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Transforming livestock by-products into nutritious extruded feed additives: a sustainable approach for modern agriculture

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ABSTRACT

The search for a solution to the challenge of providing the agriculture industry with complete feeds is relevant to modern animal husbandry in many countries, and protein is a key limiting component in feed. Along with the growth of food production, the waste it produces, which is also a valuable resource of useful components, can be recycled and used. Thus, in slaughter, butchering and meat production, a large amount of waste is generated, including by-products that can be processed further. The extrusion process is one of the best processing methods to improve the nutritional value of ingredients and feed and improve feed efficiency. In modern feed milling operations, extrusion must be considered as the main process for increasing feed profitability. The benefits of the extrusion process in improving the nutritional value and efficiency of ingredients and feeds depend on many factors, such as the structure and chemical composition of the ingredients, the processing conditions and the equipment used in processing. This article substantiates the need to develop technologies for involving production waste in their further use in medium- and long-term growth in the demand for food. A technology for producing an extruded feed additive based on vegetable feed with the addition of slaughter waste is presented. The formulation of a feed additive in which different percentages of slaughter waste of 5.10% and 15% corn was replaced with by-products was studied. The water activity of the obtained extruded feed additives was studied, where, at a content of 15% slaughter waste, it was low compared with that of the other two samples. Further research will allow procuring fodder products with a high biological value and utilising unclaimed by-products of livestock slaughter.

Keywords: cattle slaughter waste, extrusion, heat treatment, technology, chemical composition, protein

INTRODUCTION

At present, the problem of vegetable protein on a global scale is turning into a vital one, and protein is becoming a strategic raw material. Therefore, reducing protein deficiency is one of the most important and complex tasks of world agricultural science and practice, requiring urgent solutions. Increasing feed protein production is the main way to solve the protein problem. The chemical industry contributes to replenishing feed protein resources, but the share in feed protein production is small. The lack of protein in compound feeds, as well as the usefulness of protein itself, is the main factor constraining the intensification of the industry: a protein shortage of 30%-40% increases unproductive costs by a factor of 1.4. Especially acute is the shortage of proteins of animal origin, which are essential for growing young animals and breeding animals **[1]**.

Recently, by-products, including heads, legs and entrails, have become increasingly valuable as feed or feed additives in animal diets **[2]**. The animal nature of these by-products significantly contributes to their energy density; protein and amino acid contents; acid quality, and fat, calcium and phosphorus contents. The by-products could be successfully used as animal feed, but if not properly disposed of, they can damage the environment **[3]**.

With the increase in production at slaughterhouses, the quantity of by-products and technical slaughter products increases simultaneously, and enterprises need help to dispose of waste or process all raw materials without producing residue. In modern conditions, there can be no other answer to this question: to increase its profitability and competitiveness, it is necessary to introduce new, efficient technologies **[4]**.

The effective functioning of enterprises for producing meat from farm animals depends on the competent use of all the resources and by-products of its processing and slaughter waste. Most of the by-products have a valuable chemical composition and can be used to produce food and feed. When processing raw materials of animal origin, for example, at meat processing plants, blood is collected, endocrine-enzymatic raw materials are collected and processed, and intestinal raw materials are collected. Enzyme preparations, feed flour and dry vegetable and animal feed are obtained from waste. Equally important is the proper organization of slaughter sites and compliance with technological, veterinary and sanitary rules. If the rules of processing, transportation and storage are violated, meat products' nutritional value and shelf-life decreases, and losses increase **[5]**, **[6]**.

The approximate percentage of live weight of various animals considered inedible material is as follows: 49% for cattle, 47% for sheep and lambs, 44% for pigs and 37% for broilers **[7]**, **[8]**.

According to the Food and Agriculture Organization of the United Nations (FAO), total meat production worldwide, excluding China, is growing by 1.9% annually **[9]**. Accordingly, the amount of by-products produced by the meat industry is also growing worldwide. The meat processing industry collects and processes part of the slaughter waste, mainly by-products, to obtain raw materials used in animal feed and pet food.

Today, dry food is widely used due to its ease of acquisition, transport, storage and distribution, as well as the positive results of growth and conversion rates. Today, the two most widely used technologies for feed production are granulation and extrusion. The forage produced by these processes is denser, with lower moisture content and provides better preservation **[10]**, **[11]**.

The extrusion process is widespread today as it can be used to produce all kinds of feed, whether floating, fast sinking or slow sinking, depending on the needs of each species. Extrusion is a high-temperature, short-time process that minimizes nutrient loss while improving the digestibility of starches and proteins compared to granulated foods. Extrusion is a process in which food products are not only pressed, as in granulation but are also ‘cooked’, requiring higher humidity, temperature and pressure levels than granulation. All of these requirements must be met to achieve the desired degree of expansion when exiting the extruder. As a result, extruded feed is a higher-quality product that increases the profitability of farms **[11]**.

During the extrusion process, starches are converted into easily digestible forms. The expansion of starches during high-pressure extrusion gives the feed a lighter and bulkier texture, in contrast to the denser granules obtained by low-pressure heat treatment. The extrusion also makes starches water soluble, so extruded feeds easily turn back into a slurry when water is added. Simple sugars and starches found in roughage, such as hay, also become more available to the body due to the breakdown of fibrous material.

The use of feed obtained as a result of extrusion has several advantages:

– High digestibility – about 95% of the feed is easily digested by animals compared to crushed grain (up to 40%). This increases productivity and gives you the maximum benefit from animal husbandry (more milk, meat products, and eggs). After extrusion, the digestibility of legumes (soybeans, peas, vetch, etc.) increases up to 10 times. This will allow the body to get the maximum amount of proteins, amino acids and vitamins that legumes are so rich in.

– Profitability – the extruded product is consumed half as much as conventional whole grains. It effectively replaces food of animal origin (extruded peas completely replace reverse when feeding calves older than a month old).

– Minimum resource costs – grain can be processed without preliminary sorting and drying. The raw materials must be free of earth, straw, stones, etc.

– Efficiency – even damp grain lying in a granary for several years lends itself to extrusion. The processing of grain production waste (buckwheat husks, etc.) makes it possible to obtain nutritious feed for pigs, sheep and goats.

– Good eating by animals due to the pleasant bread taste and aroma.

– Stimulation of growth and strengthening of immunity.

– Providing the body with the necessary sugar without the use of food additives.

– Feeding hygiene – feed can be fed dry without additional processing. Animals do not scatter or burrow in leftover food. As a result, there is no other dust content in the air. And this contributes to improving working conditions for personnel and protecting equipment from premature breakdowns.

– Long shelf life due to low moisture content.

– Reducing the mortality of young animals by 2 times from gastrointestinal diseases due to the sterility of the feed **[12]**.

Water is the main component of all biological systems, since food products, except for dry fruits, contain more water in quantitative terms than any other substances. The quality and safety of products depends on their moisture content and binding energy, which reflects the water activity indicator. The indicator of water activity (aw, aw-water activity) characterizes the relationship between the material's moisture and the microorganisms' ability to use it for their biological activities **[13]**.

The efficient use of by-products directly impacts the country's economy and environmental pollution. The non-use or under-use of by-products leads to potential revenue loss and additional and increasing costs to dispose of these products. Failure to properly use animal by-products can create serious aesthetic problems and catastrophic health problems. In addition to the pollution and hazard aspects, in many cases, meat, poultry and fish processing wastes have the potential to be used to recycle raw materials or to be turned into useful products of higher value. Regulatory requirements are also important as many countries restrict the use of organ meats for reasons of food safety and quality. Offal such as blood, liver, lungs, kidneys, brains, spleen and rumen have good nutritional value **[14]**.

Scientific hypothesis

The replacement of corn for by-products is enriched with a feed additive. The water activity of the obtained extruded feed additives at 15% slaughter waste was low compared to the other two samples. Research makes it possible to obtain fodder products with a high biological value and utilize unclaimed by-products of livestock slaughter.

MATERIAL AND METHODOLOGY

Samples

Waste from the slaughter of livestock, a feed additive obtained from the Almaty region (Kazakhstan), was used for the study. For the study, such waste from slaughter as: bone, skins, intestines, raw fat, contents of the gastrointestinal tract and non-food raw materials were used.

Chemicals

All reagents were of analytical grade and were purchased from Laborfarm (Kazakhstan) and Sigma Aldrich (USA).

Instruments

The following instruments were used for the work: meat grinder MIM-100 (JSC 'Torgmash', Republic of Belarus), hammer crusher H-115 (POM AUGUSTOW, Poland) and grain extruder PE-170 (Agrotechservice, Russia).

Laboratory Methods

When performing laboratory studies, generally accepted and special modern physical and chemical methods were used:

- Humidity was determined on an MX 50 moisture analyser (Japan).
- Crude protein according to GOST 13496.4-93.
- Crude fibre according to GOST 31675-2012.
- Raw fat according to GOST 13496.15-97.
- Raw ash content according to GOST 26226-95.
- Contents of exchange energy using spectroscopy in the near infrared region according to GOST 51038-97.
- The degree of dextrinization according to GOST 29177-91.

Description of the Experiment

The feed additive was prepared in the experimental production workshop of the Kazakh Research Institute of Processing and Food Industry, according to previously developed recipes, using a PE-170 extruder with a 170 kg/h capacity.

Number of samples analysed: Four samples were analysed.

Number of repeated analyses: All tests were performed in triplicate.

Number of experiment replication: Replications were conducted twice.

Design of the experiment: The control recipe, without including by-products was developed according to the recommendations for cattle **[44]**. A mixture of slaughter waste was added to the test formulations, replacing corn with 5%, 10% or 15% slaughter waste. Extrusion was carried out under the conditions of a feed mill at LLP 'Kazakh Scientific Research Institute of Processing and Food Industry.' The pre-cleaned and washed slaughter waste was crushed in a MIM-100 meat grinder. The crushed raw material was further dried in a thermostat at 35-

38°C for 5-6 hours. The components were weighed according to the recipe and mixed on a vertical mixer 'SV-5Sh'. Grinding of grain components was carried out separately for each type on an H-115 hammer mill, and then samples were analysed. Extrusion was carried out on a PE-170 extruder press. Water activity (aw) was determined on an Aqualab 4TEDUO activity analyser.

All by-products were individually crushed, dried and ground according to the extrusion technology. The humidity of by-products was studied at different temperature conditions of drying (Figure 1).

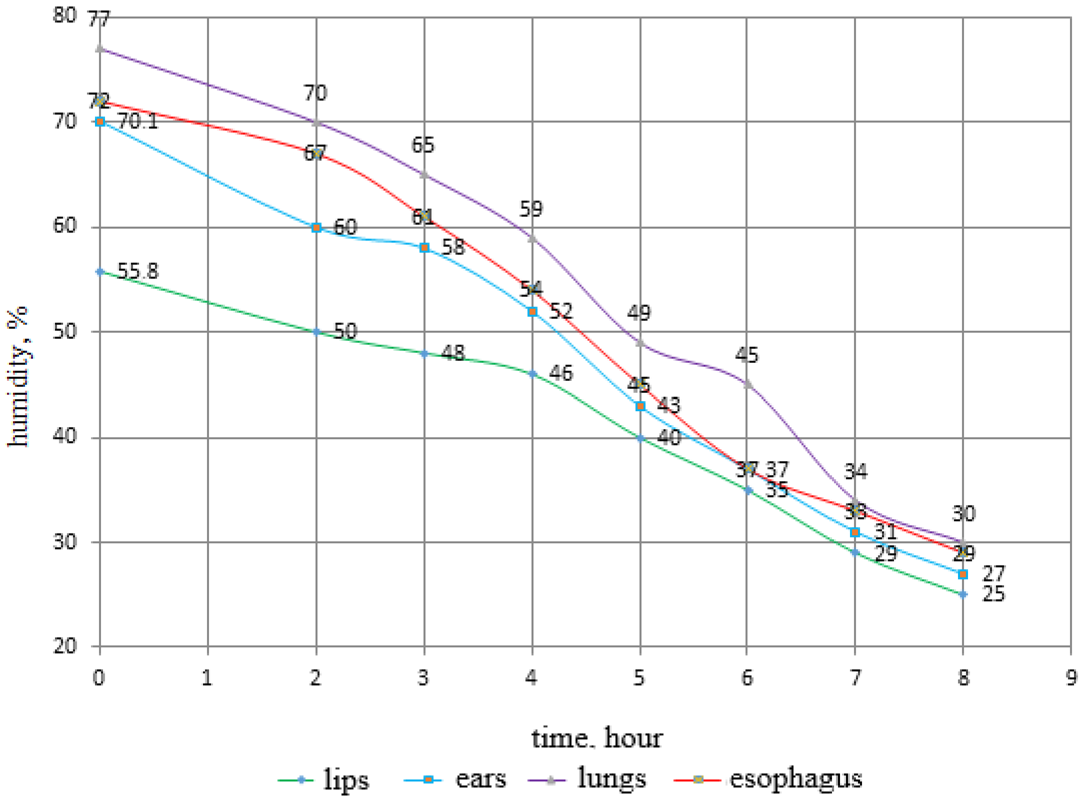

Figure 1 Change in moisture content in beef offal (lungs, ears, lips, oesophagus) during drying.

The final moisture content of offal ranged from 25% to 30%. A recipe was developed from vegetable and animal raw materials to create a feed additive. This recipe replaced 5.10% and 15% corn with by-products obtained after drying. Three recipes were developed using offal at 5%, 10% and 15%. The component composition and chemical composition of the control formulation and three experimental formulations are presented in Table 1.

Table 1 Feed additive formulation.

Components	Content (%)		
Corn (crushed grain)	37.0	32.0	27.0
Waste from slaughter	5.0	10.0	15.0
Wheat bran	40.0	40.0	40.0
Grain waste	7.0	7.0	7.0
Corn bran	5.0	5.0	5.0
Feed zeolite	4.0	4.0	4.0
Salt	1.0	1.0	1.0
Premix	1.0	1.0	1.0
Total	100.0	100.0	100.0
Crude protein	18.2 ±0.14	18.6 ±0.21	18.8 ±0.25
Crude fibre	3.3 ±0.05	3.4 ±0.06	3.4 ±0.04
Crude fat	2.34 ±0.03	2.33 ±0.04	2.34 ±0.05
Ash	2.15 ±0.02	2.14 ±0.04	2.12 ±0.05
Exchange energy (MJ)	12 ±1.06	12 ±1.06	12 ±1.06

As seen from Table 1, the protein content in the extrudates also increases with an increase in the content of by-products. These results are consistent with the results of studies on the increase in protein content, including 5% and 10% beef lungs **[43]**.

During extrusion, the raw material is subjected to a complex baro-hydro-thermal effect; as a result, complex physicochemical changes occur in it, providing sterilization, dehydration and restructuring of polysaccharides and protein. Anti-nutritional compounds such as urease, protease inhibitors and trypsin are entirely or significantly destroyed. The critical point of technologies based on dehydration is the high hygroscopicity of the resulting product, accompanied by its saturation with water vapour from the air with a corresponding increase in humidity, contamination with microflora and a decrease in shelf life. A distinctive feature of the analysed technology is a highly efficient product cooling system, which allows a sharp decrease in the temperature and hygroscopicity of the product within a few seconds after extrusion **[15]**, **[16]**, **[17]**.

In the experimental workshop of the Kazakh Research Institute of Processing and Food Industry, extruders were extruded on a PE-170 brand extruder at a temperature of 130-140 °C and a pressure of 2-3 MPa. In this case, the passage time of the feedstock in the unit was 8-10 s.

The main technological parameters that determine the nature and intensity of the extrusion process and the depth of physical and chemical changes in extrudates are the temperature and pressure of the extruded materials in front of the matrix; humidity of the extruded product; time spent by the product in the working area of the extruder; frequency of rotation of the pressing screw and ratio of starch to protein in the extruded mixture.

Statistical Analysis

The experiments were performed in triplicate. All measurements are given with standard deviation values. Differences in the measurements of the experimental and control groups were calculated using analysis of variation (one-way ANOVA) using Tukey's test. The measurement value $p < 0.05$ was considered as significant.

RESULTS AND DISCUSSION

The forces of internal friction of the processed mixture and friction on the parts of the body and screw heat the mixture in the extruder. The finished product (Figures 2-5) in the ratio of the feed additive specified in the recipe leaves the forming device in the form of an endless tow.

Figure 2 Extruded feed additive from recycled slaughter (5%).

Figure 3 Extruded feed additive from recycled slaughter (10%).

Figure 4 Extruded feed additive from recycled slaughter (15%).

Figure 4 Extruded feed additive (control sample).

During the experimental work, the measurement and control of the technological parameters of the extrusion process were carried out under laboratory conditions. The temperature was measured using an infrared meter. The results of studies of the grain extrusion process are shown in Table 2.

Table 2 Research results of the grain extrusion process.

Product name	Preparation	Humidity (%)		Degree of dextrinization (%)	Extruded grain temperature (ºC)	Extruder capacity (kg/h)	Specific electricity consumption (kW.h/t)	Engine load (A)
		before	after					
Experience 1 (5% by-products)	hydrated	15.0 ±0.14	8.8 ±0.06	38.5 ±0.17	135 ±1.45	148 ±2.5	82.0 ±0.24	55.0 ±0.26
Experience 2 (10% by-products)	hydrated	15.3 ±0.15	8.4 ±0.05	40.6 ±0.21	135 ±1.45	150 ±2.35	80.6 ±0.24	55.0 ±0.20
Experience 3 (15% by-products)	hydrated	14.8 ±0.12	7.6 ±0.04	57.2 ±0.42	138 ±1.46	155 ±2.21	78.8 ±0.23	55.0 ±0.24
Control	hydrated	15.0 ±0.11	8.8 ±0.03	38.1 ±0.39	135 ±1.47	147 ±2.21	82.4 ±0.24	55.0 ±0.23
Significance	-	n.s.	n.s.	*	n.s.	*	n.s.	n.s.

Note: Indicated values: ± – standard deviation calculated from three parallel measurements, * – p <0.05, significant, n.s. – not significant (p >0.05).

During extrusion, a trend towards a decrease in the moisture content in the composition of the extrudates with an increase in the content of by-products was observed. The degree of dextrinization and the productivity of the extruder increased significantly as the offal content increased (p <0.05). In terms of the extrusion temperature, specific energy consumption and engine load, no significant changes were depending on the level of offal in the extrudates.

The indicator aw refers to the most important element of barrier technology since its lower values serve as an effective barrier to developing negative technological and pathogenic microorganisms, as the rate of chemical and biochemical processes, including spoilage, depends on the water activity level. Moisture products are classified according to their moisture content: high-moisture products have aw > 0.9, intermediate moisture products 0.6 < aw < 0.9 and low-moisture products aw < 0.6.

Water activity characterizes the product itself and is determined by its chemical composition and hygroscopic properties. Equilibrium relative humidity characterizes the environment in hygrothermal equilibrium with the product. Water activity characterizes the form of the moisture bond in the product. Of the total amount of water contained in a food product, microorganisms, for example, can use only a certain "active" part of it for their vital activity. And for each type of microorganisms there are maximum, minimum and optimal water activity values. Deviating the value of aw from the optimal leads to inhibition of the vital processes of microorganisms and sometimes to their death. With the help of this indicator, the degree of participation of water in various chemical, biochemical and microbiological reactions occurring in the product both during the manufacturing process and during its storage is assessed: lipid oxidation, enzymatic and non-enzymatic activity, hydrolytic reactions, development of microorganisms. Table 3 shows the water activity of the feed additive with different ratios.

Table 3 Water activity.

Recipe with content	Water activity value
5%	0.3798
10%	0.3440
15%	0.3458

The data in Table 3 shows that the feed additive's water activity is low, with aw < 0.6. In products with low humidity, microbiological processes do not occur, and they retain their qualities for a long time. It follows from the table that the water activity of the feed additive containing 15% slaughter waste is low compared with that of the other two samples.

One of the main problems for the production of livestock products in the Republic of Kazakhstan, as in many other developing countries, is the lack of a high-quality, year-round forage base. The increase in population and the rapid growth of world economies is leading to an increase in demand for animal products. At the same time, the demand for fodder crops for livestock is also increasing. Therefore, in the future, maintaining food security will depend on the expansion and efficient use of non-traditional resources, as well as on innovative technologies for the manufacture of feed and feed additives for animals **[18]**, **[19]**.

By controlling the functional and technological indicators in the product, particularly the aw indicator, it is possible to predict its storage capacity, which will make it possible to create 'stability maps' of products and determine the optimal conditions for their storage **[20]**, **[21]**.

Only 60% of a slaughtered pig in Germany ends up on a plate in the form of cutlets or sausages. Parts unfit for human consumption, such as bones, hooves, and some internal organs, are processed into pet or fish food, used in the chemical or fertilizer industry or converted into biofuels **[22]**, **[23]**. Of the 8.6 million tons of total carcass weight in 2019, about 2.6 million tons of these 'animal by-products' were used in this way. Additional losses occur during wholesale and retail trade and at the consumption stage, when goods expire or products are prepared for consumption but not eaten. According to the latest available data, 11.9% of global meat production was lost between slaughter and retail in 2016. Meat waste: much less than the whole fog **[24]**, **[25]**.

Due to the relatively high consumption of meat and meat products, consumers' production losses and product waste at the consumption stage becomes significant. It is estimated that up to 23% of production in the meat sector is wasted. The largest share is generated at the consumption level, accounting for 64% of total food waste, followed by production (20%), distribution (12%) and primary production and post-harvest processing (3.5%). Food loss and waste data in the meat sector is very limited **[26]**, **[27]**. At the same time, meat and meat products are characterized by adverse environmental impacts (meat has the highest emissions per kilogram of food compared with other foods), which requires sustainable management with these products in the entire chain (stage of production, processing, transportation and consumption) **[28]**, **[29]**. The increase in food waste has serious negative consequences for the global environment, climate, water and land resources **[30]**.

Food waste and wastage have become an important political issue as the demand for food on a global scale is steadily increasing due to an increase in population and consumption **[31]**, **[32]**.

René Renato Balandrand-Quintana et al. note in their article that agro-industrial waste is an economical source of proteins that must be used, for which it is necessary to improve traditional extrusion methods **[33]**, **[34]**, **[35]**. Emphasizing the potential of agricultural waste, Christiana O. Giola et al. said: 'Today, waste is seen and mentioned as a raw material for producing various products and is well valued for its economic value **[36]**, **[37]**. Technology has significantly increased the physical and nutritional value of many production wastes. Instead of exporting their waste for meagre foreign exchange earnings, many countries are developing the technological capacity to convert more waste into useful products' **[38]**, **[39]**.

One of the universal methods for preparing feed raw materials for feeding animals and poultry, as well as for processing biological waste, is the extrusion method, which allows the use of secondary raw materials for feed purposes with virtually no restrictions. Experts have repeatedly noted the high nutritional value of such processed products, which can acquire many new, initially absent useful qualities and properties, as well as nutritional value **[40]**, **[41]**.

However, the waste's high moisture content (MC) and the specificity and presence of numerous microorganisms make it a highly unstable material. Its disposal, transportation and processing in factories create significant problems **[42]**. Using suitable extrusion parameters (temperature, material holding time and raw material quality) allows us to obtain a completely sterile product with attractive physical and chemical properties and a high nutritional value**.**

CONCLUSION

Examination of finished extrudates showed a trend towards a shift in protein composition with an increase in the content of the offal mixture (lungs, oesophagus, ears and lips – 1:1:1:1). Further study of this direction will make it possible both to obtain extrudates with a high biological value and to utilize unclaimed by-products of slaughter. The final moisture content of offal ranged from 25% to 30%. A recipe was developed from vegetable and animal raw materials to create a feed additive. This recipe replaced 5.10% and 15% corn with by-products. The value of animal waste is determined by the high content of complete proteins in it, which have in sufficient quantities all the essential amino acids necessary for the intensive development and fattening of farm animals, as well as mineral salts, trace elements and fats. As an additive to the diet, they compensate for the lack of protein in plant foods and increase their digestibility.

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