Energy return and production competitiveness of ekstrudat from grain mix and vegetable additive

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Abstract. Carrying out researches on extrusion of grain crops with inclusion of vegetable components and assessment of their energy value and competitiveness is a important task. Due to this quality indicator of the ekstrudat on the basis of wheat, barley, oats with inclusion of pulp of green grasses have been defined, the assessment of energy return and energy efficiency ratio has been carried out. The energy value of grain crops increased after extruding by 8.33 – 10.86%. The pulp of green grasses was mixed with seed of wheat or barley or oats in number of 10, 15 and 20% of the mass of mix. After mechanical dehydration of a grass mix the energy value of pulp was 10.68 MDzh/kg. At joint extruding of grain crops with pulp from a grass mix the power value of the ekstrudat decreased and was 0.12-0.21 MDzh/kg. Reduction of power value of the ekstrudat leads to decrease in power return by 0.12-0.21 MDzh/kg. At the same time the energy efficiency ratio is increased by 5.44-6.4%. Increase in power efficiency ratio is connected with reduction of energy input on grain crushing. Extrudat on the basis of wheat mix and 20% of pulp corresponded to the greatest value of energy return and energy efficiency ratio. The equations of linear regression have been received for the mathematical description of change of energy return and energy efficiency ratio. Use of pulp as a part of mix before extruding allows to receive a ready-made product with lower cost price in connection with reduction of grain mass as a part of the ekstrudat.

1. Introduction
The resource-saving production technologies and the possibility of receiving functionally effective products with the minimum costs of production and consumption are of great importance now. Those products which give maximum result with relatively little input, have competitive advantages.

There are many approaches to competitiveness assessment, however in terms of saving of resource potential, search of such objective indicator which does not depend on a financial situation in the market is critical. The assessment of "energy efficiency" which allows to consider both process parameters, and the functional and consumer properties defining competitiveness of products can be used as such indicator.

Among the technologies providing the raw material resources saving, the fodder and food extrudat technological production lines, which are widely adopted in agrarian and industrial complex of Russia and the food industry, seem to be interesting. [1, 2].

The process of extrudat production promotes change of structural and mechanical qualities of initial raw materials, increase in qualitative characteristics and comprehensibility of a ready-made product due to short-term influence of high temperature and pressure [3, 4, 5].
Improvement of the production technology of ekstrudat is directed to receiving a ready-made product
with programmable properties due to usage of plant mix as components.

Ekstrudat is received on the basis of wheat, oats, barley, and also in mix with other plant components [6, 7, 8, 9]. Use of mixes in the production technology of ekstrudat allows to reduce the consumption of grain and to reduce the cost price of a ready-made product. It is reasonable to use the pressed mass (pulp) of green grasses as a plant component of mix for extruding.

It is reasonable to define efficiency of the production technology of ekstrudat taking into account the initial raw materials through an indicator of energy return. The authors [10, 11] recommend to use energy efficiency ratio to compare competitiveness of technological processes of finished goods production. Energy return is possible when value of power efficiency ratio ($\eta$) more than a unit [12].

Due to this it is relevant to analyse the change of energy return and energy efficiency ratio in production of ekstrudat, depending on the initial raw materials.

The research objective was to define the quality indicators of the ekstrudat on the basis of wheat, barley, oats with inclusion of pulp of green grasses and assessment of energy return and energy efficiency ratio.

Research tasks: to carry out the comparative analysis of quality indicators of ekstrudat; to estimate energy return and competitiveness of production of ekstrudat on the basis of grain crops and pulp of green grasses.

2. Objects and methods of the research
Extrudat on the basis of wheat, oats and barley with addition of pulp from fodder grasses mix grown up in Sukhobuzimsky district of Krasnoyarsk region was the object of the research. Wheat Novosibirsk-15, barley Ach, oats Selma have been used in the researches.

The pulp was being received on a hydraulic press. As a result of mechanical dehydration the green material was divided into two fractions - green juice and pulp. Green juice was used to produce a proteinaceous and vitamin coagulate, the pulp was mixed up with grain. The pulp was brought into mixes in number of 10, 15 and 20% on weight. Increase in quantity of pulp is limited by humidity of the mix arriving for extruding. The received mixes were maintained within 30 minutes for uniform distribution of moisture and extruded at a temperature of 120-140 °C and pressure of 4-5 MPas on an extruder ETR-45 KFSO.

The analysis of quality of initial raw materials and ekstrudat was being carried out in the research test centre of Krasnoyarsk agricultural university. Calculation of power indicators was being made on dry basis [11].

Energy return ($\Delta E$) of different types of production was being determined by formula (1):

$$\Delta E = E_1 - E,$$

where $E_1$ is the energy value of the finished product unit, MJ/kg; $E$ – specific energy cost on production, MJ/kg.

The energy efficiency coefficient ($\eta$) was being calculated by the formula (2):

$$\eta = \frac{E_1}{E}$$

3. Results and discussion
In studies, the energy value of pulp after mechanical dehydration of grass mixture was 10.68 MJ/kg.

The energy value of wheat extrudate compared to native wheat increased from 13.08 to 14.17 MJ/kg; oats from 12.15 to 13.47 and barley from 12.81 to 13.84 MJ/kg (figure 1).

When replacing 10, 15 and 20 % of wheat by pulp, the energy value of the extrudate decreased from 14.17 to 13.96 MJ/kg (figure 1a). The mass fraction of protein, fiber and ash in the extrudate increased by 0.98, 2.00 and 1.83%, respectively, fat and nitrogen-free extractives decreased by 0.43 and 4.38 % compared to wheat extrudate.
Energy return with increasing pulp in the composition of the extrudate from 10 to 20% is reduced by 0.21 MJ/kg compared to the production of wheat extrudate. The energy efficiency ratio is increased by 0.81 (figure 2a).

Figure 1. Change in the energy value of the extrudate (MJ/kg) depending on the content of pulp in a mixture with grain: a – wheat, b – oats, C – barley.

Figure 2. Change in energy return (ΔE) and energy efficiency ratio (η) of production from the extrudate depending on the content of pulp in the mixture, MJ/kg with grain: a – wheat, b – oats, C – barley.
When replacing 10, 15 and 20 % oats with pulp, the energy value of the extrudate decreased by 0.12 MJ/kg (figure 1b). The mass fraction of fiber and ash in the extrudate increased by 2.56 and 0.58%, respectively, and protein, fat, and nitrogen-free extractives decreased by 0.34, 0.27, and 2.53 % compared to oat extrudate.

With an increase in the amount of pulp from 10 to 20 % in a mix with oats after extrusion, there was a decrease in energy return by 0.12 MJ/kg compared to the production of oat extrudate. The energy efficiency ratio was increased to 0.91 (figure 2b).

When replacing 10, 15 and 20 % barley by pulp, the energy value of the extrudate decreased by 0.12 MJ/kg (figure 1c). The mass portion of cellulose and ash in the extrudate increased by 1.48 and 0.27%, respectively, and protein, fat, and nitrogen-free extractives decreased by 0.21, 0.25, and 1.29 % compared with barley extrudate.

Energy return with an increase in pulp in the composition of the extrudate from 10 to 20% also decreased by 0.12 MJ / kg compared with the production of extrudate from barley. At the same time, the energy efficiency ratio increased by 0.92 (Figure 2c).

The regression equations have been obtained for a mathematical description of the change in energy return and energy efficiency ratio depending on the pulp content in the mixture (C, %) and on the crop used - wheat, oats or barley - expressed through the energy value of its extrudate (E₁i, MJ / kg).

The change in energy return (ΔE) is described by the following formula (3):

\[ \Delta E = b_1 + b_2 C + b_3 E_{1i}, \]  

(3)

where \( b_1 = -0.797 \); \( b_2 = -0.0075 \); \( b_3 = 0.9915 \).

The determination ratio \( R^2 = 0.77 \), statistically significant with a reliability of 95%.

The change in energy efficiency ratio (\( \eta \)) is described by the following formula (4):

\[ \eta = b_1 + b_2 C + b_3 E_{1i}, \]  

(4)

where \( b_1 = -1.0065 \); \( b_2 = 0.0509 \); \( b_3 = 1.0535 \).

The determination ratio \( R^2 = 0.98 \), statistically significant with a reliability of 95%.

A graphic representation of the regression equations is presented in figures 3 and 4.

**Figure 3.** Dependence of the change in energy return \( \Delta E \) on the pulp content in the mixture (C, %) and the energy value of the extrudate (\( E_{1i}, \text{MJ/kg} \)).

**Figure 4.** Dependence of the change in the energy efficiency ratio (\( \eta \)) on the pulp content in the mixture (C,%) and the energy value of the extrudate (\( E_{1i}, \text{MJ/kg} \)).
The equations and their graphical representation make it possible to predict changes in energy return and energy efficiency ratio depending on the pulp content in the mixture and the energy value of the feedstock.

4. Conclusion

Studies have shown that extruding wheat, oats and barley can increase their energy value by 8.33, 10.86 and 8.04% respectively. With the introduction before the extrusion of grain crops of pulp from grass mixture in the amount of 10, 15 and 20% by weight, the energy value of the extrudate decreases slightly and it is 0.12-0.21 MJ/kg.

The energy value reduction of the extrudate is followed by energy return decrease by 0.12-0.21 MJ/kg.

At the same time, the energy efficiency ratio is increased by 5.44-6.40 %, which is associated with a decrease in energy costs for grain grinding.

The upper-range value of energy returns and energy efficiency ratio corresponded to an extrudate based on a mixture of wheat and 20% of pulp.

Regression equations and their graphical representation obtained as a result of experimental studies will be useful for predicting changes in energy return and energy efficiency ratio depending on the content of pulp in the mixture and the energy value of the feedstock.

The use of pulp in the mixture before extrusion allows to obtain a finished product with a lower cost due to the decrease in the mass of grain in the extrudate.

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