



Optimization of the Extrusion Process in the Production of Compound Feeds for Dairy Cows

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Abstract

The paper proposes a way of enriching the composition of mixed fodder by combining two promising technologies with known effects: inclusion of germinated grain in the composition and extrusion. Crude and digestible protein, fiber, fat, and mineral elements Ca, K, Na, and P were studied. Inclusion of sprouted grain into mixed fodder and subsequent extrusion contribute to improvements in taste qualities, increased edibility, and assimilation of mixed fodder, as well as nutritive value. Taking into account the obtained knowledge about the influence of temperature regime and content of germinated triticale grain in mixed fodder production, it is advisable to continue research to adapt the technology and develop formulations for different types of animals and farm birds. The purpose of the study was to optimize the process of extrusion of sprouted triticale grain in order to reduce energy consumption and obtain high-quality extrudates. To achieve this goal, the following tasks were set: to analyze the regime factors affecting the fat content based on the optimization of technological modes of extrusion. To optimize the technology of extrusion of triticale grain of the Kozha variety, the fat content was chosen as the target function. Optimization of the technology of extrusion of triticale grain of the Kozha variety was carried out by the method of nonlinear programming. The following optimal technological modes of grain extrusion were obtained: The content of sprouted triticale grain is 15%, and the extrusion temperature is 140°C. With these optimal grain processing modes, the target function was 1.12%. The practical significance of the technology of the production of compound feeds with the use of extrusion in order to improve the quality and increase the shelf life.

Keywords:

Feeding;
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1- Introduction

The efficient use of nutrients in forages is to increase their nutritional and biological value. The use of modern feed preparation technologies (pelleting, extruding, expanding, micronizing, etc.) allows for a significant increase in the efficiency of their use and increases animal productivity. More complete use of forages can be achieved by increasing the metabolism of the animal organism and the metabolic energy of the forage, increasing the transformation of nutrients in the forage into products through the use of new technologies for the preparation of forages for feeding [1].

Extrusion, based on high-temperature processing regimes, has found application in feed preparation, particularly in fish farming, but the potential use of this processing method has not been fully developed. Research in this area is

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promising, and the raw material base for extrusion for feed purposes is being studied. Extrusion is a widely used technological process with a simultaneous effect of temperature and pressure, which increases the digestibility of plant raw material components (in particular protein and starch) and reduces the content of anti-nutritional components.

The extrusion process involves various chemical transformations of the material to be processed. Depending on the initial structural and mechanical properties of the raw material, optimum processing conditions are provided for each type of raw material. The chemical transformations must be carried out as intensively as possible, but at the same time, they must ensure the required quality of the final extruded product (no burning, mechanical breakdown of the processed material, etc.) [2, 3]. Extrusion can increase starch digestibility through gelatinization, melting, starch fragmentation, breaking down anti-nutritional factors, and facilitating starch access to digestive enzymes. Extrusion can also increase the digestibility of proteins, amino acids, and nitrogen [4, 5].

Extruded triticale (\times Triticosecale Wittmack) has been studied as a promising ingredient for human nutrition as well as for feeding fish. Its nutritional value has been confirmed in these studies, but little research has been shown, for example, in compound feeds. It is known to feed mixed fodder to dairy cows with sprouted triticale grain and extruded methods to increase milk yields and the chemical composition of milk [6].

It is known that the chemical composition of triticale varies greatly, with some genotypes having a relatively higher concentration of lysine, the limiting amino acid of cereals. Therefore, the chemical composition as well as the genetic variability of triticale nutrition have been studied in many papers. Nutrients such as starch, non-starch polysaccharides (e.g., arabinoxylans), polyphenols (e.g., phenolic acids), alkylresorcinols, and vitamins (e.g., vitamin B1) have attracted the attention of researchers. This factor indicates the potential of triticale as an alternative to cereals for various foods and beverages. Triticale grain is used in the production of compound feeds for almost all types of livestock [7, 8]. It is a working hypothesis that triticale grains have the potential to be used more effectively in animal feed if preparation methods are used that lead to the digestibility of components, such as germination and extrusion [9]. Sprouting grain is a well-known method to increase its biological and nutrient value.

To increase the stability of the extrusion process and improve the quality of the finished product, it is necessary to study the mechanisms of physical and chemical changes occurring with feed components relevant for animal nutrition. Thanks to extrusion technology, it is possible to vary the formulations and include new components, creating nutritious feeds with a high degree of digestibility [10, 11]. The aim of the study is to investigate the effect of changing the extruding temperature and the amount of germinated triticale grain on the nutritional and chemical characteristics of the compound feed. The base of non-traditional feeds is expanding every year to study the possibilities of their use as feed ingredients and identify the most promising ones from an economic point of view. Such objects must have high nutritional properties (primarily in terms of protein and fat content), provide rapid accumulation of biomass, serve as sources of biologically active substances, and be safe from the point of view of veterinary and ecological issues [12, 13].

In high-temperature short-time (HTST) extrusion cooking, a moisture, temperature, pressure, and mechanical shear regime are applied to the grains/ingredients [14]. Compared with other hydrothermal/thermal processes such as roasting, boiling, microwaving, and autoclaving, extrusion cooking affords a continuous, consolidated multi-operational (involving mixing, heating, pressure cooking, and mechanical shearing) process that is energy efficient and produces a high-quality output. Gregson CM, Lee TC Quality modification of food by extrusion processing [15]. Adoption of HTST extrusion by the feed industry has resulted in increased production of dry pet foods, fish, and livestock ingredients and concentrates using lesser-known cereals and legumes [16].

2- Materials and Methods

The technological scheme for the production of extruded feed is shown in Figure 1.

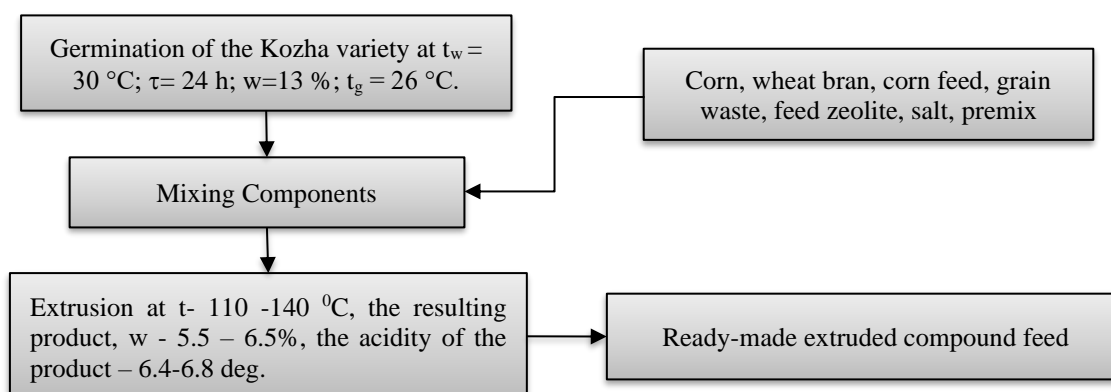


Figure 1. Technological scheme of production of extruded compound feeds

Samples: triticale grain, sprouted grain, mixed feed, extrusion. The object of the study is sprouted triticale of the variety Kozha, included in the State Register of Breeding Achievements of the Republic of Kazakhstan, zoned in Almaty and Zhambyl regions. In order to achieve the objectives, it is planned to use local raw materials. Chemicals: calcium chloride, hexane, sodium, magnesium, distilled water, nitric acid, and hydrochloric acid.

Preparation of raw materials: Instruments laboratory scales, mill, dryer, filter paper, muffle furnace. Laboratory Methods Standard methods for physico-chemical indicators were used to assess the quality of the raw materials [17]. The quality parameters of mixed fodder were determined in accordance with the methods outlined in the following regulations:

- Mass fraction of crude protein GOST 13496.4-93 [18];
- Mass fraction of digestible protein GOST 13496.4-93 [18];
- Mass fraction of raw fat GOST 29033-91 [19];
- Mass fraction of crude fiber Wende method;
- Mineral element calcium GOST EN15505-2013 [20];
- The mineral element potassium AAS method;
- Mineral element phosphorus GOST 26657-97 [21];
- Mineral element sodium GOST EN15505-2013 [22];
- Fodder, mixed fodder. Methods for determination of soluble and readily hydrolysable carbohydrates GOST 26176-91 [23].

Description of the Experiment Experimental organoleptic and chemical tests were carried out in an accredited laboratory of the Kazakh Scientific Research Institute of Processing and Food Industry. The extrusion of mixed fodder was carried out on an extruder of the PE-20 brand. As technological modes affected the quality indicators of extruded triticale grain, the following were selected:

C – Content of sprouted triticale, %;

t – the extrusion temperature, °C.

The quality of the extruded grain in the conducted studies was evaluated by several indicators:

y_1 – the mass fraction of crude protein, %;

y_2 – the mass fraction of the digested protein, %;

y_3 – mass fraction of crude fat, %;

y_4 – mass fraction of crude fiber, %;

y_5 – mineral element calcium, mg/100 g;

y_6 – mineral element potassium, mg/100 g;

y_7 – mineral element phosphorus, mg/100 g;

y_8 – the mineral element sodium, mg/100 g.

The extruder brand PE-20 was used for the experiments (Figure 2).

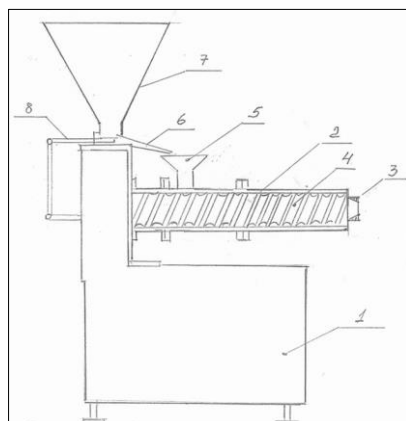


Figure 2. Extruder of PE-20 brand-1- the bed; 2-4 – working element; 3- die nut; 5- loading hopper; 6- tray; 7- bunker; 8- metering device

The basic technological parameters determining the character and intensity of the extrusion process and the depth of physical and chemical changes of extrudates were revealed: temperature and pressure of the extruded material before matrix; humidity of the extruded product; duration of the product being in the extruder working zone; frequency of pressing screw rotation; ratio in the extruded mixture of starch and protein [24]. This allowed research to use an optimum mode of extrusion of mixed fodder: temperature 110–140 °C, pressure 2-3 MPa, and a passage time of 8–13 s for the initial raw material in the unit. The investigated inclusion of germinated triticale grain in mixed fodder ranged from 5 to 15% in increments of 5%.

1. Number of samples analyzed: All analyses were performed in three repetitions.
2. Number of repeated analyses: All analyses were performed in three repetitions.
3. Number of experiment replication: All experiments were carried out in three repetitions.

All studies were carried out in fivefold replications. The validity of the experimental data was assessed by methods of mathematical statistics using Microsoft Excel for Windows 2010. The data obtained have a significant probability of 0.91. In order to obtain a reliable assessment of the impact of individual factors of grain processing on the quality indicators under study, methods of multifactorial planning of experiments were applied. Data processing and all the necessary calculations were carried out using the algorithm and sequential regression analysis program PLAN developed by Stankevich & Ostapchuk [25].

3- Results

Increasing production, including that of animal origin, intensifies research into the application of more efficient housing and feeding technologies, feed processing methods, new formulations, and feed resources. Global demand for animal products is expected to increase by 70% in 2050 compared to 2000 due to global population growth, increasing incomes, and urbanization. There is a need for innovation in a number of areas related to animal nutrition, including feeding technologies [26]. Feed production technology comprises the processing of ingredients and the production of animal feed and is an integral part of livestock production systems for the production of high-quality and nutritious products. The aim is to convert low-quality ingredients into higher-value feed components and to improve the utilization of nutrients in feedstuffs.

The extrusion technology provides forage with high zootechnical and consumer values. The resulting feed is characterized by high nutritional value (protein 22–24%), easier digestibility, biological activity, as well as enzyme, vitamin, and mineral value. The products obtained after extrusion meet the accepted standards for nutrition and content of the necessary set of vitamins and microelements, are veterinarian-safe, and can be certified [27].

Extrusion is a continuous process under the influence of moisture, pressure, temperature, and mechanical shear, resulting in more intense physical and chemical changes compared to raw materials, which increase nutrition and digestibility [28]. This increases protein digestibility and amino acid availability due to the destruction of secondary bonds in protein molecules. Thanks to the relatively low temperatures and short duration of heat treatment, the amino acids themselves are not destroyed. At the same time, the extruders successfully neutralize factors that have a negative effect on the nutritional value of the raw material, such as trypsin inhibitors, urease, and others. Extrusion technology is particularly beneficial for protein supplements for ruminants, as it increases the amount of protein that is not destroyed in the rumen of the animal and also ensures that the protein is more completely absorbed in the small intestine. As a result, livestock productivity is increased and feed intake is reduced [29].

It is known that extrusion has increased the nutritive value of rye and wheat grains, as the content of such indicators as total nutritive value (in equivalent) and metabolizable energy per absolute dry matter has not changed, but the protein content has increased by 3% and 4% and the sugar content by 62% and 143% in rye and wheat, respectively [30]. The extruded feed is shown in Figure 3. The chemical composition of the grain before and after extrusion is shown in Table 1.



Figure 3. Extruded compound feeds: 1 – Kozha; 2 – loose

Table 1. Chemical composition of the grain before and after extrusion

Parameter	Rye			Wheat		
	Before	After	Difference	Before	After	Difference
<i>Content in 1 kg of natural moisture</i>						
1. Feed units	1.09	1.16	+0.07	1.11	1.16	+0.05
2. Metabolic energy, MJ	10.76	11.47	+0.71	10.89	11.38	+0.49
3. Crude protein, g	109.8	120.6	+10.8	126	139	+13
4. Digestible protein, g	91.13	91.6	+0.53	110.9	121.5	+10.6
5. Sugar, g	63.8	110	+46.2	36.4	93.2	+56.8
<i>Content in 1 kg of absolutely dry matter</i>						
1. Feed units	1.27	1.27	0	1.28	1.28	0
2. Metabolic energy, MJ	12.54	12.54	0	12.5	12.5	0
3. Crude protein, g	127.9	131.8	+3.9	145.3	151.2	+5.9
4. Sugar, g	74.4	120.3	+45.9	42.0	102.4	+60.4

The extrusion of mixed fodder in the studies improved the chemical composition of the fodder compared to unextruded fodder, a process that intensified when one of the components of the fodder mixture was germinated beforehand [31, 32].

Taking into account the need to conduct a large number of experiments, mathematical methods of planning multifactorial experiments were applied. For the above factors C and t, a matrix of a complete factorial experiment of the PFE-22 type containing 4 experiments was compiled. The levels of factors (experimental conditions) and the obtained experimental values of the quality indicators listed above for each cultivation of the triticale melon variety y_1 – y_8 are given in Table 2.

Table 2. The planning matrix and the results of experiments to determine quality indicators of extruded triticale varieties obtained under various technological modes of extrusion

N	Modes		Quality indicators of triticale grade Kozha							
	C, %	t, °C	y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8
1	15	140	15.64	11.50	1.12	10.14	93.40	348.14	291.5	41.5
2	5	140	15.58	12.15	1.04	10.05	86.93	312.14	321.4	45.6
3	15	110	17.63	12.96	0.81	16.01	56.58	453.10	260.9	33.1
4	5	110	15.71	11.63	0.91	10.76	84.51	367.19	283.1	39.5

Summary data on the obtained regression equations for natural variables is given in Table 3. The same table shows the root-mean-square errors of the Se experiments and the inadequacy of the Sn.ad., as well as the calculated Fp and critical Fkp values of the Fisher criterion, indicating that both obtained equations adequately describe the experimental data with a confidence probability of $p = 0.05$.

Table 3. Regression equations and statistical characteristics of the dependences of the quality indicators of the triticale extrudate on the extrusion modes

Regression equations in natural variables	Standard deviation		Criteria Fischer	
	Experimental	Inadequacies	Calculated	Critical
$y_1 = 15.15 + 0.607C - 0.00407Ct$	0.21	0.365	2.90	18.51
$y_2 = 11.72 + 0.3557C - 0.00257Ct$	0.19	0.68	12.63	18.51
$y_3 = 0.980 - 0.08933C + 0.00071Ct$	0.0180	0.0179	1.01	200.00
$y_4 = 9.062 + 1.793C - 0.01221Ct$	0.52	0.84	2.63	18.51
$y_5 = 91.085 - 10.48C + 0.07525Ct$	2.90	6.61	5.19	18.51
$y_6 = 642.54 + 6.095C - 2.667t$	12.50	24.95	3.99	18.51
$y_7 = 171.73 - 2.605C + 1.148t$	5.40	3.85	1.97	200.00
$y_8 = -0.4446C + 0.3534t$	0.91	2.58	8.07	19.00

Extrusion processing of feed increases its nutritional value by converting complex, high-molecular-weight substances into simple ones. For young animals and poultry with poorly developed amylolytic enzyme activity, it is advisable to convert starch into easily digestible carbohydrates (dextrins and maltose), improving its digestibility [26]. An "explosion" (volume increase) of the product occurs due to a sharp drop in pressure at the outlet of the heated mass. This makes it more accessible to the influence of animal stomach enzymes and dramatically increases its digestibility [33].

A brief analysis of the regression equations obtained shows that all 8 indicators of the quality of extruded grain of the studied leather varieties in the studied range of their changes depend on the processing modes—the content of sprouted triticale C and the extrusion temperature t. To optimize the technological modes of grain extrusion for each of the triticale varieties considered, the target functions were selected:

– For the Kozha variety – the mass fraction of raw fat (y_3):

$$y_3 = 0.980 - 0.08933C + 0.00071Ct \rightarrow \max; \quad (1)$$

The remaining quality indicators of the extruded grain must be within the specified limits (restrictions):

15.58	\leq	$y_1 = 15.15 + 0.607C - 0.00407Ct, \%$	\leq	17.63
11.50	\leq	$y_2 = 11.72 + 0.3557C - 0.00257Ct, \%$	\leq	12.96
0.81	\leq	$y_3 = 0.980 - 0.08933C + 0.00071Ct, \%$	\leq	1.12
10.05	\leq	$y_4 = 9.062 + 1.793C - 0.01221Ct, \%$	\leq	16.01
56.58	\leq	$y_5 = 91.085 - 10.48C + 0.07525Ct, \text{mg}/100 \text{ g}$	\leq	93.40
312.14	\leq	$y_6 = 642.54 + 6.095C - 2.667t, \text{mg}/100 \text{ g}$	\leq	453.10
260.90	\leq	$y_7 = 171.73 - 2.605C + 1.148t, \text{mg}/100 \text{ g}$	\leq	321.40
33.10	\leq	$y_8 = -0.4446C + 0.3534t, \text{mg}/100 \text{ g}$	\leq	45.60

It is well known that different species of animals, birds, and fish have different nutrient requirements and require different levels of basic nutrients in their feed, so it is worth investigating the effect of extruding temperature and the amount of sprouted grain included on digestible (Figure 4) and digestible protein content (Figure 5).

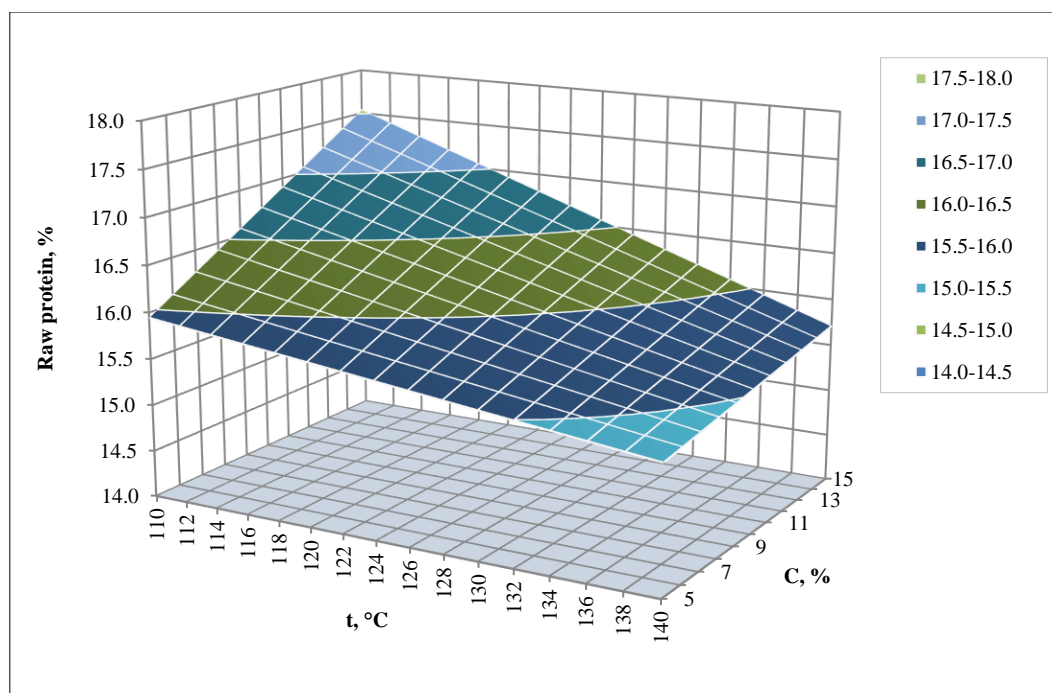


Figure 4. Linear effect of extrusion temperature and amount of germinated triticale grain on crude protein content, %

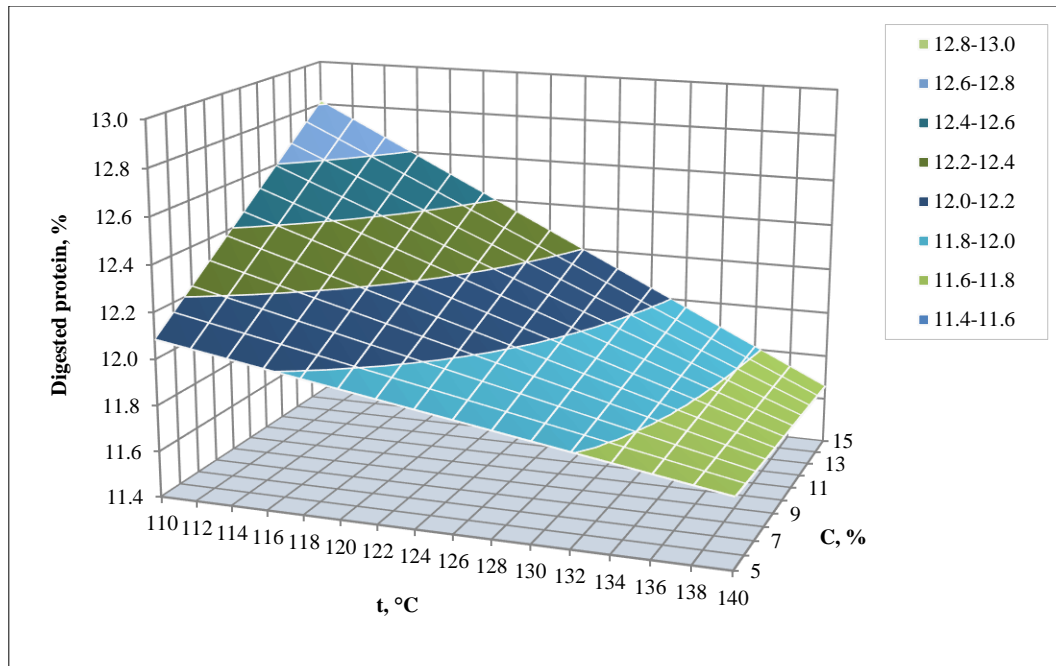


Figure 5. Linear effect of extrusion temperature and amount of germinated triticale grain on digestible protein content, %

When processed in a complex way (germination, extrusion) and the influence of the extrusion temperature and the amount of sprouted triticale grain, the amount of crude protein decreased. Under the influence of high temperature, proteins break down to amino acids, while the amino acid composition is preserved. The resulting extruded compound feed 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. Extrusion had little effect on the raw fat content (Figure 6).

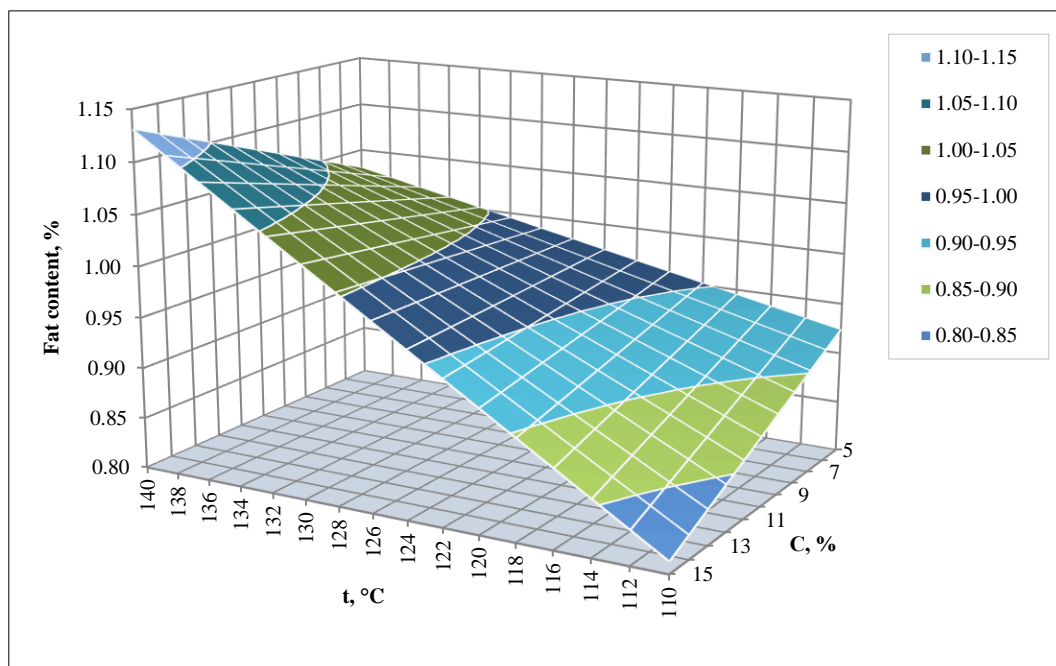


Figure 6. Linear effect of extrusion temperature and amount of germinated triticale grain on fat content, %

In studies, it was noted that the crude fat content in the extruder is significantly lower compared to non-extruded compound feeds. Part of the fat is lost at high pressure. During the extrusion process, the stability of fats increases due to the fact that enzymes such as lipase, which causes rancidity in oils, are destroyed during the extrusion process, and lecithin and tocopherols, which are natural stabilizers, retain their full activity. Grain raw materials are treated with a maximum temperature of only about 5–6 seconds, and oxidation requires a much higher temperature and longer heat treatment. The extrusion temperature t has a unique effect: with its increase, the crude fat content increases, and at $C = 5\%$ the fat increase is 0.11%, and at $C = 15\%$ more—0.32%. Fiber undergoes more profound changes during the extrusion process, which affect its content (Figure 7).

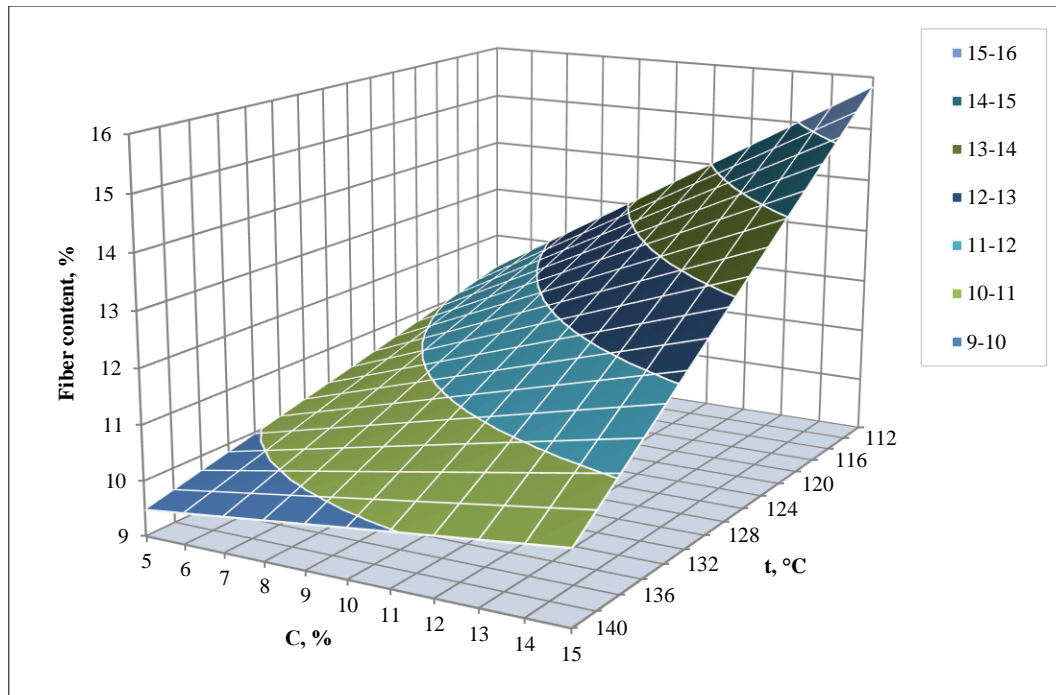


Figure 7. Linear effect of extrusion temperature and amount of germinated triticale grain on fiber content, %

Studies have shown that the percentage of crude fiber in prepared feeds, which is associated with decomposition into secondary sugar in the process, it was found that the content of the mineral element potassium decreased with increasing temperature when the extrusion temperature was 110 °C with a 5% amount of germinated triticale, by 55.06%, and at 140 °C with a 15% inclusion of triticale, by 104.96%. (Figure 8).

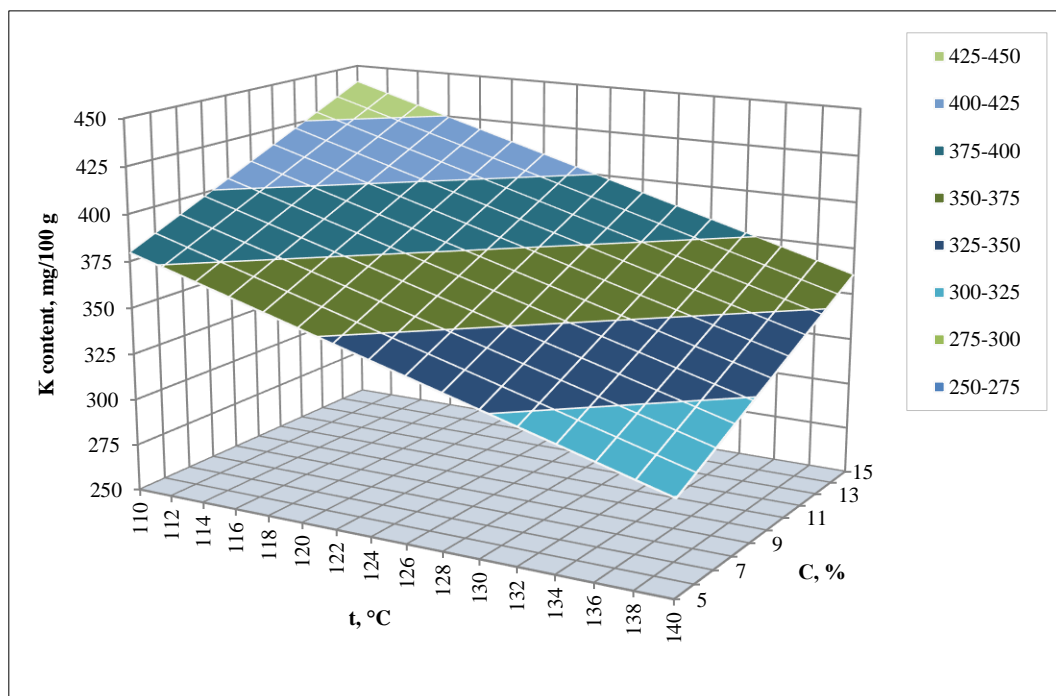


Figure 8. Linear effect of extrusion temperature and amount of germinated triticale grain on potassium content, mg/100 g

For the Kozha variety, the content of the mineral elements potassium y6 and phosphorus y7 has the same linear dependence on factor C. Temperature t has an ambiguous effect on the same indicators y6, y7—its increase reduces the mineral element potassium and increases the mineral element phosphorus y7. With increasing temperature, the extrusion process increased the amount of calcium in germinated triticale grain by 5.42% at 5% and 36.82% at 15% (Figure 9), and the amount of phosphorus in germinated triticale grain by 38.3% at 5% and 30.6% at 15% (Figure 10).

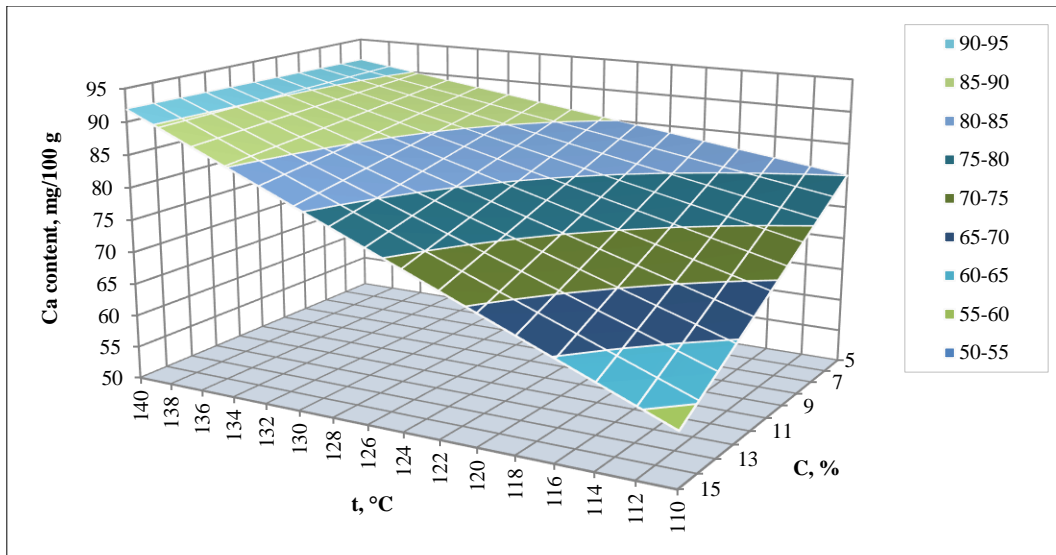


Figure 9. Linear effect of extrusion temperature and amount of triticale grain on calcium content, mg/100 g

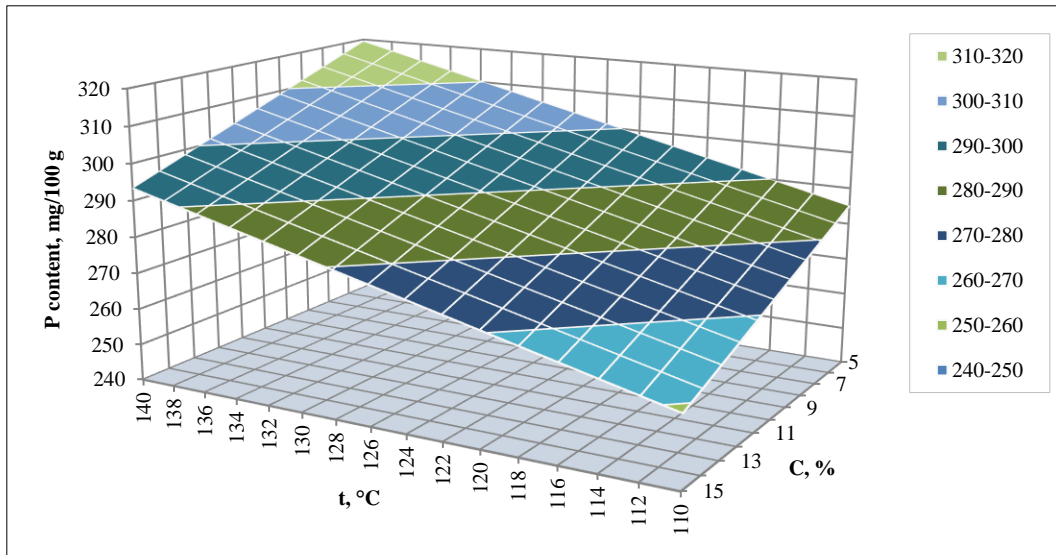


Figure 10. Linear effect of extrusion temperature and amount of germinated triticale grain on phosphorus content, mg/100 g

Exposure temperature also influenced sodium content (Figure 11). Quality indicators of grain extrudates of different grades under optimal extrusion modes shown in the Table 4.

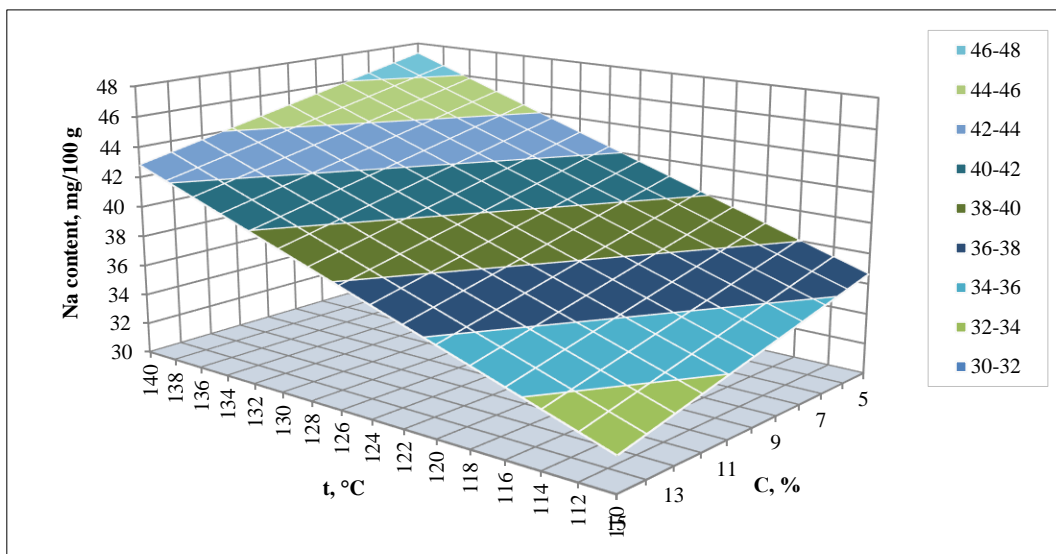


Figure 11. Linear effect of extrusion temperature and amount of germinated triticale grain on sodium content, mg/100 g

Table 4. Quality indicators of grain extrudates of different grades Kozha under optimal extrusion modes

Quality indicators	min		opt		max
Mass fraction of crude protein y_1 , %	15.58	≤	15.72	≤	17.63
The mass fraction of digested protein y_2 , %	11.50	≤	11.65	≤	12.96
Mass fraction of crude fat y_3 , %	0.81	≤	1.12	≤	1.12
Mass fraction of crude fiber y_4 , %	10.05	≤	10.33	≤	16.01
The mineral element is calcium y_5 , mg/100 g	56.58	≤	91.92	≤	93.40
The mineral element is potassium y_6 , mg/100 g	312.14	≤	360.62	≤	453.10
The mineral element phosphorus y_7 , mg/100 g	260.90	≤	293.42	≤	321.40
The mineral element is sodium y_8 , mg/100 g	33.10	≤	42.80	≤	45.60

The simultaneous effect of temperature and pressure during extrusion produces a sponge-like product that can be shaped into convenient shapes, including pellets [34, 35]. According to the research results, it can be concluded that extruded compound feeds will significantly reduce the deficiency of digestible protein and other nutrients in the diets of livestock and, accordingly, increase the efficiency of feed energy use. According to a number of researchers [36, 37], when the product is exposed to a combined effect of pressure, shear deformation, temperature, and humidity, it results in a change in the structure of its constituent parts, the inactivation of digestive tract inhibitors, the neutralization of toxic substances, sterilization, the improvement of taste, starch dextrinization, and partially the conversion of fiber to glucose. All this contributes to an increase in the digestibility of feed nutrients, which means an increase in the growth rate of animals, an improvement in the quality of agricultural products obtained, and a reduction in feed consumption.

In recent years, the extrusion technique has been extensively used in animal feed because this technology has numerous advantages, including the possibility of wide application, high productivity, energy efficiency, and high quality of the resulting product [38, 39]. Extrusion may increase the digestibility of starch through starch gelatinization, melting, fragmentation, destruction of antinutritional factors, and making starch easily accessible to digestive enzymes [40–43]. Any variation in this process, for example, a change in temperature, moisture, screw speed, pressure, and time, along with the chemical composition and structure of the extruded material, can easily influence the digestibility of feed or feed ingredients. So, to achieve better results from the extrusion process, optimum conditions should be maintained.

This extrusion process is used in many different places, has different applications, and is extensively used in the food and feed industries. Due to the increased application of extrusion, the physicochemical, functional, and nutritional effects of the extrusion process are considered to be of high importance. The destruction of anti-nutritional factors, reduction of nutrient losses, and increasing digestibility of starch and protein are considered the basis of the extrusion process.

4- Discussion

It can be concluded that the extrusion of the feed mixture contributed to an improvement in the chemical composition of the feed compared to the original composition, the process of which was intensified during the preliminary germination of one of the components of the feed composition. This effect can be explained by the fact that during the germination of grain, the main chemical compounds from complex forms pass into simpler and more easily digestible forms, so raw fiber decomposes into dextrins and simple sugars, proteins into amino acids, and fats into free fatty acids. As a result of this process, there is an increase in the amount of soluble nutrients in the final product compared to the original composition.

When processing feed, the use of the extrusion process with pre-germination is most effective compared to a single extrusion process. Triticale is widely used in agriculture [44]. It is a valuable forage, food, and technical crop obtained by combining the chromosome complexes of wheat (*Triticum aestivum*) and rye (*Secale cereale*), an artificially bred wheat-rye amphidiploid with a large multifloral spike, expressed immunity to fungal diseases, increased protein and lysine content, and higher winter hardiness in comparison with wheat. The higher content of more complete protein, sugars, vitamins, macro- and microelements, i.e., high biological value, makes triticale grain promising for a wider use in animal feeding [45–48].

Analysis of the data in Figures 1 and 2 shows that during the extrusion of mixed fodder, with an increasing extrusion temperature of 110 to 140 °C and sprouted grain content of 5 to 15%, the protein content varies from 15.58 to 17.63%, and digestible protein is 11.50 to 12.96%. This is because the processes involved in extrusion (high temperature and pressure) have a positive effect on the raw and digestible protein content.

The analysis revealed that in extruded compound feed, its content increased slightly from 0.81 to 1.12%, or by 0.31%. It is known that short-term exposure results in the rupture of fat cell walls, thereby increasing the energy value of the product and generally increasing the stability of fats due to the fact that enzymes such as lipase that cause fat deterioration are destroyed while stabilizing enzymes such as lecithin and tocopherols are retained. The percentage of fiber in the extruded feed decreased as a result of its breakdown into secondary sugars from 16.01 to 10.05% (by 5.96%), which has a positive effect on digestibility.

As the content of macronutrients in the compound feed is important for good animal nutrition, the content of potassium, calcium, phosphorus, and sodium in the extruded compound feed was analyzed. Thus, the mineral element sodium content increased by 8.4% with 5% inclusion of germinated triticale grain and by 6.1% with 15% with increasing temperature of extrusion to the compound feed. The extrusion process has a positive effect on nutritional values (crude and digestible protein, fiber) and changes the chemical composition. Potassium content decreased with increasing processing temperature and decreased to a lesser extent with the amount of sprouted triticale grain introduced. Calcium content increased with increasing treatment temperatures, as did phosphorus and sodium. However, a higher content of calcium and sodium was observed in feeds with a lower proportion of triticale.

Restrictions on the range of changes in grain processing modes were taken equal to the ranges of changes in experimental conditions: $5\% \leq C \leq 15\%$; $110\text{ }^{\circ}\text{C} \leq t \leq 140\text{ }^{\circ}\text{C}$

Using the obtained system of equations, the optimal technological modes of grain extrusion of the studied varieties were determined by the method of nonlinear programming:

- For the Kozha variety $C = 15\%$, $t = 140\text{ }^{\circ}\text{C}$;

These modes, subject to all requirements (restrictions) for all indicators of the quality of extruded triticale grain, provide the maximum values of the target functions:

- For the Kozha variety $y_3 = 1.12\%$;

Thus, the extrusion of grain of different triticale varieties under optimal technological conditions ensures maximum crude fat (Kozha grade). At the same time, the remaining quality indicators considered are within the specified limits.

5- Conclusion

At the same time, it is necessary to maximize the potential of new varieties of winter triticale, since the productivity of animals largely depends on the varietal characteristics of the crop. Triticale attracts special attention for its ability to surpass its parent forms in terms of yield and product quality, and in terms of resistance to unfavorable soil and climatic conditions and to the most dangerous diseases, it is not inferior to rye. Most researchers characterize triticale as a factor in increasing animal productivity and reducing feed costs per unit of production. It is also possible to increase the productive effect of triticale grain by extrusion. In physiological exchange experiments, it was found that due to the extrusion of triticale grain, the digestibility of the main nutrients increased. The use of triticale in diets instead of wheat reduces the cost of the diet, the cost of production, and the profitability of production.

Research in this article makes it possible to use sprouted triticale grain in the feed industry instead of wheat, barley, and rye. Germination and extrusion make it possible to reduce the energy costs of the animal's body for processing feed, inactivating anti-nutrients, and purifying the initial product from undesirable microflora. In addition, the above-mentioned method of preparing grain for feeding makes it possible to improve the absorption of nutrients by animals, thereby increasing the efficiency of feed. The inclusion of germinated triticale grain is promising for use in animal feed. In addition to the fact that the crop itself is valuable for fodder purposes, germinating its grain has a positive effect on its nutritional and biological value. Extrusion is a known technology to increase nutritional value and improve palatability and digestibility. The incorporation of germinated grains into the feed and the subsequent extrusion improve the palatability and digestibility of the feed as well as its nutritional value. This process is explained by the fact that during the germination of triticale grains, the main chemical compounds change from complex forms to simpler and easily digestible ones, so raw fiber is broken down into simple sugars, proteins into amino acids, and fats into free fatty acids. The result of germination and extrusion is an increase in the amount of soluble nutrients in the feed. The optimal parameters of extrusion and the effect of extrusion processing on fat content have been studied. The research should be continued, and the technology could be adapted for different species of farm animals and different sexually mature groups, which would require the development of different formulations and their research. The optimal technological modes of extrusion of triticale grain of the leather variety are determined: the content of sprouted triticale grain is 15%, and the extrusion temperature is $140\text{ }^{\circ}\text{C}$. Optimization of technological modes of extrusion of triticale grain of the Kozha variety in the range of 5% to 15% of sprouted triticale grain at an extrusion temperature of 110 to $140\text{ }^{\circ}\text{C}$ was carried out, and optimal extrusion modes were established in a given range.

6- Declarations

6-1-Author Contributions

Conceptualization, R.K. and G.Z.; methodology, U.C.; software, A.I.; validation, K.R. and A.S.; formal analysis, T.B.; investigation, G.Z.; resources, K.R.; data curation, T.B.; writing—original draft preparation, K.R.; writing—review and editing, G.Z.; visualization, A.I.; supervision, U.C.; project administration, U.C.; funding acquisition, A.S. All authors have read and agreed to the published version of the manuscript.

6-2-Data Availability Statement

The data presented in this study are available in the article.

6-3-Funding

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6-5-Institutional Review Board Statement

Not applicable.

6-6-Informed Consent Statement

Not applicable.

6-7-Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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