównych, pasza granulowana, granulator, wytrzymałość kinetyczna

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