



The Influence of Germinated Grain Mix on the Quality of Extruded Fodder

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ABSTRACT

The main factor in the development of modern animal husbandry is the development of methods for preparing feed for animals and enhancement of their nutritional value. To obtain high-energy feed, there is a need to use the germinated grain as one of the components for the extrusion used in animal food processing. The quality assessment of the extruded feed in terms of environmental and energy indicators based on a two-component mixture is of particular interest. In this regard, the purpose of the present research was to identify the regularities of changes in metabolic energy and the ecological-energy indicator of the feed quality, depending on the quantitative and qualitative content of the germinated component included in the extruded mixture. Wheat was mixed for 72 hours with pre-germinated grains of wheat, rapeseed, peas, oats, soybeans, or corn. The resulting mixture was extruded at a temperature of 120-130°C and pressure of 4-5 MPa. The highest metabolic energy of the feed was found in the extruded mixture containing 25% sprouted grains of soybeans, rapeseed, corn, peas, oats 15%, and wheat 10%. Regarding energy indicators, it is advisable to use 25% of the sprouted grain of soybeans, rapeseed, corn, peas, 15% of oats, and 10% of wheat in the extruded mixture as well as 10% of sprouted wheat, 25% peas, 25% corn, 10% soybeans, 20% oats, and 10% rapeseed. Based on the obtained results, a mathematical model was designed using the theory of splines. The modeling was carried out in the Maple package.

Keywords: Extrusion, Feed, Grain, Germination, Mix

INTRODUCTION

Much of the production cost in the livestock industry accounts for fodder (65-75%). To increase the productivity of the animal ration, some fodder additives were administered and different ways of preparing fodder were examined (Shcheglov, 1990; Lukht, 2004; Matyushev et al., 2019). Grain and vegetable feed are the main components of animal diets. The share of grain included in compound feed accounts for up to 70 percent or more (Okolelova, 1999).

Fodder enrichment with biologically active substances that ensure high preservation of young animals, an increase in live weight, general resistance, and productivity of farm animals is possible due to the use of germinated grain, which has an increased amount of micronutrients and easily digestible forms of nutrients in its compositions (Sayfullin, 2017; Ali et al., 2019; Farghaly et al., 2019). There is a problem of unique fodder properties preservation during the grain germination and its further use, which can be solved by extruding a mixture

while one of the components is germinated (Soder et al., 2018).

Despite the well-known publications (Sayfullin, 2017; Shvetsov et al., 2019), the regularities of changes in the quality of extruded feed depending on the quantitative and qualitative composition of the mixture is insufficiently studied. Research findings have established that feeding sprouted grain is an effective method of increasing the intensity of growth and development of young cattle (Peer and Leeson, 1985; Batrakov, 2012). Sprouted grain surpasses natural grain in protein content, essential amino acids, trace elements, vitamins E, and group B (Podletskaya, 1980; Lardy, 2017).

Extrusion was carried out at a temperature of 120-150°C and pressure of 4-5 MPa, starch dextrinization occurs, the digestibility of feed increases because nutrients become more accessible to animals (Salazar-Villanea et al., 2018). Since the bar thermal effect increases in the process of extrusion, the sterilization of grain (i.e. barley, corn, wheat, bran, etc.) and the inactivation of toxic substances may occur (Kosolapov, 2018). Some authors

noted the expediency of using extruded feeds with sprouted grain in animal diets in their works (Sofronov et al., 2017; Shvetsov et al., 2019). Sayfullin (2017) conducted a comparative assessment of the developed recipes for feed mixtures using wheat, barley, and corn grains, prepared for feeding by crushing, germination, and extrusion. The research results have shown that the most effective method is germination and the mixture extrusion. Compared with the crushing of the mixture, the proposed method has increased the profit and the level of profitability by 2.4-9.0% and 0.4-2.2%, respectively (Sayfullin, 2017). Due to the improvement of the chemical composition of the feed mixture of pre-germinated rapeseed grain with subsequent extrusion, the average daily gains of calves increased by 9.8%, compared with the use of only one extrusion (Sayfullin, 2017).

Studies on the pre-germinated grains of corn, wheat, and barley to the feed mixture have shown that the introduction of the obtained feed component into the feed ration of livestock has made it possible to increase the profitability of livestock production by 2.2% (Shvetsov et al., 2019).

The process of grain germination is influenced by the preliminary processing method (Chaplygina et al., 2020). The extruded feed is assessed by ecological and energy indicators based on a two-component mixture, one of which is germinated.

In this regard, the present research aimed to identify the patterns of changes in metabolic energy and the ecological-energy indicator of the feed quality depending on the quantitative and qualitative content of the germinated components included in the extruded mixture.

MATERIALS AND METHODS

Ethical approval

The Present experiment does not contain any studies with human participants or animals performed by any of the authors.

Main process

Studies to determine the regularity of changes in the quality of extruded feed depending on the properties of the initial mixture were carried out at the Engineering Center of the Federal State Budgetary Educational Institution of Higher Education of Krasnoyarsk State Agrarian University, Krasnoyarsk, Russia. The material for the research was the seeds of rapeseed Trapper B4 2018, peas Radamir Elita, wheat Novosibirskaya 15 Elita, corn Rosso140, soybean Zaryanitsa RS1, oats Sayan RS 3. They were provided from the educational sector in Sukhobuzimsky University district of the Krasnoyarsk Territory.

Table 1. The amount of germinated grain mixed with non-germinated wheat

Mix №	Wheat grain not sprouted, %	Sprouted grains wheat, %	Sprouted grains rapeseed, %	Sprouted grains peas, %	Sprouted grains oats, %	Sprouted grains soybeans, %	Sprouted grains corn, %
1	90	10	-	-	-	-	-
2	85	15	-	-	-	-	-
3	80	20	-	-	-	-	-
4	75	25	-	-	-	-	-
5	90	-	10	-	-	-	-
6	85	-	15	-	-	-	-
7	80	-	20	-	-	-	-
8	75	-	25	-	-	-	-
9	90	-	-	10	-	-	-
10	85	-	-	15	-	-	-
11	80	-	-	20	-	-	-
12	75	-	-	25	-	-	-
13	90	-	-	-	10	-	-
14	85	-	-	-	15	-	-
15	80	-	-	-	20	-	-
16	75	-	-	-	25	-	-
17	90	-	-	-	-	10	-
18	85	-	-	-	-	15	-
19	80	-	-	-	-	20	-
20	75	-	-	-	-	25	-
21	90	-	-	-	-	-	10
22	85	-	-	-	-	-	15
23	80	-	-	-	-	-	20
24	75	-	-	-	-	-	25

Wheat grain was used as the main component in the research. Before germination, the grains were subjected to a disinfection process (Chaplygina et al., 2020). Control grain samples with a layer of 20 cm were soaked and germinated in the water at a temperature of $20 \pm 1^\circ\text{C}$. Grain germination was carried out for 72 hours, taking into account the soaking time. Sprouted grains (wheat, rapeseed, peas, oats, soybeans, and corn) with sprouts and roots up to 2 mm were introduced into the mixtures in amounts of 10%, 15%, 20%, and 25% (Table 1). Sprouted grains (wheat, rapeseed, peas, oats, soybeans, corn) with sprouts and roots up to 2 mm were introduced into the mixtures for extrusion. A total of 24 mixtures were obtained: with 10%, 15%, 20% and 25%, germinated wheat, mixtures with 10%, 15%, 20%, and 25% germinated rapeseed, with 10%, 15%, 20%, and 25% sprouted peas, with 10%, 15%, 20%, and 25% sprouted oats, with 10%, 15%, 20%, and 25% sprouted soybeans and with 10%, 15%, 20%, and 25% sprouted corn.. The prepared mixture was subjected to extrusion on an EK-100 extruder. The extrusion process began with the wheat grains extrusion. Upon reaching a temperature of 120-130°C, the extrusion of experimental samples started. After extrusion, the prototypes were cooled and crushed.

The extrudates with pre-germination production is shown in Figure 1. The raw materials, prepared mixture, and extruded feed were investigated according to accredited methods at the research and development center Krasnoyarsk State Agrarian University, Federal state budgetary institution ‘Krasnoyarsk Rosselkhoz nadzor Reference Center’ and Federal State Budgetary Institution Center of Agrochemical Service’ (Krasnoyarsk, Russia).

The amount of metabolizable energy (W, Fat mass/kg dry matter) determines the energy value of the finished product, and the ecological-energy indicator of product quality (E.) evaluates both the energy and environmental safety of the feed.

In this case, the environmental safety of feed is assessed through the concentration of heavy metals contained in the product and, in turn, determines the environmental safety coefficient (K). Therefore, the ecological and energy indicator of the quality of finished products is determined by the following formula:

$$E : W K, \tag{formula 1}$$

and the environmental safety factor is introduced as a weighted mean square:

$$K = \sqrt{\sum_i p_i \left(1 - \frac{m_i - \underline{m}_i}{\bar{m}_i}\right)^2}, \tag{formula 2}$$

Where, $p_i > 0$ refers to the weight coefficient of the i metal,

$\sum_i p_i = 1$; \bar{m}_i is the maximum permissible mass of the i metal in the original product (majorant), m_i denotes the mass of the i metal in the original product; and \underline{m}_i signifies the minimum possible mass of the i metal in the original product (background, minorant). If the content of heavy metals in the feed is minimal ($m_i = \underline{m}_i$), then the environmental safety factor is equal to one (Tsuglenok, 2004).

Statistical analysis

A regression analysis of the data on the content of nutrients, heavy metals, and exchange energy in the extrudates was carried out using the DataFit analysis package. The data obtained were used to develop a mathematical model using the theory of splines. The modeling was carried out in the Maple package.

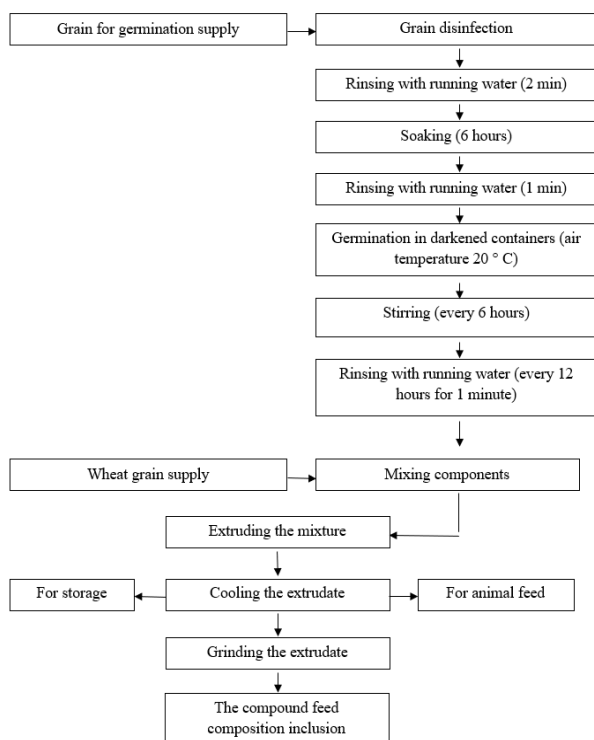


Figure 1. Scheme of extrudate productions with a preliminary germination as one of the components

RESULTS

With an increase in the mass fraction of germinated grain in the mixture before extrusion from 10 to 25%, the exchange energy of the finished feed (Fat mass/kg dry matter) increased with the introduction of peas by 0.03, soybeans by 0.02, corn by 0.61, rapeseed by 0.2 and decreased with the introduction of wheat by 0.38 and oats by 0.2.

Moreover, with an increase in sprouted oats in the mixture to 15%, the exchange energy of the extruded feed increased to 12.84 Fat mass/kg dry matter, and with a further increase in the mass fraction of oats, the extrusion process was unstable, and the exchange energy decreased. The maximum values of the exchange energy depending on the quantitative and qualitative composition of the mixture with the inclusion of germinated grain are presented in Figure 2.

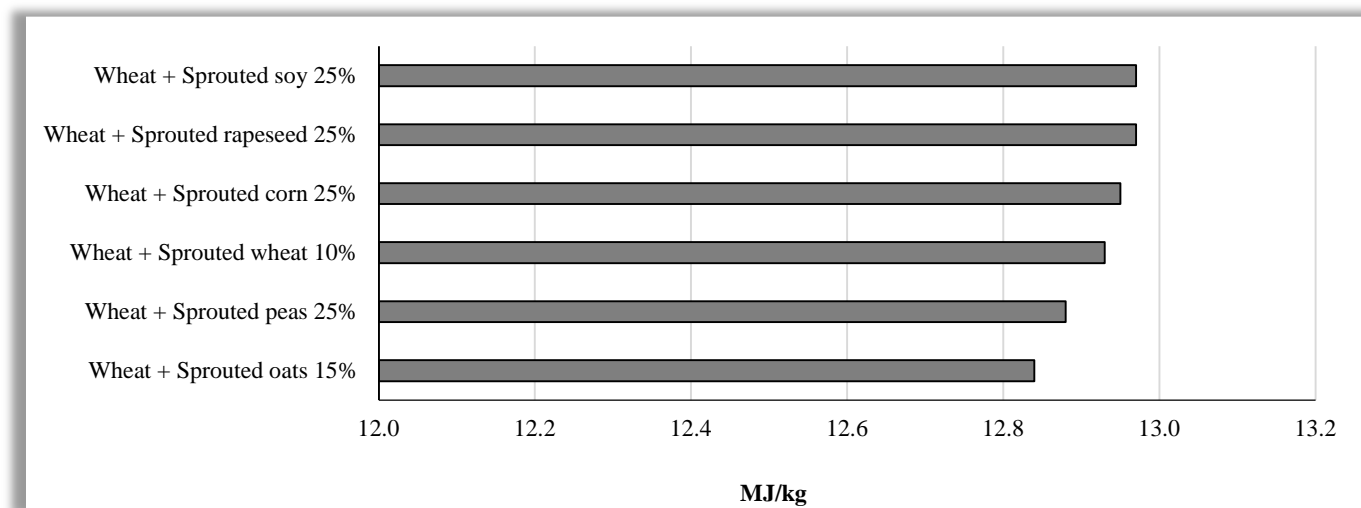


Figure 2. The maximum value of the exchange energy of the extruded feed, depending on the quantitative and qualitative composition of the mixture with the inclusion of sprouted grains

At the preliminary level of research, a statistical analysis of the experimental values of general and particular indicators of the quality of grain feed was carried out. For the main research, the authors obtained model representations of these indicators depending on the biochemical composition of the sample developed an analytical model and an application program in the Maple language.

It was found that the value of exchange energy (W, Fat mass / kg) depending on protein (x₁,%), fat (x₂,%), fiber (x₃,%), ash (x₄,%), starch (x₅,%), sugar (x₆,%), as well as the content of carotene (x₇, mg / kg), phosphorus (x₈,%) and calcium (x₉, mg / kg) can be measured by function 1:

$$W(x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9) : 12.82164827 + 0.04399687835x_1 + 0.1244376067x_2 - 0.135216771x_3 - 0.06582409334x_4 - 0.001801310033x_5 + 0.002435657045x_6 + 0.01047258968x_7 - 0.02631638797x_8 - 0.00002555708139x_9, \quad (\text{function 1})$$

The coefficients identified both the positive (+) and negative (-) effects of the biochemical composition on the studied indicator of exchange energy. The content of heavy metals (K, units) depending on protein (x₁,%), fat (x₂,%), fiber (x₃,%), ash (x₄,%), starch (x₅,%), sugar (x₆,%), as well as the content of carotene (x₇, mg / kg), phosphorus (x₈,%) and calcium (x₉, mg / kg) is represented by the function 2:

$$K(x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9) : 0.6359931709 - 0.004654778495x_1 + 0.001172784388x_2 - 0.006615132491x_3 + 0.04048605947x_4 + 0.0008828936953x_5 - 0.00007621782146x_6 - 0.002150250226x_7 + 0.02549878848x_8 - 0.0001459300349x_9 \quad (\text{function 2})$$

The coefficients identified the influence of the biochemical composition on the investigated indicator of the heavy metal content. With an increase in the mass fraction of germinated grain in the mixture before extrusion from 10 to 25%, the ecological-energy indicator

of the quality of the finished feed (Fat mass/kg dry matter) increased with the introduction of peas, corn, and oats by 1.34, 0.96, and 0.34, respectively, and decreased with the introduction of rapeseed by 1.44, wheat by 0.43, and soybeans by 0.38. The maximum value of the ecological-energy indicator of the extruded feed quality, depending on the quantitative and qualitative composition of the mixture with the germinated grain, is presented in Figure 3.

The value of the ecological-energy index (E, fat mass / kg) depending on protein ($x_1, \%$), fat ($x_2, \%$), fiber ($x_3, \%$), ash ($x_4, \%$), starch ($x_5, \%$), sugar ($x_6, \%$), as well as the content of carotene ($x_7, \text{mg / kg}$), phosphorus ($x_8, \%$)

and calcium ($x_9, \text{mg / kg}$) is represented by the following function 3:

$$E(x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9) : 8.130627447 - 0.03932534192 x_1 + 0.07349631047 x_2 - 0.163009832 x_3 + 0.4576073698 x_4 + 0.01198632547 x_5 + 0.009938439014 x_6 - 0.01843433948 x_7 + 0.3588742755 x_8 - 0.00180813858 x_9. \quad (\text{function 3})$$

The research results indicated a change in the quality of extruded feed depending on the quantitative and qualitative composition of the mixture (one of the components was germinated).

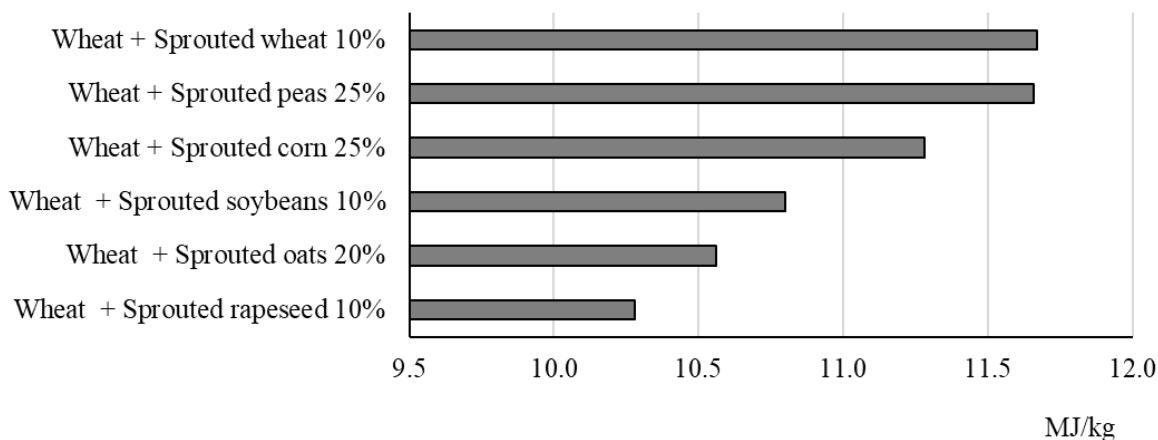


Figure 3. The maximum value of the ecological-energy indicator of the extruded feed quality depending on the quantitative and qualitative composition of the mixture with the germinated grains

DISCUSSION

The exchange energy of the finished extruded feed varied depending on the seedlings used in the mixture and their quantity. According to the data obtained, an increase in the proportion of sprouted grain in the mixture was revealed up to 25% using soybeans, peas, rapeseed, and corn led to an increase in the content of metabolic energy in feed. When using sprouted wheat, an inverse relationship was observed, meaning that the amount of exchange energy decreased with an increase in the proportion of germinated grain in the mixture. The use of germinated oat grain of more than 15% is not advisable, as it leads to an instability of the extrusion process under the given conditions.

Based on the research data on energy indicators, it is advisable to use 25% of a sprouted grain of soybeans, rapeseed, corn, peas, 15% oats, or 10% wheat in the extruded mixture as one of the components.

This content of sprouted grain in the mixture could be recommended for practical use in agricultural production, but an assessment of not only the nutritional value but also the safety of feed is required. It is advisable to carry out a comprehensive assessment using the ecological and energy quality index of the extruded mixture. Data analysis on the content of heavy metals in seedlings grain suggested that their total quantity increased and decreased, respectively.

The largest total amount of heavy metals was noted in rapeseed, the minimum in wheat. Accordingly, in rapeseed, the minimum value of the ecological-energy indicator K. The ability of rape seedlings to accumulate heavy metals was previously noted in other studies (Radionov *et al.*, 2007).

The ecological and energy indicator of the extruded feed quality containing sprouted rape Data analysis on the content of heavy metals in seedlings grain suggests that their total quantity increases and decreases respectively in

the row K wheat < peas < corn-soy << oats < canola. The ability of rape seedlings to accumulate heavy metals was previously noted in other studies had the lowest value (Radionov et al., 2007). The greatest value was noted when using pea seedlings in a mixture.

The analytical model and the applied program obtained based on the research results allow predicting the content of exchange energy, heavy metals, and the value of the ecological-energy index of the extruded mixture, one of the components of which is germinated, depending on the biochemical composition of the feed. The convergence of the experimental and calculated data on the ecological and energy index ranged from 92% to 96%.

Thus, to obtain ecologically safe livestock products, it is reasonable to use an extruded mixture in the animal diet, containing sprouted grains as one of the components with a high ecological and energy index of feed quality.

CONCLUSION

Using the methods of a natural and computational experiment with an analytical model and an applied Maple-program, it can be concluded that it is rational to use sprouted grain as one of the components of an extruded mixture in the diet of animals to obtain ecologically safe livestock products in various natural and ecological conditions.

To obtain feed with the highest ecological and energy quality indicators, it is advisable to use one of the proposed germinated components in the amount of 10% wheat, 25% peas, 25% corn, 10% soybeans, 20% oats, or 10% rapeseed. The ecological and energy indicator of the quality of extruded feed containing sprouted rape had the least value. The greatest value was noted when using wheat or pea seedlings in a mixture.

Acknowledgments

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Authors' contributions

The authors carried out the formulation of problems, germination of grain, development of formulations of mixtures, obtaining extrudates, data analysis, statistical processing, and the development of a mathematical model. V.V. Matyushev carried out the setting of tasks and planning of the experiment, germination of grain,

extrusion of mixtures, and analysis of research results. Chaplygina I.A. carried out the planning of the experiment, germination of grain, extrusion of mixtures, analysis of research results. Semenov A.A. carried out the germination of grain and the extrusion of mixtures.

A. A. Belyakov carried out mathematical processing and construction of a mathematical model.

Competing interests

The authors declare no conflicts of interest.

Ethical considerations

All ethical issues (Including plagiarism, consent to publish, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy) have been checked by the authors.

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