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Engineering in the production technology of extruded feed additives

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Abstract. The production of fodder from ecologically clean raw materials is an effective way of increasing the volume of fodder while reducing the economic costs of their production. The use of natural feed additives in feed improves their consumption. Innovative engineering in the technology of production of feed additives is carried out through the improvement of the technology of feed additives using fruit and vegetable raw materials. At present, sufficiently large stocks of fruit and vegetable raw materials are permanently accumulated in Ukraine, which are insufficiently used in fodder production. At the same time, improving the consumption and increasing the efficiency of the use of feed, as well as obtaining the maximum livestock productivity is increasingly ensured by the use of natural feed additives in the composition of feed. That is why the production of fodder from ecologically clean raw materials, as a transition to alternative technologies, is one of the most effective ways to increase the volume of fodder with a decrease in the economic costs of their production. Today, there is no such practice in private households. The inclusion of fruit and vegetable raw materials in feed formulations is relevant for improving their quality. The aim of the work was to expand the range of animal feed and to improve the production technology of extruded feed mixture. The laboratory and analytical method was used in the work. The authors presented the technology, which consists in preliminary preparation of raw materials: cleaning, grinding, dosing according to the composition of the recipe, mixing and special processing to improve technological properties and increase feed value with processes: pre-mixing, aging and extruding the mixture, cooling and grinding the product depending from the purpose of feed. The results can be used to improve the technology for the production of nutritious feed for animals and provide more farms

Keywords: grain, fruit and vegetable raw materials, feed additives, extrusion technology

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INTRODUCTION

Innovation is the process of applying advanced technologies, products, or the result of study in the form of new methods, products, technological processes, etc. Innovative engineering in the technology of production of feed additives is carried out through the improvement of the technology of feed additives using fruit and vegetable raw materials, aging and extrusion of feed mixtures according to the composition of the recipe, cooling and grinding of the extrudate.

Quite large stocks of fruit and vegetable raw materials are constantly accumulating in Ukraine, which are still insufficiently used in fodder production. At the same time, improving consumption and increasing the efficiency of feed use, as well as obtaining maximum animal productivity is increasingly ensured by the use of natural feed additives in the composition of feed. That is why the production of fodder from ecologically clean raw materials, as a transition to alternative technologies, is one of the most effective ways to increase the volume of fodder with a decrease in the economic costs of their production. Today, private households do not have technologies for extruding a mixture of grain and fruit and vegetable raw materials as a natural, ecological and safe feed for fattening animals.

In order to improve the nutrition of animals and improve the quality of feed, including in private farms of the population, it is important to add fruit and vegetable raw materials to the recipe composition of the feed.

To ensure the successful development of highly productive animal husbandry, it is necessary to constantly expand the raw material base and the range of products of compound feed production [1].

Feed additives are used to balance feed rations due to the lack of certain nutrients, improve the consumption of basic feeds, increase the digestibility and assimilation of feed nutrients, and are used as prevention of the stressful state of farm animals, etc. [2; 3]. The main feed additives include non-protein nitrogenous substances, energy, mineral, vitamin substances, as well as antibiotics, probiotics, enzymes, antioxidants, organic acids, etc.

The methods of production of feed additives are different and depend on the enterprises that produce them and on the physical and technological properties of the raw materials. The preparation of additives for introduction into compound feed takes place along separate technological lines depending on the variant of the technological process, for example, minerals, vitamin substances, antibiotics, probiotics, enzymes, antioxidants, organic acids are introduced into the composition of premixes along the lines of the same name; supply to production – along the supply line of protein and mineral raw materials [4-6].

The purpose of the work is to expand the range of compound feed for animals by improving the technology of extruding a mixture of grain raw materials with fruit and vegetable components. Methods of determining the physical and technological properties of compound feed components. Sampling and separation of the weight from the extruded mixture was carried out in accordance with DSTU ISO 6497:2005 "Feed for animals. Sampling methods" (ISO 6497:2002, IDT) and DSTU ISO 6498:2006 Animal feed. Preparation of samples for research (ISO 6498:1998, IDT), which were adopted to replace GOST 13496.0-80 "Compound feed, compound feed raw materials. Sampling methods".

The modulus of grain size was determined based on the results of studying the residues on sieves (GOST 13496.8-92). For this, a laboratory classifier and sieves with round holes with a diameter of 5.0 were used; 4.0; 3.0; 2.0; 1.0 mm. A sample weighing 100 g was taken from the sample of the crushed product. It was then sifted on a laboratory classifier for 5 minutes. Residues from each sieve and collection bottom were weighed on PS/X2 "Radwag" scales with an accuracy of 0.01 g.

The coarseness module (M) of the crushed product is determined by the formula:

$$M = \frac{d_1P_1 + d_2P_2 + \cdots + d_nP_n}{100} = \frac{\Sigma_{i=1}^{n} diPi}{100}, \tag{1}$$

where d_1 is the average size of the holes of two adjacent sieves, mm; P_1 – fraction mass yield (residue on each sieve), %; n is the number of fractions into which the weight is divided. The degree of crushing of root crops was determined in the same way as for grains. But considering that chopped vegetables have low flowability, the technique is slightly different. Determination of the dispersity of pulp (the VNIIICOP method). The size of the particles and their number are determined using a sieve analysis

Equipment: a set of metal sieves with perforations from 5 to 3 mm; chemical beaker for 300 ml; technical scales for 200 g; kapron sieve No. 18.

MATERIALS AND METHODS

From the average pulp sample, after thorough mixing, weigh 150 g in a chemical beaker on technical scales. Blot with paper towels to remove residual moisture. A set of sieves is collected so that their perforation gradually decreases. A kapron sieve is put on the lower sieve with a perforation of 3 mm from the lower side. Pour water almost to the top in a glass with a sample, stir gently and pour the mixture onto the top sieve. The pulp is slightly leveled on the surface of the sieve and the entire set of sieves with perforations of 5.0, 3.0 mm and kapron mesh, without disassembling, is brought to the water tap under a calm stream of water. Washing is carried out for 5 minutes, slowly rotating the sieve so that the entire mass on the sieve is evenly washed with a stream of water. After washing, pulp particles are carefully collected from each sieve into a napkin made of two layers of gauze and squeezed by hand until the release of water stops. Then each fraction is carefully collected with gauze on filter paper, soaked on both sides with filter paper and weighed on a technical scale with an accuracy of 0.1 g.

RESULTS

Fruit and vegetable crops are used to improve the taste and nutritional qualities of feed. As experimental samples, we selected root vegetables of standard quality: table beet, table carrot, parsnip, potato, fruit: grape pomace and extruded products from their mixtures with grain crops. The organoleptic evaluation of fruit and vegetable crops revealed full correspondence of the characteristics of these plants to certain species. The physical properties of fruit and vegetable cultures indicate the possibility and favorable conditions for their use at all stages of the technological process [11].

An analytical review of the literature on the study of the assortment, nutritional value of compound feed and means for improving the taste of feed [1-3; 6], as well as research on the physical and technological properties of fruit and vegetable raw materials – table beets, carrots, parsnips, potatoes [11] testify to the possibility of using these plants in the production of feed additives. That is why the next stage of the work was the improvement of the technology for the production of feed additives using fruit and vegetable raw materials – beets, carrots, potatoes, parsnips and grape pomace (Fig. 1).

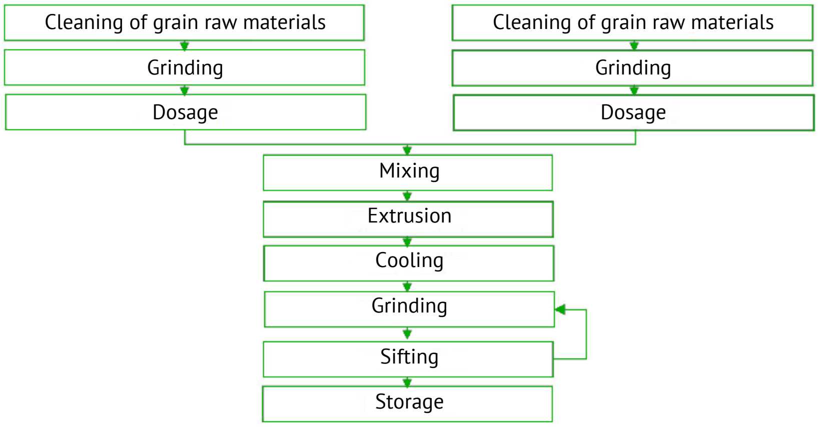


***Figure 1**. Block diagram of advanced extrusion technology*

One of the stages of studying the process was extrusion in laboratory conditions of UNUS on a Ukrainian-made KMZ-2M press-extruder. Research was also conducted on a PEK-40x5B laboratory extruder at the National University of Food Technologies [7].

The grain was crushed on a hammer crusher (brand DM-03), using sieves with different hole diameters (6.0, 4.0, 3.0 mm). We obtained a product with different grind size and different granulometric composition. Vegetable components were cleaned from soil and other impurities by sorting and washing. Mixtures with the addition of vegetable components to the grain in their native form were created by hand, by mixing different ratios of components. The product was fed into the extruder manually and with the help of a vibratory feeder. During the extrusion process, the readings of the ammeter and thermometer were recorded and the time was recorded. After extrusion, the product was cooled at room temperature and relative humidity of 60%. After cooling, the product samples were packed in a separate hermetic container, part of which was previously crushed.

Our improved technological scheme for the production of feed additives using fruit and vegetable raw materials is presented in Figure 2.

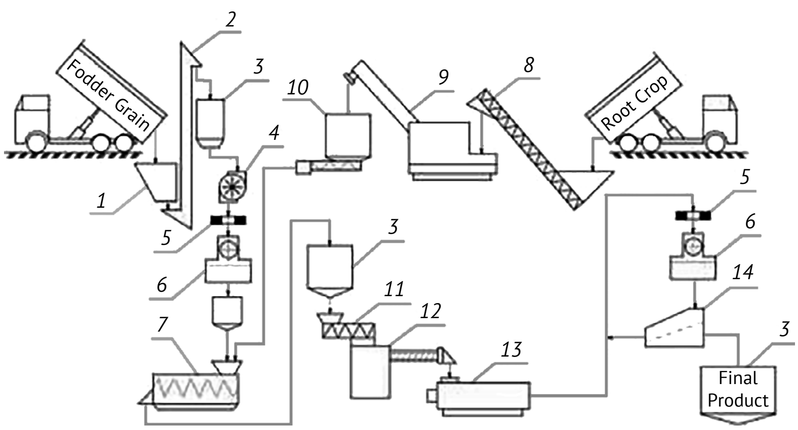
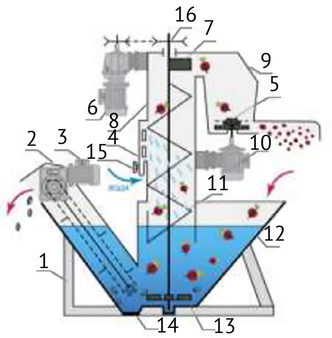


***Figure 2**. An improved technological scheme for the production of extruded feed additives using fruit and vegetable raw materials: 1 – bulk bunker; 2 – transporter-noria; 3 – storage hopper; 4 – dispenser; 5 – magnetic catcher; 6 – hammer crusher; 7 – mixer; 8 – conveyor; 9 – root crop washer-shredder; 10 – hopper-dispenser of crushed root crops; 11 – extruder feeder; 12 – extruder; 13 – cooler; 14 – sifter*

The production of a high-quality product at a large-tonnage production involves preliminary cleaning of grain raw materials from foreign impurities on a two-chamber pneumatic separator CA-4, with a capacity of up to 6 t/h, which does not require connection to the power grid, because it works due to the flow of air created by the crusher. Next, the grain is sent by pneumatic transport for grinding on the DKR-5D hammer crusher with a capacity of up to 5 t/h. The required grinding size is determined by the sizes of the sieve holes on the crusher.

The crushed product is unloaded by pneumatic transport into a 3-ton super-dosing hopper, and then dosed into a mixer to create a mixture of the required composition.

Cleaning of root crops – table beets, carrots, parsnips, potatoes from extraneous impurities takes place on the CSC-5 installation (Fig. 3), which simultaneously cleans and grinds raw materials. Before starting work, the bath is filled with water. The necessary level of water in the bath is maintained by a drain nozzle located on the conveyor casing. The rotating movement of water in the bath is created by an impeller fixed on the auger shaft.



1 – Frame
2 – Transporter-stone catcher
3, 6, 10 – Electric motors
4 – Water sprayer
5 – Casing
7 – Ejector
8 – Shredder
9 – Shredder cover
11 – Sink auger
12 – Bath
13 – Impeller
14 – Luke
15 – Water supply valve
16 – Auger drive pulley

***Figure 3**. CSC-5 vegetable chopper*

The root crops loaded into the bath are suspended under the action of the rotating water flow, picked up by the auger and sent to the chopper. Partially washed roots and tubers in the bath are additionally washed with a jet of water in the auger housing. Stones and other heavy objects fall to the bottom of the tub and are thrown by the impeller into the conveyor-stone catcher. After cleaning, the root crops are chopped with horizontal knives and sent to the lower disk, where they are finally chopped with vertical knives. To obtain fine grinding, the product is additionally passed through a tray. The crushed product is discharged through the tray using the blades of the lower disc.

Cleaning and grinding of grain is carried out using the modes that are given in the "Rules for the organization and management of the technological process of the production of compound feed products" [9].

The raw material prepared in this way is fed into the periodic weighing doser, where it is dosed in the specified ratios. The dosed mixture enters the mixer, where the components are evenly mixed, then it is fed to the 5-ton hopper for aging before extrusion.

The mixture of crushed grain and wet components is fed to the KMZ-2M extruder or another brand, with a grain processing capacity of 380 kg/h. The resulting product is cooled in a vertical or horizontal cooler to a temperature that does not exceed the ambient temperature by more than 15-18°C, if necessary, it is crushed on hammer crushers and sifted on separators using sieves that provide the required size prescribed by the standard. Extrusion and cooling of the mixture is carried out using the established modes "Rules of organization and management of the technological process of compound feed production" [10].

We calculated the cooling process of the mixture of extruded grain with fruit and vegetable raw materials after processing in KMZ-2M and PEK-40x5B extruders.

Output data: temperature of the mixture at the exit from the extruder, Q1=120°C; moisture content of the extruded mixture, W1=11.0%; productivity of the KMZ-2M extruder for wet product G1=430 kg/h; PEK-40x5V extruder for wet product G1=30 kg/h; number of extruders – 1 pc.; temperature of the extruded mixture after cooling, Q2=28°C; moisture content of the extrudate after cooling, W2=10.0%; air temperature, t1=15°C; relative air humidity, φ1=67%; exhaust air temperature, t2=25°C; relative humidity of exhaust air, φ2=40%.

The amount of moisture that evaporates during cooling of the extruded mixture:

$$W = G1\left(W1 - \frac{W2}{100} - W2\right), \frac{kg}{hr}, \quad (2)$$

for KMZ-2M:

$$W = 430\left(11{,}0 - \frac{10{,}0}{100} - 10{,}0\right) = 4{,}8\frac{kg}{hr}, \quad (3)$$

for PEK-40x5V:

$$W = 30\left(11{,}0 - \frac{10{,}0}{100} - 10{,}0\right) = 0{,}33\frac{kg}{hr}. \quad (4)$$

The average performance of the extruder on the dry mixture:

$$G2 = G1 - W, \frac{kg}{hr}, \quad (5)$$

for KMZ-2M:

$$G2 = 430 - 4{,}8 \ = \ 425{,}2\,\frac{kg}{hr}, \quad (6)$$

for PEK-40x5V:

$$G2 = 30 - 0{,}33 \ = \ 29{,}67\,\frac{kg}{hr}. \quad (7)$$

The amount of heat introduced into the cooling unit by the hot mixture:

$$q\text{пр} = \left(\frac{G2}{W}\right) \cdot C(Q1 - \ Q2), \frac{kJ}{kg} \ \textit{of evaporated moisture}. \quad (8)$$

The average specific heat in the mixture is 1.927 J/(kg·degree):
for KMZ-2M:

$$q\text{пр} = \left(\frac{425{,}2}{4{,}8}\right) \cdot 1{,}927(120 - 28) = 15704 \ \frac{kJ}{kg} \ \textit{of evaporated moisture}, \quad (9)$$

for PEK-40x5V:

$$q\text{пр} = \left(\frac{29{,}67}{0{,}33}\right) \cdot 1{,}927(120 - 28) = 15939 \ \frac{kJ}{kg} \ \textit{of evaporated moisture}. \quad (10)$$

The difference between the amount of heat introduced into the cooler together with the extruded mixture and its amount removed from the cooling unit:

$$\Delta\, cool \ = \ q\text{пр} \ + (Q1 - \ q\text{н.сер}), \frac{kJ}{kg} \ \textit{of evaporated moisture}, \quad (11)$$

for KMZ-2M:

$$\Delta\ \text{охл.} = \ 15704 + (120 - 0) = 15824, \frac{kJ}{kg} \ \textit{of evaporated moisture}, \quad (12)$$

for PEK-40x5V:

$$\Delta\, cool \ = \ 15939 + (120 - 0) = 16059, \frac{kJ}{kg} \ \textit{of evaporated moisture}. \quad (13)$$

According to the I-d diagram of moist air, we determine the specific air consumption for cooling the extruded mixture, which is l=555 dry air/kg of evaporated moisture.

Total weight consumption of air for cooling the extruded mixture:

$$L = l \cdot W, \frac{kg}{hr}, \quad (14)$$

for KMZ-2M:

$$L = 555 \cdot 4{,}8 = 2664\,\frac{kg}{hr}, \quad (15)$$

for PEK-40x5V:

$$L = 555 * 0{,}33 = 183\,\frac{kg}{hr}. \quad (16)$$

Volume flow rates of moist air at the entrance to the cooling unit:

$$V_{in} = L \cdot V_0, \frac{m^3}{h}, \quad (17)$$

for KMZ-2M:

$$V_{in} = 2664 \cdot 0.8421 = 2243, \frac{m^3}{h}, \quad (18)$$

for PEK-40x5B:

$$V_{in} = 183 \cdot 0.8421 = 154, \frac{m^3}{h}, \quad (19)$$

at t1=15°C, φ=67%, V0=0.8421 m^3/h of dry air.

The amount of air at the outlet of the cooling unit:
for KMZ-2M:

$$Vout = 2664 \cdot 0.9727 = 2591\,\frac{m^3}{h}, \quad (20)$$

for PEK-40x5B:

$$Vout = 154 \cdot 0.9727 = 150\,\frac{m^3}{h}, \quad (21)$$

at t1=25°C, φ=40%.

Specific air flow in the cooling unit:
for KMZ-2M:

$$\frac{2243}{430} = 5.22\,\frac{\frac{m^3}{h}}{kg}\,\textit{of mixture}, \quad (22)$$

for PEK-40x5V:

$$\frac{154}{30} = 5.13, \frac{\frac{m^3}{h}}{kg}\,\textit{of mixture}. \quad (23)$$

According to the above calculations, the specific air consumption in the cooling unit should be 5.1-5.2 (m^3/h)/kg of the mixture.

At the final stage of production, the finished product is checked in magnetic separators for the presence of metallomagnetic impurities, weighed on automatic scales and sent to packaging and storage. It is also possible to use a feed additive as a raw material for the production of compound feed for farm animals.

In order to find out the behavior of vegetable raw materials in the mixing process, we conducted a study to determine the effectiveness of the mixing process based on the statistical characteristics of the mixtures that included vegetable raw materials. Such a characteristic is the coefficient of variation (heterogeneity) of the distribution of the key component in the mixture. Research has established that the coefficient of variation of the distribution of the key component is 4.6...5.4%, which indicates a good distribution of the key component - salt. Therefore, it can be concluded that other components of feed additives are well distributed in the mixture.

The traditional technological scheme for the production of compound feed involves the following main lines: line of grain raw materials; film separation line; a line of floury raw materials; line of loose herbal flour; line of pressed and lumpy raw materials; line of fodder products of food industries; line of meal; salt preparation line; chalk and other mineral raw material preparation line; a line for processing packaged raw materials and a line for introducing premixes [10].

Based on the results of the conducted research, we recommend introducing feed additives into the composition of compound feed at the meal line. The technological line for the introduction of feed additives is included in the technological scheme, which is shown in Figure 4.

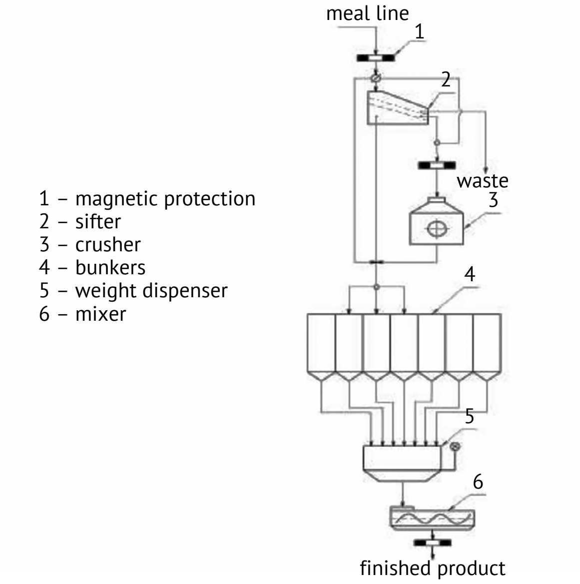


Figure 4. *Technological diagram of the extruded raw material input line*

According to the given technological diagram (Fig. 4), feed additives are fed to the hopper, from where to the sieve (2) to remove random impurities. For this purpose, the installation of sieve frames No. 100 with hole sizes of 10 mm diameter or No. 8 with cells of 8×8 mm size is provided, which are used to separate random impurities of large sizes. The passage from this sieve is sent through the magnetic separator (1) to the overdosing hoppers. Cleaning from extraneous impurities is carried out using the regimes established by the "Rules for the organization and management of the technological process of the production of compound feed products" [10].

Based on the fact that the macromolecules of the extrudates are packed rather loosely, cavities are often formed between the molecules, into which water enters, and as a result, the volume and degree of swelling increase. Physical indicators of mixtures of corn grain with vegetable root crops of different concentrations are given in Table 1.

Table 1. *Physical indicators of a mixture of corn grain with root vegetables depending on their concentration (n=3, P≥0.95)*

Mixture of corn grain with root vegetables			Volumetric mass, kg/m³	Swelling, ml/g	Angle of natural slope, degree	Flowability, cm/s	Swelling coefficient
			Beet				
Concentration of vegetable component, %	0 (K)	initial	637.1	4.17	32	22	-
		extruded	138.4	8.53	41.4	3.7	3.23
	2.5	initial	654.9	4.13	34.6	20	-
		extruded	149.5	8.43	41.3	3.5	3.06
	5.0	initial	668.7	4.07	36.7	19	-
		extruded	157.2	8.23	42.7	3.0	2.63
	10.0	initial	692.4	3.98	39.8	17	-
		extruded	198.3	7.42	43.2	2.7	1.73
	15.0	initial	732.1	3.89	41.5	15	-
		extruded	240.8	6.07	43.8	2.5	1.53
	22.5	initial	778.7	3.74	46.4	13	-
		extruded	270.9	4.43	45.4	2.3	1.02

Table 1, Continued

Concentration of vegetable component, %							
		Carrot					
0 (K)	initial	625.2	4.17	32.0	22	-
	extruded	135.6	8.50	41.4	3.7	3.23
2.5	initial	667.7	4.12	34.6	20	-
	extruded	142.3	8.49	41.5	3.5	3.19
5.0	initial	700.4	4.06	36.2	19	-
	extruded	152.5	8.43	42.6	3.0	2.28
10.0	initial	700.4	3.92	39.3	17	-
	extruded	193.8	7.77	41.2	2.7	1.65
15.0	initial	733.1	3.83	42.4	15	-
	extruded	245.2	6.65	43.9	2.5	1.34
22.5	initial	774.3	3.73	45.9	13	-
	extruded	258.5	4.56	45.2	2.3	1.05

Thus, in extruded corn grain with root vegetables, the degree of swelling is 8.53 ml/g, while in the untreated form it is only 4.17 ml/g (Table 1).

Increasing the number of root vegetables in the corn feed mixture reduced the swelling of the mixture. Thus, the degree of swelling of the mixture with a concentration of components of 2.5%, depending on the root crop, was 8.43-8.49 ml/g. In turn, increasing the content of root vegetables to 10% caused a decrease in the indicator to 7.40-7.77%, and 15% of vegetable supplements reduced the degree of swelling to 6.07-6.65%. Increasing the concentration of root vegetables in the mixture to 22.5% reduced swelling to the level of 4.43-4.56%.

Thus, the swelling of a mixture of corn grain with vegetable root crops of different concentrations showed that with an increase in the amount of the vegetable component, the swelling of the extruded product significantly decreases, which indicates a decrease in the ability of the mixture with high concentrations of components to absorb water.

The angle of natural inclination in the raw material was 32 degrees. An increase in the concentration of vegetable components in the fodder mixture contributed to a gradual increase in the angle of natural inclination to 45-46 degrees. Extrusion helped increase this indicator by 1-9 degrees. The parameters of the raw mixture and the finished extrudate were equalized by the amount of root vegetables at 22.5%, and the angle of natural inclination was 45-46 degrees. In turn, with an increase in the concentration of vegetable components, the flowability of the products decreased. Significant changes were noted in the amount of swelling of the material, which is directly related to the volumetric mass. Thus, the coefficient of swelling of extruded corn was 3.23. In the extruded mixture of corn and table beet, as its concentration increased, the coefficient tended to decrease from 3.06 at 2.5% content to 1.02 at 22.5% content. On the other hand, in the extruded mixture of corn with table carrots, with an increase in its concentration, the coefficient of swelling tended to decrease from 3.19 at 2.5% content to 0.97 at 1.03% content.

The technological scheme for the production of compound feed provides for the installation of an additional extrusion line for carrying out special heat treatment of a mixture of grain crops and obtaining an extruded feed mixture.

The technological indicators of processing a mixture of corn grain with root vegetables in the extruder in the pre-matrix zone of the extruder are given in Table 2.

Table 2. *Technological indicators of grain-vegetable mixture processing in an extruder*

Content and type of vegetables, %	(K)	Beet, %					Carrot, %				
		2.5	5.0	10.0	15.0	22.5	2.5	5.0	10.0	15.0	22.5
Productivity, kg/h	27	28	27	25	23	18	27	25	23	20	17
Extruder motor load	6.4	5.8	5.2	4.8	4.5	4.3	5.7	5.4	4.7	4.4	4.2
Specific electricity consumption of energy, kWh/t	117	102	94	93	95	115	104	103	98	105	120
Temperature, °C	171	164	158	147	139	132	166	159	146	139	133

Productivity by adding 2.5% of crushed beets to corn grain increased by 1 kg/h. When the concentration of vegetables increases to 22.5%, productivity decreases to 15-17 kg/h.

The specific consumption of electricity when extruding corn grain is 117 kWh/t, and with the addition of fruit and vegetable raw materials it decreases by 2.5% to 102-104 kWh/t. The reduction process continues up to a concentration of 10.0% and is 93-96 kWh/t. A further increase in the concentration of fruit and vegetable raw materials caused an increase in the specific consumption of electricity to 115-120 kWh/t.

In general, the energy consumption for extruding mixtures with carrots was higher than for the addition of beets and differed by 2-5 kWh/t.

There is no significant difference in the extrusion parameters of mixtures of corn grain with carrots and beets.

CONCLUSIONS

The improved technology for the production of fodder mixture consists in preliminary preparation of raw materials: cleaned, crushed, dosed according to the composition of the recipe, mixing and special processing to improve technological properties according to the processes: pre-mixing, aging and extrusion of the mixture, cooling and grinding of the product depending on the purpose of the feed.

It was established that with an increase in the concentration of vegetable roots in the extruded mixture, the physical properties of the feed improve, in particular, the volumetric weight of the mixture with a concentration of vegetable roots up to 15% increases, with a simultaneous decrease in the flowability and swelling coefficient of the extruded mixture.

REFERENCES

[1] Kucher, M. (2003). Production of compound feed at the enterprises of the state joint-stock company "Bread of Ukraine": State, problems, prospects. *Efficient Poultry and Animal Husbandry,* 2, 5-7.

[2] Durst, L., Vyttman, M., & Ibatulyn, I. (Eds.). (2003). *Feeding of farm animals*. Vinnytsia: New Book.

[3] Ibrahimov, A. (2003). Flavoring and aromatic additives in animal feed. *Compound Feed,* 5, 63.

[4] Ulianych, I., Kostetska, K., & Holubiev, M. (2017). Expanding of recipes for compound feeds. *Collected Works of Uman National University of Horticulture*, 91,121-129.

[5] Ulianych, I., Kostetska, K., & Holubiev, M. (2018). Chemical composition of the extruded product of a mixture of corn and barley grains with fruit and vegetable components. *Collected Works of Uman National University of Horticulture,* 92, 109-119.

[6] Yehorov, B., Tarakhtii, A., Kuznetsov, M., & Tyshchenko, Ya. (1999). Production of compound feed and premixes in Ukraine. *Compound Feed*, 2, 10-11.

[7] Kostetska, K. (2018). The optimal diameter of the hole of the extruder matrix during the production of extruded feed mixtures. In *Innovative technologies in crop production: Problems and their solutions*: *Materials of the international scientific and practical conference* (pp. 301-304). Zhytomyr: Polish National University.

[8] Osokina, N., & Kostetska, K. (2016). Physical and mechanical properties and quality indicator of barley. *Collected Works of Uman National University of Horticulture,* 2, 48-51.

[9] Martynenko, Ya. (1975). *Industrial production of animal feed.* Moscow: Kolos.

[10] Levchenko, V., Strii, V., Prytula, V., & Lishchynska, Z. (1990). *Rules for the organization and conduct of the technological process for the production of feed products*. Kyiv: Institute Of Grain Growers.

[11] Shapovalenko, O., Yevtushenko, O., & Ulianych, I. (2012). Extruding grain with adding sheep components to the feed. *Storage and Processing of Grain*, 11, 62-64.

Інжиніринг в технології виробництва екструдованих кормових добавок

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Анотація. Виробництво кормів із екологічно чистої сировини є ефективним способом збільшення об'ємів кормів зі зменшенням економічних витрат на їх виробництво. Використання природних кормових добавок у складі кормів поліпшує їх споживання. Інноваційний інжиніринг у технології виробництва кормових добавок здійснюється через удосконалення технології кормових добавок з використанням плодоовочевої сировини. Наразі в Україні перманентно накопичуються достатньо великі запаси плодоовочевої сировини, які є недостатньо застосовуваними у кормовиробництві. Водночас, поліпшення споживання та підвищення ефективності використання кормів, а також отримання максимальної тваринницької продуктивності все частіше забезпечується використанням природних кормових добавок у складі корму. Саме тому, виробництво кормів із екологічно чистої сировини, як перехід на альтернативні технології, є одним із найбільш ефективних способів збільшення обсягів кормів зі зниженням економічних витрат на їх виробництво. На сьогодні у приватних господарствах населення відсутня така практика. Включення плодоовочевої сировини до рецептури кормів є актуальним для підвищення їхньої якості. Метою роботи було розширити асортимент кормів для тварин та удосконалити технологію виробництва екструдованої кормової суміші. У роботі було застосовано лабораторний та аналітичний метод. Автори представили технологію, що полягає у попередній підготовці сировини: очищенні, подрібненні, її дозуванні відповідно до складу рецепту, змішуванні та спеціальній обробці для покращення технологічних властивостей і підвищення кормової цінності з процесами: попереднього змішування, відлежування та екструдування суміші, охолодження та подрібнення продукту залежно від призначення корму. Результати можуть бути використані для вдосконалення технології виробництва поживних кормів для тварин і забезпечення більшої кількості господарств

Ключові слова: зерно, плодоовочева сировина, кормові добавки, технологія екструдування