The effect of extrusion on the nutrient content of barley as a feed material

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Abstract. Currently, one of the ways to prepare grain for feeding is the extrusion method, during which the grain is subjected to a short-term, but very intense impact. A study was conducted on the effect of the extrusion process on the nutrient content of barley used as feed for farm animals. In order to identify the effectiveness of extrusion, the article presents the results of an experiment on changing the chemical composition of extruded grain compared to whole grain. The results of the studies indicate that the dry matter content has significantly increased compared to whole grain. From organic substances, the carbohydrate composition of grain was most significantly transformed. At the same time, in the composition of biologically active substances, the proportion of starch decreased from 94.4 to 80.4 %, and the proportion of sugar increased from 4 to 5.6 %. The total amount of minerals in the extrusion process also decreased slightly, but only a decrease in the calcium content and an increase in the potassium content were statistically significant. The results obtained allow us to state that the extrusion process is a promising way to improve the quality and safety of grain feed and requires further study and improvement.

1. Introduction
One of the important tasks facing the Russian agro-industrial complex is to increase the digestibility of grain components of feed, increase the content of nutrients in feed. In addition, feed accounts for the largest share in the structure of costs for the production of livestock products. One of the promising directions for the intensification of technological processes is the change in the physical and chemical properties of feed products when exposed to them by various methods, among which is the processing of raw materials by extrusion. This process is the most promising, since grain raw materials are simultaneously exposed to high temperature, pressure and moisture [1-3]. Extrusion makes it possible to change the properties of the finished product due to changes in the parameters of the technological process.

The current trend in the development of extrusion technologies is to ensure a maximum reduction in the energy consumption of extrusion processes while simultaneously improving the quality of the extruder.
The extrusion process is the simplest and most effective way to increase the nutritional value of grain feed, in which the grain is subjected to barothermal treatment. The priority advantage of the extrusion process is the transformation of the structure of the initial grain raw materials, there are changes in the physical and chemical properties and nutritional value. As a result, farm animals are provided with high-quality feed, balanced in nutritional value and useful substances, in addition, they have a longer economic use. The extruded feeds have a low moisture content, which allows them to be stored ideally for 6 months without rotting or mold. Unlike other types of feed, extrudate is practically sterile and does not contain toxins, which affects the reduction of mortality of young animals [3, 4]. This method is the most effective for reducing the content of anti-nutritional substances and natural toxins.

The study of various technological processes is necessary in order to have certain information that can be obtained using experimental and theoretical data about the process under study. These data are necessary as initial data with the best technical and economic indicators, and for confirming the feasibility of manufacturing and operating machinery and equipment in real conditions [4, 5].

Currently, the demand for extruded feed from livestock enterprises has increased significantly. There are scientific data that contain data on the study of the extrusion process. However, the established extrusion processes need to be clarified and studied in connection with the specific conditions of feed production on the farm. The aim of the paper is to study the content of nutrients in the extruded barley grain obtained in the conditions of farming.

2. Methods and materials
The grain of barley grown in the conditions of the economy of the Nizhny Novgorod region, Knyaginino, was used as a raw material. The extruded grain was obtained using an E-500 extruder (Jasko, Russia).

The initial enters the hopper of the shredder from an external feed system. Productivity during grain processing at a bulk weight of the feedstock of 750 kg/m², humidity of 16% to 310 kg/h. After switching on the electric motor, and then the feeder, the mixture from the hopper is fed into the receiving funnel, and then into the screw part of the shredder. When passing through the screw part, the mixture is crushed, subjected to heat treatment (120…150°C, 25…40 s), mixed under pressure (20…30 atm.) and squeezed out of the shredder. The mixture is heated by friction forces when moving along the screw part. When processing grain, the finished product exited through the hole of the exhaust device in the form of a beam. The blades of the shutter grind it when it comes out of the screw part.

Adjustment of the process temperature and the grain explosion rate was carried out by grinding the gap between the nut and the tips, as well as by changing the area of the outlet hole by replacing the outlet sleeve.

The qualitative characteristics of the samples were evaluated in accredited testing laboratories of the Chuvash State Agricultural Academy and in the Federal Center for Animal Health Protection. Sampling of whole and extruded barley grains was carried out by the medium sample method in accordance with ISO [6].

The following parameters were determined in the samples of whole grains and the finished product. The dry matter content in the raw material was determined by drying at a constant weight at the temperature of 102…105°C.

The crude protein content is determined by salting the organic matter of the analyzed sample with sulfuric acid in the presence of a catalyst, alkalizing the reaction product, distilling and titrating the released ammonia, calculating the mass fraction of nitrogen and calculating the mass fraction of crude protein by multiplying the result by the conversion coefficient of the mass fraction of nitrogen by the mass fraction of crude protein equal to 6.25 [7].

The crude fiber in the samples was determined as follows. The test sample is treated with boiling dilute sulfuric acid, the resulting residue is separated by filtration, then washed and treated with a boiling potassium gyrooxide raster. The residue is separated by filtration, washed, dried, weighed and calcined. The mass fraction of crude fiber in the sample is the value of the mass loss of the dry fiber residue during salting [8].
The analysis of the determination of crude fat consists in the extraction of fat from the sample with petroleum ether by the Randall method, which is a modified version of the Soxlet method. The crude fat from the sample is extracted first with a boiling, and then with a cold solvent, reducing the time required for extraction. The solvent is removed and the dried extracted fat is weighed [9].

To determine the starch content, a polarimetric method was used, for which it is necessary to first transfer it to a soluble state and hydrolyze it, which is achieved by treating the object under study with hydrochloric acid. In order to remove the accompanying substances that interfere with the determination (mainly proteins), and to clarify the hydrolysate, the solution is treated with a Carreira reagent. The transparent solution is polarized [10].

The carotene content was determined by a photometric method, the essence of which consists in dissolving carotene in petroleum ether or gasoline and photometric measurement of color, the intensity of which depends on the carotene content [11]. Part of the feed was ozonized in a muffle furnace to produce raw ash, which includes the inorganic part of the feed, micro and macro elements and their salts. This method is based on burning a feed sample in a muffle furnace at 550°C [12].

The method for determining calcium in samples consists in the salting of organic substances of the analyzed sample, processing the resulting ash with a solution of hydrochloric acid, precipitation of calcium in the form of calcium oxalate, followed by dissolution of the precipitate with a solution of sulfuric acid to form oxalic acid, which is titrated with potassium permanganate [13].

The method for determining phosphorus is as follows: in dry ozonization of the sample with calcium carbonate and heating the residue with hydrochloric and nitric acids (for organic feed) or in wet ozonization of the sample with a mixture of sulfuric and nitric acids (for mineral compounds and liquid feed). The aliquot part of the hydrolysate is mixed with a molybdenum-vanadate reagent and the optical density of the resulting yellow solution is measured at a wavelength of 430 nm (atomic absorption spectrophotometer AA-6300, Shimadzu, Japan) [14]. The determination of copper, zinc, potassium, sodium and magnesium was carried out by dissolving the analyzed sample in hydrochloric acid, if necessary with salting in a muffle furnace at a temperature of (550±15) °C, removing the present silicon compounds by precipitation and filtration, and then atomizing the resulting solution in an acetylene-air flame. The absorption of each element in the analyzed solution is measured in comparison with the absorption of the same element in the calibration solution [15].

We also determined the content of toxic elements in the sample (cadmium, arsenic, mercury). The method is based on dissolving the sample in nitric acid, diluting the solution to the desired volume and introducing a certain volume of the solution into the electrothermal atomizer of an atomic absorption spectrometer, followed by measuring the absorption value of resonant radiation emitted by a hollow cathode lamp with free atoms of each element (atomic absorption spectrometer MGA-915 MD, Atompribor, St. Petersburg) [16].

Such a mycotoxin as ochratoxin A is extracted from the grain with a mixture of chloroform and an aqueous solution of phosphoric acid and isolated by separation of liquid phases. The isolated aqueous bicarbonate solution is transferred to a cartridge for solid-phase extraction and ochratoxin A is eluted with a mixture of ethyl acetate-methanol-acetic acid. Ochratoxin A is separated by reverse-phase high-performance liquid chromatography (liquid chromatograph with FLD and DMD Agilent LC-1200, Agilent, USA) [17]. Determination of the T-2 toxin consists in the extraction of the toxin, purification of the extract by liquid-liquid extraction with subsequent post-purification on a chromatographic column [18].

3. Results and discussion
As a result of the impact of the extrusion process on the barley grain, an extrudate with a pleasant bread taste and smell is obtained. A comparative analysis of the chemical composition of whole barley with extruded grain indicates differences in the content of nutrients. The chemical composition and nutritional value of barley before and after extrusion is shown in table 1. It can be seen from the above data that the extrusion process had a positive effect on chemical composition of barley grain. Moisture content of
finished product was lower compared to whole grains (10.0 versus 8.80 %). In addition, with the noted comparison in barley grain, mass fraction of dry matter was significantly lower by 4.64 abs. % (P <0.05).

**Table 1.** Chemical composition and nutritional value of barley grain.

| Indicator                          | Grain          | Extruded grain |
|-----------------------------------|----------------|----------------|
| Crude protein, %                  | 12.38          | 11.44          |
| Crude ash, %                      | 3.49±0.14      | 3.13±0.13      |
| Crude fat, %                      | 2.34±0.06      | 1.96±0.05 (P <0.05) |
| Crude fiber, %                    | 4.09±0.05      | 3.95±0.07      |
| Nitrogen-free extractive substances, % | 68.40±0.30    | 73.68±0.73      |
| Starch, %                         | 64.58          | 59.22          |
| Dry matter, %                     | 88.02±0.003    | 92.66±0.19 (P <0.05) |
| Carotene, %                       | 0.216±0.003    | 0.151±0.003 (P <0.05) |

Such an indicator as grain moisture is fundamental for high preservation of grain. Microorganisms cannot develop on dry grain, which are the main factor in its deterioration during storage. An increase in the humidity of the feedstock leads to a better splitting of the extruded raw materials and leads to a decrease in the volume density. The resulting extruded barley showed a slight decrease in the level of crude protein, which is associated with protein denaturation as a result of short-term exposure to high pressure and temperature. The literature sources indicate that despite the decrease in the protein content during the extrusion process, its digestibility in the animal's body increases [19].

The data on the effect of extrusion on the quality of fats are contradictory. A number of authors in their studies indicate that hydrolytic processes occurring in phospholipids in the presence of moisture create conditions for the formation of mesophosphatid forms of free fatty acids, which negatively affects the quality of products [20, 21]. In our studies, it was noted that the crude fat content in the extruder is significantly lower by 0.38% (P <0.05) compared to whole grains. Most likely, some of the fat was not lost at high pressure. In the process of extrusion, stability of fats increases, due to the fact that enzymes such as lipase, which cause rancidity of oils, are destroyed during extrusion process, and lecithin and tocopherols, which are natural stabilizers, retain their full activity. Grain raw materials are exposed to maximum temperatures for only about 5-6 sec, and oxidation requires a much higher temperature and longer heat treatment.

Studies have shown that the percentage of crude fiber in cooked feed was 0.14 %, which is associated with decomposition into secondary sugar in the process. In the extruded grain, content of nitrogen-free extractive substances increased significantly due to a slight decrease in content of other organic substances. At the same time, the proportion of starch in nitrogen-free extractive substances decreased from 64.58 to 59.22 %, most likely due to gelatinization of starch in grain.

During extrusion process, the starch is gelatinized, which increases its assimilation in animal's body. When leaving the extruder, temperature and pressure drop sharply, which leads to an increase in finished product in volume. At the same time, the share of sugar in finished product increased from 4 to 5.6 %.

As reported Leonard and his co-authors concluded that the destruction of starch macromolecules occurring during the extrusion process, leading to the formation of sugars and dextrins, which increases the digestibility of the finished product in the animal's body [19-21].

A decrease in content of carotene under the influence of high temperature was noted; it decreased in extruded barley grain by 0.05 mg/kg. The essential importance in efficiency of the use of grain feed relates to mineral composition (table 2).

The process of extrusion of barley grain led to a change in the mineral part of the grain. A slight increase in such elements as potassium, copper, and sodium was noted. At the same time, it should be taken into account that some loss of raw ash occurs during grain extrusion.
Table 2. Mineral substances of extruded grain.

| Content                          | Type of a grain | whole     | extruded  |
|----------------------------------|-----------------|-----------|-----------|
| Crude ash, %                     |                 | 3.49±0.41 | 3.13±0.36 |
| Macronutrients, g/kg:            |                 |           |           |
| Calcium                          |                 | 1.25±0.001| 1.19±0.005|
| Phosphorus                       |                 | 4.03±0.28 | 3.37±0.25 |
| Potassium                        |                 | 1.92±0.065| 2.05±0.215|
| Sodium                           |                 | 0.69±0.065| 0.70±0.09 |
| Magnesium                        |                 | 0.96±0.039| 0.95±0.045|
| Macronutrients, mg/kg:           |                 |           |           |
| Copper                           |                 | 6.15±0.87 | 6.79±0.33 |
| Zinc                             |                 | 35.0±0.70 | 33.6±1.78 |

It is known that the method of grain disinfection is of great practical importance. As a result of the barothermal effect that occurs during the extrusion process, the grain is sterilized, as a result of which the content of toxic elements and mycotoxins in the prepared extrudate is not excellent (table 3). It is known that the method of grain disinfection is of great practical importance. As a result of barothermal effect arising in the process of extrusion, grain is sterilized, as a result of which content of toxic elements and mycotoxins is not excellent in the prepared extrudate (table 3).

Table 3. Content of toxic elements in extruded grain.

| Toxic elements          | Content, mg/kg |
|-------------------------|----------------|
| Cadmium                 | not found (< 0.05) |
| Arsenic                 | not found (< 0.05) |
| Mercury                 | not found (< 0.00255) |
| Mycotoxins              | not found (< 0.0025) |
| Ochratoxin A            | not found (< 0.0025) |
| T-2 toxin               | not found (< 0.01) |

The table shows that relatively low level of detection of ochratoxin A in the studied samples did not exceed the maximum permissible level. The permissible level of ochratoxin A in grain and its processed products is 0.5 mg/kg. T-2 toxins in quantities not exceeding the maximum permissible level were found in the studied grain samples.

In addition, cases of detection of mycotoxins, including at levels exceeding the maximum permissible level, may result from a violation of storage conditions, including during transportation of food grains. Thus, intensification of agricultural production actualizes constant monitoring of product safety and interaction of regulatory bodies and manufacturers.

4. Conclusion

Thus, the conducted studies show that as a result of extrusion, there is a change in nutrients in barley. The obtained data reflect that the extrusion process had a positive effect on the chemical composition. Thus, the moisture content in the finished product was lower compared to whole grain. The extrusion process affected the hydrocarbon part of the grain. It was noted that the percentage of crude fiber in the finished grain was 0.14%, which is associated with the decomposition of secondary sugar in the process. The level of nitrogen-free extractives has increased significantly due to a slight decrease in the content of other organic substances. The proportion of starch decreased, which is associated with the gelatinization of starch in the grain. The amount of sugar in the finished product has increased.
Therefore, extruded barley will allow you to balance the nutrients when included in the diet of feeding farm animals.

References

[1] Zaitsev V and Konstantinov V 2015 Proc. Int. Scientific and Practical Conf. Dedicated to the 90th Anniversary of the Birth of Honored Scientist of the Russian Federation Volgogradsky GAU p 57 [in Russian]

[2] Manceron S, Ben-Ari T and Dumas P 2014 Feeding proteins to livestock: Global land use and food vs. feed competition. OCL 21 408 doi:10.1051/ocl/2014020

[3] Pakhonov V, Braginet S, Alferov A and Stepanova Yu V 2016 Research of the process of extruding a mixture of grain concentrates with ground green mass of leguminous herbs Bulletin of Don State Technical University 2 (85) 154 [in Russian]

[4] Braginet S, Bakhchevnikov O and Khlystunov V 2021 Aquafeed extrusion (review). Taurida Herald of the Agrarian Sciences. 1(25) 38 doi: 10.33952/2542-0720-2021-1-25-38-49.

[5] Pakhomov V, Braginet S, Bakhchevnikov O, Alferov A and Ore D 2020 Technologies of extrusion of feed and food products, including insect biomass. Agricultural Science of the Euro-North-East. 21(3) 233 doi.org/10.30766/2072-9081.2020.21.3.233-244 [in Russian]

[6] ISO 24333:2017 Cereals and cereal products. Sampling

[7] ISO 5983-1:2005 Feeds, mixed feeds and raw material. Determination of mass fraction of nitrogen and calculation of mass fraction of crude protein. Part 1. Kjeldahl method

[8] ISO 6865-2015 Animal feed. Method for determining the content of crude fiber

[9] ISO 11085-2016 Feeds, cereals and cereals-based products. Determination of crude fat and total fat content by the Randall extraction method

[10] ISO 6493-2015 Animal feeding stuffs. Determination of starch content. Polarimetric method

[11] ISO 6558-2-2019 Fruits, vegetables and derived products. Determination of carotene content by spectrophotometric method

[12] ISO 5985:2002 Feeds, compound feeds, material for compound feeds. Methods for determination of ash content, insoluble in hydrochloric acid

[13] ISO 6490-1:1985 Feeds, compound feeds. Methods for Determination of calcium content titrimetric method.

[14] ISO 6491-2016 Feeds, compound feeds, feed raw materials. Determination of phosphorus content by spectrometric method.

[15] ISO 6869:2000 Feeds, compound feeds. Determination of the contents of calcium, copper, iron, magnesium, manganese, potassium, sodium and zinc by atomic absorption spectrometry method

[16] ISO 7523-2016 Nickel. Determination of silver, arsenic, bismuth, cadmium, lead, antimony, selenium, tin, tellurium and thallium contents. Electrothermal atomic absorption spectrometric method

[17] ISO 15141-2-2013 Foodstuffs. Determination of ochratoxin A in cereals and cereal products. Part 2. High performance liquid chromatographic method with bicarbonate clean up

[18] MU 5-1-14/1001 Guidelines for the express determination of mycotoxins in grain, feed and components for their production [in Russian]

[19] Ma X, Jin T, Yoo J, Kim M and Ryu G 2019 Effects of plant ingredients on physicochemical properties of extruded fish feed. Food Engineering Progress. 23 1 doi:10.13050/foodengprog.2019.23.1.1.

[20] Riaz M and Rokey G 2012 Preconditioners in food and feed extrusion: common problems and their solutions Extrusion Problems Solved In book: Extrusion Problems Solved 64 doi: 10.1533/9780857095206.64.

[21] Leonard W, Zhang P, Ying D and Fang Z 2020 Application of extrusion technology in plant food processing byproducts: an overview. Compr. Re. Food Sci. F. 1 218 doi:10.1111/1541-4337.12514.