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RESEARCH ARTICLE
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Development of an Extrusion Technology for Pressed Sugar Beet Pulp with Dry Feed Components

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ABSTRACT

A persistent challenge for Kazakhstan's compound feed industry is the disproportionately high reliance on grain-based inputs, which constitute approximately 60–80% of feed formulations. By contrast, in Western Europe this share typically does not exceed 12–15%, largely due to the broader incorporation of food-industry by-products. A major by-product of Kazakhstan's food industry is sugar beet pulp. Raw beet pulp has a moisture content of up to 93% and a shelf life of only three days. As a result, it is typically pressed and then dried using energy-intensive technologies, particularly drum dryers powered by natural gas. This study aims to develop an extrusion technology for combining pressed sugar beet pulp with feed components, enabling the replacement of imported dry beet pulp with domestically produced pressed pulp. The core concept of the research is the utilisation of pressed sugar beet pulp as a moisture-retaining agent during extrusion, using dry feed components as the sorbent. The cost of extruding pressed sugar beet pulp with dry feed components is three times lower than the cost of producing dry beet pulp using a natural gas-powered drum dryer. This study confirms that the extrusion process remains stable under the following conditions: inclusion of up to 10% pressed beet pulp with a moisture content of 65%–74%; an extrusion temperature of 80–165°C; and a screw rotation speed of 500 rpm. The practical significance of this research lies in reducing the production cost of compound feed.

Keywords: Rye; Peas; Sugar beet pulp; Compound feed; Extrusion.

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INTRODUCTION

During the production of granulated sugar, a pulp by-product is formed comprising 80–82% of the mass of processed sugar beet, with a dry matter content of 7.0% (Daisheva et al., 2025). The raw pulp contains (in terms of dry matter) about 45–47% cellulose, up to 50% pectin substances, 2% protein, 0.6–0.7% sugar, and about 1% mineral substances, as well as vitamins and organic acids. Raw pulp is used as animal feed at daily rates of 50–60kg per head for fattening bulls, 35kg for dairy cattle, 2.5–3.5kg for small cattle, 2.0–15.0kg for horses and 0.5–5.0kg for pigs (Jeong et al., 2022; Komarova et al., 2025). The raw pulp can be stored for only three days, and its sale is possible only within a 100-km radius of the sugar mill, as transportation over long distances is unprofitable (Keaokliang et al., 2018). In addition, raw pulp is not used in the production of compound feed because feed compounding equipment is designed primarily to work with dry ingredients. These problems have been solved by drying and granulating the pulp: granulated dry pulp can be stored for up to two years, transported over any distance and used in the production of compound feed.

In 2024, more than 1.3 million tons of sugar beet were harvested in Kazakhstan, the processing of which produced 0.84 to 1.04 million tons of pulp. This material creates opportunities for strengthening and developing the feed base of livestock and poultry farming in the agro-industrial complex (Jemai & Vorobiev, 2006; Khusnitdinova et al., 2023). Drying is an energy-intensive process that significantly impacts the production cost. In Kazakhstan, local production would compete with imported granulated dry pulp for 135–140KZT/kg (Dautkanov and Dautkanova 2022). To reduce energy costs, raw pulp is pressed before drying, which mechanically removes free moisture. Mechanically extracting one ton of water (for example, from clover with a moisture content of 75%) requires only 2kWh, whereas evaporation of a similar volume of water

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through drying requires 743kWh (Gregson & Lee 2004). Using mechanical de-watering, raw sugar beet pulp can be pressed to several target moisture levels: 86–90% (pressed pulp), 78–82% (pressed pulp), and 65–78% (deeply pressed pulp). Conventionally, dehydrated pulp is classified by dry matter (DM) content after pressing as follows: low pressing, 10–14% DM; medium pressing, 18–22% DM; and deep pressing, 22–35% DM (Tamova et al., 2021). In Russian sugar factories, pulp is typically pressed to 82–86% moisture using various press designs, including the PSZhN-68 (to approximately 88–90% moisture), the A2-PPV (to 79–82% moisture), and comparable units (Semenikhin et al., 2021).

In Kazakhstan, the Aksu Sugar Plant has implemented technology and installed a production line for pressed pulp with packaging in 800 kg roll bales, the shelf life of which exceeds 12 months (Leontowicz et al., 2001). The technology of packaging pressed pulp with a moisture content of 70%–80% in polymer sleeves or roll bales using special agro-stretch film is the most effective way to store feed, as it eliminates the need for energy-intensive drying and granulation processes. Pressed pulp in rolls or roll bales contains 0.16 feed units, has a density of 1 t/m³, a weight of 0.8–1.2 tons and can be stored for a year or more without loss of nutritional properties (Arehart & Banbury 1971; Ayas, 2024). In European sugar factories, sugar beet pulp is dehydrated to a moisture content of 65%–74% using presses from various manufacturers, including the PB32FS press from Babbini (Italy), which has a drive power of 560kW and a capacity of 140–160tons/hour (Ivashchuk et al., 2024). In Russia, FARSAL LLC produces the Stord BS-64S horizontal twin-screw press, which performs deep pressing of pulp to a moisture content of 74%–77% with a capacity of 9.7 tons per hour and an electric motor power of 37–56kW (Jokić et al., 2005).

The efficiency of pressing the pulp before drying is confirmed by the following indicators. Fuel consumption while drying pressed pulp with a moisture content of 86% is 69.6% of the mass of dried pulp, and with a moisture content of 82%, it is 50.8%. Using a deep pressing press reduces natural gas consumption by a factor of 2.1 to 2.4. For drying raw pulp, the main technology used is gas-powered drum dryers. For example, at the Borinsky sugar plant in Russia, the pulp is first pressed to a moisture content of 68–76% using a Babbini press and then dried in a drum dryer to a moisture content of 11–13%. The drying process utilises a heat carrier, a mixture of air and combustion products from natural gas, at a temperature of 110–140°C for 90–120 minutes, with a natural gas consumption of 170 m³ per ton of dried pulp (Zobova et al., 2021a). Chernikov and Kaplunov considered drying pulp with an initial moisture content of 80% in a drum dryer using air heated to 60–90°C by natural gas, calculating a gas consumption rate of 150–180 m³ per ton of dried pulp (Reshetova et al., 2018). However, these figures do not agree with a different study that showed pre-pressing pulp to a moisture content of 65%–70% reduces fuel consumption during drying to 30% of the dry pulp weight and, if pressing to a moisture content of 82–86%, to 50% (Zobova et al., 2021b).

Therefore, if after deep pressing of pulp to a moisture content of 68%–76% on Babbini presses, the consumption of natural gas during drying in a drum dryer is 170 m³ per ton of dried pulp, which corresponds to the consumption of equivalent fuel up to 30% of the mass of dry pulp, then, when drying pulp with a moisture content of 80% under the same conditions, the consumption of natural gas will increase to 283 m³, which is equivalent to the consumption of equivalent fuel up to 50% of the mass of dry pulp. Thus, on average, between 180 m³ and 283 m³ of natural gas is required for drying one ton of pressed pulp, depending on the initial moisture content of the raw material being dried. For granulating dried pulp with a moisture content of 12%–14%, various pellet presses are used; the most common models are B6-DGV/1 and more modern B6-DGV/1K, with a capacity of 18–25 tons/hour (depending on the size of the holes in the matrices) and a 279kW electric motor (Reshetova et al., 2018).

For the production of 1 ton of granulated sugar beet pulp at 12–14% moisture, the typical resource inputs are 3.5kW of electricity for pressing, 170m³ of natural gas for drying, and 11.16kW of electricity for granulation. In monetary terms, these correspond to approximately 118KZT for pressing, 6,698KZT for drying, and 376KZT for granulation, for a total of about 7,192KZT per ton. Consequently, drying accounts for the overwhelming share of production costs (≈93%), making it the most cost-intensive stage in manufacturing granulated dry pulp.

In the context of sustainable development of the agro-industrial complex of the Republic of Kazakhstan, there is an urgent need to improve the efficiency of animal feed production, including the rationalisation of raw material use and the introduction of energy-saving technologies. The feed industry of Kazakhstan is characterised by a high level of dependence on grain raw materials, the share of which in compound feed reaches 60%–80%. At the same time, in developed countries of Western Europe, this figure is only 12%–15% due to the wider use of alternative sources of nutrients, including by-products of the food industry (Bekhta et al., 2025). This imbalance suggests a significant potential for improving technological processes in Kazakhstan's compound feed production, as well as the possibility of reducing feed costs by utilising local raw materials, such as food industry waste. One of the most common and accessible by-products of sugar beet processing is pulp, the residue after sugar extraction, which has high nutritional value. However, despite its value as a feed component, sugar beet pulp has an extremely high moisture content (up to 93%) and a very limited shelf life (no more than three days), which significantly complicates its transportation, storage, and industrial use. Currently, to increase shelf life, the pulp is pressed and then dried, which requires significant energy costs, especially under traditional technologies, such as drum dryers operating on natural gas. Thus, the current practice of recycling the pulp as a dry product is associated with high costs, making its use in compound feed economically impractical (Alami et al., 2025). In response to the above challenges, this study develops an innovative, energy-saving, and economically sound technology for processing sugar beet pulp, which enables its use in compound feed without the need for expensive drying. In particular, the purpose of this study is to develop technology for extruding pressed sugar beet pulp mixed with dry components of compound feed, thereby eliminating the energy-intensive drying process and replacing imported dry pulp with a domestically produced pressed product. Extrusion is a thermomechanical process applied to raw materials, during which structural and chemical changes occur due to high pressure, friction, and temperature. Extrusion can yield finished feed with a high degree of digestibility, improved organoleptic properties, and a long shelf life. One of the key features of the proposed technology is the use of the moisture contained in the pressed pulp as a natural humectant of the extrusion mass, while the dry components of the compound feed, such as wheat bran, cake, meal and others, act as sorbents that help achieve the required consistency and structure of the extrudate. This synergy of components enables the avoidance of additional water or steam introduction during the extrusion process, significantly simplifying the technology and reducing its energy costs (Batievskaya & Yegorov, 2019; Zhakatayeva et al., 2020).

Based on the above, the objective of the study is multifaceted and includes the following aspects: Technological — development and validation of the process of extruding a mixture of pressed pulp and dry components, including the selection of optimal parameters (e.g. temperature, pressure, screw speed, and mass ratio of components) that ensure stable and efficient operation of the extrusion equipment. Economic — substantiation of the economic feasibility of introducing this technology to the Kazakh agro-industrial complex, including a comparison of the costs of traditional drying of pulp and its processing by extrusion. The calculations show that the costs of producing extruded feed using pressed pulp are a third of the costs of producing dry pulp in the traditional way (166KZT versus 527–558KZT for an equivalent amount of product). The secondary use of sugar beet pulp as a highly nutritious, environmentally friendly and affordable component of compound feed fulfils the agrarian and raw material usage interest. It can also significantly reduce the consumption of expensive grain crops, freeing up resources for other agricultural sectors. The biological aspect involves the study of the effect of extruded feed containing pressed pulp on the physiological and productive indicators of farm animals, including nutrient digestibility, weight gain, milk yield, feed consumption, and other key parameters. Based on experimental data, it has been proven that the use of such feed increases digestibility by 10%–30%, increases milk yield by 20%–30%, promotes average daily weight gain by 15%–30% and reduces feed consumption by 8%–12%.

Infrastructure — development of logistic and organisational solutions for storage and transportation of pressed pulp in the form of bales or rolls, which have a shelf life of up to 12 months. This extended shelf life means they are available not only near sugar factories but also in remote areas. Implementation of the set research objective will achieve several strategically important results:

- Increasing energy efficiency and sustainability of feed production;
- Reducing dependence on imported feed components;
- Expanding the range of raw materials;
- Strengthening the production base of livestock and poultry farming;
- Increasing the competitiveness of domestic products in the domestic and foreign markets.

Thus, the proposed research objective is focused not only on solving a specific technological problem but also on creating conditions for a comprehensive modernisation of the feed production sector in Kazakhstan. Its implementation will be a significant contribution to the development of "green" and resource-saving technologies that address the modern challenges of food security, economic efficiency, and environmental sustainability. The study is interdisciplinary and employs a systems approach, encompassing food production technology, agricultural engineering, animal husbandry, agricultural economics, and ecology. The purpose of this study is to develop a scientifically sound, resource-saving technology for extruding pressed sugar beet pulp with dry components of compound feed, aiming to enhance the efficiency, sustainability, and profitability of Kazakhstan's compound feed industry. The proposed technology is intended to become an innovative solution that promotes the integration of modern approaches to utilising by-products and forming new economic ties between the food and agricultural industries.

MATERIALS & METHODS

The object of the study is an energy-saving technology for extruding pressed sugar beet pulp with the addition of dry components of compound feed. The study materials included:

- raw sugar beet pulp obtained from the Koksu sugar plant located in Balpyk Bi village, Koksu district. Zhetysu, Republic of Kazakhstan. The Koksu sugar plant is a key sugar beet processing enterprise in the region. The raw materials used in the study were obtained directly from this plant.
- dry components of compound feed, including rye and peas (Fig. 1).

Fig. 1: Research materials: 1 - ground rye, 2 - peas, 3 - pressed pulp, 4 – extruded mixture – extrudate.

Samples of the analysed materials were selected and prepared in accordance with the requirements of GOST 13496.0-2016 (2016). Materials were weighed using a laboratory balance (VK-300) and electronic scales (TV-S-

32.2-A2). The moisture content of the components, mixtures, and extrudates was determined using the thermographic method with an EVLAS-2M moisture analyser. The moisture content of the pulp was adjusted in a drying cabinet. The moisture content of the feed raw materials was determined using thermogravimetric analysis. The sample was dried at a controlled temperature, and the mass loss was subsequently measured. The result is displayed as a percentage of the moisture content of the original mass of the raw materials. The sample was dried at a specific temperature (usually 105±2°C) determined using a built-in infrared or halogen heater. The process continues until a constant mass is reached (or at a specified drying time or rate). The instrument automatically records the dynamic mass loss as the moisture evaporates. The humidity was calculated using the formula:

$$W = \frac{m_{init} - \mathrm{m}_{final}}{\mathrm{m}_{init}} \times 100\,\% \qquad (1)$$

where m_{init} is the initial mass of the sample and m_{final} is the mass after drying.

To ensure the homogeneity of the composition and the stability of the physical and chemical characteristics of the compound feed, the raw materials were crushed and mixed using a laboratory crusher and mixer. Fine crushing is necessary to reduce the particle size of the components, promoting uniform moisture distribution and improving the heat and mass transfer during the extrusion process. Thorough mixing ensures the uniform distribution of the pressed cake and dry components, thereby increasing the repeatability and reliability of the experimental results. The extrusion process was carried out on a laboratory twin-screw extruder (SYSLG 32), which allows for the precise regulation of process parameters (temperature, screw rotation speed, and pressure) and ensures a high degree of mechanical and thermal processing. The use of a twin-screw design of the extrusion system ensures more intensive mixing and plasticisation of the material compared to single-screw models, which is critically important when working with components that differ in moisture and structure, such as pressed cake and dry grains. This achieves high homogeneity in the extrudate and accuracy in studying the influence of the composition on the technological and feed properties of the finished product (Fig. 2).

Fig. 2: The apparatus used for the study: 1 - drying oven; 2 - laboratory mixer; 3 - twin-screw extruder (SYSLG 32).

During the studies conducted on the laboratory extrusion unit, the following temperature parameters were set and maintained in the extruder zones:

- The first zone — 80°C: zone of preliminary heating and the beginning of raw material plasticisation;
- The second zone — 120°C: activation of heat and mass transfer processes and the beginning of component melting;
- The third zone — 140°C: intensification of shear deformations and completion of starch gelatinisation, decomposition of cellulose and protein structures;
- The fourth zone — 165°C: zone of intensive heat treatment and extrudate exit through the forming matrix.

The screw rotation speed was set at 500 rpm, ensuring optimal mechanical action and sufficient material density inside the extruder chamber. A matrix with a hole diameter of 5 mm was used to form the extrudate, which meets the requirements for the granulometric composition of animal feed.

Research Methodology

The methodology is based on the methods of system analysis and synthesis of technological processes, which enabled the comprehensive assessment of the possibilities of using pressed sugar beet pulp as a raw material component of compound feed.

System analysis was used to identify factors limiting the use of pressed pulp in feed production, including its high humidity, transport labour intensity and unstable physicochemical properties; formulate steps for processing the pulp into a more stable and convenient form for storage; and select the most rational solutions and build an algorithm for technological processing.

System synthesis enabled the development of an energy-saving technology that incorporates crushing, mixing, moisture adjustment and extrusion stages. This technology ensured a stable output of extrudate with a given moisture content and physicochemical characteristics suitable for use in feed production.

Particular attention was paid to the interaction of components, that is, grains, legumes and pulp, under extrusion processing conditions, which made it possible to consider their moisture, thermal conductivity and behaviour during thermomechanical action (Faliarizao et al., 2024; Valsalan et al., 2025). In addition, the ratio of absolutely dry matter (ADM) in dry and pressed pulp was calculated, which made it possible to accurately adjust the compound feed recipe to account for the added moisture. The energy intensity of traditional and developed technologies was also estimated, which confirmed the energy efficiency of the proposed approach.

Research Hypothesis

Compound feed recipes for animals and poultry typically involve 1%–10% dry pulp and 60%–85% other dry components (i.e. grains, legumes, and bran). However, in Kazakhstan, sugar beet pulp is not dried but instead pressed to a moisture content of 68–74% and packed into bales, which have a shelf life of up to 12 months. At the same time, imported granulated dry beet pulp is offered on the market, but its high price makes its use in compound feed economically inexpedient. There is thus a clear opportunity to replace imported dry beet pulp with domestically produced pressed beet pulp in compound feed recipes, which will reduce production costs, eliminate energy-intensive drying, and utilise locally available and produced raw materials.

RESULTS AND DISCUSSION

The proposed feed production system involves extruding a mixture of pressed pulp and specific dry components of compound feed and then adding the resulting extrudate to the compound feed at the final stage of production.

This approach offers several important advantages for the feed industry. First, it significantly reduces energy costs by eliminating the need for the drying stage of beet pulp processing. Second, extrusion enhances the digestibility of feed components, thereby improving the overall nutritional value of compound feed. Finally, it promotes the rational use of locally available feed resources, decreasing dependence on imported dried pulp and contributing to greater self-sufficiency in feed production.

The production flow is diagrammed in Fig. 3 (Yazykbayev, 2022).

The energy-saving method was developed based on prior research into the use of dry pulp in compound feed. In particular, the share of dry pulp in compound feed formulations ranges from 1% to 9% (Anwar Alsaliheen et al., 2023; Yeletska & Berestova, 2024). This research focused on the formulation of compound feed concentrate KK-63 intended for young cattle (6–12 months), containing 77% rye, 5% peas, 7% sunflower cake, 6% dry pulp, 2% beet molasses, 1% premix P63-1, 1% precipitate and 1% table salt. Rye and peas were selected as sorbent components based on their compositional constraints and the potential of thermal processing to mitigate them. Rye contains protease inhibitors (e.g., trypsin and chymotrypsin inhibitors), toxic resorcinol derivatives, and highly viscous non-starch polysaccharides (pentosans, pectins, and β-glucans), all of which limit its inclusion rate in feeds. Similarly, peas contain anti-nutritional factors such as tannins, phytates, and lectins that depress nutrient digestibility. These compounds can be effectively reduced or inactivated by preliminary heat treatment—particularly extrusion—thereby improving the technological functionality of rye and peas as sorbents and enhancing their nutritional value in compound feeds (Dawod et al., 2020; Iegorov et al., 2023; Alikhani et al., 2024).

As part of the experimental work to develop a compound feed recipe using pressed pulp and extrusion processing, the possibility of using all the components as moisture carriers or sorbents was carefully analysed. Based on the technical and technological analysis and taking into account the physical and chemical properties of each ingredient, a decision was made to limit the extrusion processing to a few components for the following reasons: Meals and cakes (for example, sunflower) have already undergone technological heat treatment during their production process. Additional exposure to high temperatures during the extrusion process is not only impractical but can also lead to the degradation of the structural and nutritional properties of proteins, as well as increased oxidation of fats, which will decrease the nutritional value of the compound feed.

Premixes contain temperature-sensitive biologically active substances, including vitamins, micro- and macro-elements, and enzyme complexes. Exposing these substances to temperatures above 70–80° C leads to significant losses of biological activity. Because extrusion occurs at temperatures up to 165°C, the premixes cannot be included at this stage in order to protect the nutritional value of the final product. Precipitate and table salt are mineral additives that do not contain organic compounds that require thermal modification. They do not require heat treatment, and high temperatures can lead to undesirable physical changes (e.g. sintering), complicating their uniform distribution in the compound feed. Considering the above reasons, the raw beet pulp obtained from the Koksu sugar plant was used as the humidifier and binder in the extrusion mixture. The initial moisture content of the pulp was about 78%, making it an effective component for regulating the moisture content of the mixture. To achieve a technologically optimal level of moisture content, the pulp was pre-dried to 70% moisture, which corresponds to deeply pressed pulp. To determine the equivalence in terms of the content of ADM, 0.6kg of dry pulp (with a moisture content of 14%, according to GOST 34874-2022 (2023) was replaced with pressed pulp with a moisture content of 70%. The calculation showed that 0.6kg of dry pulp contains 0.52kg of ADS. To obtain a similar ADS content when using pressed pulp, it is necessary to take 1.73kg, which provides an equivalent nutrient load.

The final composition of the mixture was 7.7kg of rye, 0.5kg of peas, and 1.73kg of pressed cake. The total mass of the mixture was 9.93kg, and it had a final moisture content of 22.9%. The mixture was processed in a twin-screw extruder with step-by-step increases in temperature as follows: 1st zone, 80°C; 2nd zone, 120°C; 3rd zone 140°C; and 4th zone, 165°C. These zones were selected to ensure sufficient heat treatment for protein denaturation, starch gelatinisation and inactivation of anti-nutritional factors while maintaining the structure of the extrudate. The mass of the obtained extrudate is 8.8kg. The moisture content of the finished product is 12.9%, which meets the requirements for storage and stability of compound feed.

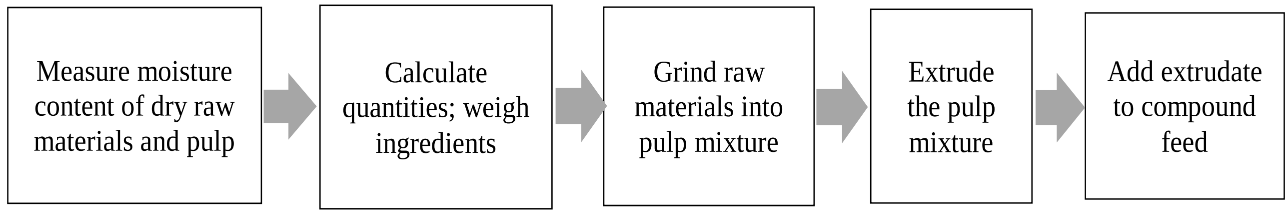

Fig. 3: Production flow of energy-saving method for producing compound feed based on pressed sugar beet pulp.

Final Composition of Compound Feed and Results of Experimental Replacement of Dry Pulp with Pressed Pulp

To further develop energy-saving technology for the production of compound feed, partial or complete replacement of imported dry pulp with domestic pressed sugar beet pulp was implemented. As a result of optimising the recipe for compound feed KK-63, after replacing 6% of the dry pulp with an equivalent amount of pressed pulp with a moisture content of approximately 70% and subsequent extrusion of the resulting mixture, a new composition of the final product was formed. The final compound feed formulation consisted of an extrudate—prepared as a mixture of rye, peas, and pressed beet pulp—at 88% (8.8kg per 10kg batch), sunflower cake at 7% (0.7kg), beet molasses at 2% (0.2kg), premix P63-1 at 1% (0.1kg), a phosphorus-containing additive ("precipitate") at 1% (0.1kg), and table salt at 1% (0.1kg).

The proposed compound feed recipe enables not only the effective use of domestically produced raw materials but also significantly reduces production costs by eliminating the energy-intensive process of drying the pulp. Additional experimental substitutions in the compound feed recipe were performed by varying the content of pressed pulp at levels of 2% and 9% of the total feed weight (10kg). The purpose of these experiments was to study the effect of the pressed pulp content on the moisture content of the mixture and the final extruded product, as well as to determine the stability limits of the technological process, that is, the points at which it does not require additional moisture removal. The results of these experiments are given in Table 1.

With an increase in the proportion of pressed pulp from 2% to 9%, the relative humidity of the original mixture increases from 16.6% to 26.9%, corresponding to the permissible range for a stable extrusion process. The humidity of the finished extrudate ranges from 9.04% to 15.5%, which is within the normal range, ensuring good preservation of the product during storage. These results confirm the technological feasibility of using pressed pulp in compound feed without preliminary drying. The experiments also show that extrusion of mixtures containing up to 9% wet pulp occurs in the normal mode and does not require modification of the equipment, provided that the optimal process parameters are observed (i.e. extrusion temperature, screw speed, and processing time). This makes the proposed scheme promising for implementation in the compound feed industry to improve the economic efficiency and sustainability of production. The efficiency assessment of the proposed extrusion technology is based on a comparison of energy and financial costs with the traditional drying method widely used in the feed industry. The primary criterion for comparison is the energy costs associated with processing the pulp, a key component of the feed. As already mentioned, raw beet pulp is subjected to deep pressing before subsequent processing, that is, drying or packing into bales or rolls. As a result, the moisture content of the raw material is reduced to 65%–76%. This pressing stage is common and mandatory for both the traditional drying technology and the new extrusion technology, allowing for a direct comparison without considering the costs of preliminary dehydration (Sharikov et al., 2018; Novikova, 2024).

In traditional technology, excess moisture in the pulp is considered ballast, which must be removed by thermal drying. About 170–180 m^3 of natural gas is consumed to evaporate water from 1 ton of pressed pulp. The cost of natural gas in Kazakhstan for legal entities is 51.7KZT/m^3 (including VAT). Accordingly, the cost of drying 1 ton of pulp is 8,789–9,306KZT. To produce 1 ton of complete compound feed, about 6% (60kg) of dry pulp is required. Therefore, the cost of drying only this proportion of pulp is 527–558KZT per ton of compound feed. In the proposed extrusion technology, 6% of dry pulp is replaced by 173 kg of pressed pulp with a moisture content of 65%–76%. This approach eliminates thermal drying, resulting in significant energy savings.

In this formulation, the moisture present in pressed beet pulp performs a critical functional role: it acts as a natural humectant for the dry components, which is particularly advantageous during extrusion. By contrast, using dried pulp necessitates the addition of water or steam to achieve the required plasticisation, thereby increasing energy demand (Stepanov et al., 2019; Sharikov et al., 2022). To estimate extrusion costs, 52kg of absolute dry matter (ADM)—the ADM contained in 173kg of pressed pulp—was used as the basis. The measured energy consumption for extrusion was 4.42kWh; at an electricity tariff of 37.53KZT per kWh, the total extrusion cost for 52kg ADM was 166KZT. When benchmarked against conventional drying, the cost for producing 60kg of dry pulp via traditional methods was 527–558KZT, whereas extrusion of the equivalent ADM in pressed pulp cost 166KZT. Thus, processing expenses were reduced by more than threefold, underscoring the economic efficiency of the proposed technology.

In addition to saving energy, extrusion technology has several significant technological and quality advantages:

- Destruction of anti-alimentary substances, such as proteinase inhibitors in rye and peas, which improves the bioavailability of components.
- Increased digestibility of nutrients due to thermomechanical treatment: the structure of the feed becomes more accessible to the digestive enzymes of animals.
- Improvement of the physical and technological properties of the compound feed. The resulting extruded mass is characterised by a granular form, uniform composition and reduced dust formation.

Table 1: Indicators of mixtures with replacement of 2% and 9% of dry pulp in compound feed weighing 10kg with raw pressed pulp

Humidity and weight of rye, peas, kg (%)	Humidity and weight of pressed pulp to replace dry pulp (2% and 9%), kg (%)	Humidity and mass of the mixture, kg (%)	Moisture and mass of extrudate, kg (%)
8.6 (13)	0.57 (70)	9.17 (16.6)	8.41 (9.04)
7.9 (13)	2.57 (70)	10.49 (26.9)	9.08 (15.5)

Values in parentheses are percentages.

To assess the efficiency of the developed technology for extruding pressed sugar beet pulp as part of compound feed, a comparative analysis was conducted of known technologies for extruding food and feed products with wet plant additives. One example is the technology for extruding mixtures of wheat with carrot pomace, used in the production of ready-to-eat food products (Al-Khayri et al., 2021; Balji et al., 2024; Medvedev & Safin, 2024). The experimental matrix comprised wheat grain (11.7% moisture) blended with carrot pomace (84% moisture) at inclusion rates of 5%, 10%, 20%, 25% and 30%. Incorporating 5% pomace raised the mixture moisture to 15.4%, while a 10% addition produced a moisture level that exceeded the acceptable range for the standard extrusion settings. Higher pomace additions yielded mixture moistures of 26.5% (20%), 28.9% (25%), and 34.5% (30%). For formulations with moisture contents above ~20%, process adaptations were necessary; specifically, the extruder was fitted with a steam-extraction (venting) system on the working barrel to maintain stable operation (Saraswati Samodra et al., 2024; Karyadi et al., 2025). Mixtures containing up to 10% wet additives were extruded successfully without requiring any modifications to the extruder design. However, when the proportion of wet additives increased to 20–25%, stable extrusion necessitated steam removal from the barrel to prevent process disruption. Under these conditions, the resulting extrudates had a moisture content of 7.5–18.4%. Comparable results have been reported in studies on extrusion of barley mixtures supplemented with root vegetables such as beetroot and table carrots (Kozar et al., 2020; Goderska et al., 2022). In these cases, mixtures containing 2.5–22.5% beetroot and carrot (moisture content up to 88%) were extruded at temperatures ranging from 120 to 170°C. The findings indicated that inclusion of vegetable additives up to 10% had no adverse effect on the extrusion process, while levels of 15% or more led to reduced process stability and difficulties in extrudate formation. Similar technologies have also been explored for feeds incorporating green mass from forage crops (Rojas et al., 2019; Vandenbossche et al., 2019). For example, a piglet diet consisting of 20% green alfalfa mass, 21% wheat, 36% barley, 13% soybean meal, 2% fish meal, 2% vegetable oil, 3% feed yeast, and 2% mineral supplements was successfully extruded. The wheat–barley–alfalfa mixture, with an initial moisture of 65–70%, was processed at 138–142°C, producing extrudates with final temperatures of 87–95°C, 15.2% moisture, and uniform composition. It was noted that the proportion of green mass should not exceed 30%, as higher inclusion rates lead to excessive moisture, reducing the shelf life of the feed (Lankhorst et al., 2007; Iztayev et al., 2024). The present study shows that extrusion of pressed beet pulp mixtures demonstrates results consistent with these previously reported technologies. In the pulp-based experiments, mixture moisture ranged from 16.6% to 22.9%, compared with 15.4–34.5% in other vegetable or green-mass formulations. The resulting extrudates had final moisture contents of 9.0–15.5%, which aligns closely with the 7.5–18.4% range reported in related studies. Temperature conditions during pulp extrusion (80–165°C) also overlapped with those in other experiments (120–170°C). Importantly, the inclusion of 2–9% pressed pulp did not necessitate any extruder design modifications, as the mixture moisture remained within acceptable limits. The extrudates obtained were of satisfactory quality and comparable to those derived from grain–vegetable or grain–green mass mixtures. The functional role of pressed pulp moisture is central to this process. Acting as a natural humectant, it reduces the need for additional water or steam input, thereby lowering the energy costs associated with extrusion. A comparative analysis highlights that the developed extrusion technology for pressed pulp not only matches global standards for processing wet plant-based additives but also demonstrates significant energy efficiency. By simultaneously improving feed quality, lowering costs, and eliminating dependence on energy-intensive drying, this technology represents a promising alternative to traditional methods. Its combination of economic and technological benefits positions it as a viable candidate for large-scale industrial adoption in compound feed production.

Conclusion

An energy-saving technology for producing compound feed based on pressed sugar beet pulp has been developed, enabling the replacement of imported dry pulp with domestic raw materials in Kazakhstan. The use of pressed pulp in bales or rolls with a shelf life of up to 12 months makes the technology accessible and effective for widespread use in livestock and poultry farming. A key advantage of the technology is that it does not require water or steam during extrusion due to the use of pressed pulp as a natural humectant. The pressed pulp provides water for the dry components of the compound feed, which are used as sorbents. This significantly simplifies the process, reduces the cost of additional resources and improves the economic performance of production.

Technological compatibility: the extrusion of mixtures with the addition of up to 10% pressed pulp (humidity 70%) occurs in the normal mode without complications. However, when up to 30% pressed pulp is added, steam extraction technology is required, requiring modification of the extruder design.

Reduced feed cost: replacing imported dry pulp with pressed pulp reduces dependence on external supplies and increases the availability of raw materials.

Reduced energy costs: producing 6% dry pulp in the feed from the pressed pulp (humidity 65%–70%) with traditional drying costs of 527–558KZT and extruding an equivalent amount of pressed pulp with dry components costs only 166KZT, which is three times cheaper.

Increased feed efficiency: extruded feed improves the physiological and productive indicators of animals, increasing feed digestibility by 10%–30%, increasing milk yield by 20%–30%, increasing average daily weight gain by 15%–30%, decreasing feed consumption by 8%–12%, which reduces feeding costs, and reducing consumption of grain components by up to 30%, making the compound feed more economical. The results are of practical interest to the sugar industry, as they provide a method for efficient processing and utilisation of pulp in the compound feed industry, thereby reducing the cost of raw materials and energy. They are also of interest to livestock and poultry farms, as they can increase feeding productivity and improve production profitability. Thus, the proposed technology of extruding compound feed with pressed pulp has high economic, technological and biological efficiency. It enables a significant reduction in costs while also improving the quality of feed and animal productivity indicators, making it a promising option for Kazakhstan's agro-industrial complex and other countries.

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