Available online at www.ijournalse.org

Emerging Science Journal

(ISSN: 2610-9182)

Vol. 9, No. 6, December, 2025

Extrusion Technology for Complex Processing of Brewery Waste Into Feed Products for Livestock and Poultry

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Abstract

An energy-efficient extrusion technology for the complex processing of wet brewing waste into feed products for animals and poultry is proposed and evaluated. The study aims to replace traditional energy-intensive drying methods – typically involving natural gas, steam, or boiler exhaust gases – with a more sustainable extrusion process. The approach allows direct utilization of wet brewing by-products, such as brewers' grains and brewers' yeast, without preliminary drying, thereby reducing energy consumption by up to 50%. The technological development was based on systems analysis and synthesis of extrusion processes, combining wet brewing waste with dry feed components. The research identified optimal parameters for extrusion: a feed mixture to compound feed component ratio of 1:1.85–2; initial moisture content of 28–30%; extrusion temperature of 140–150 °C; and barrel pressure of 4–8 MPa. The final product was a partially dehydrated mass with a moisture content of 60–65%, suitable for use as a feed additive or complete compound feed. The results demonstrate improved product quality and extended shelf life due to thermal and mechanical treatment during extrusion. The novelty of the approach lies in bypassing the conventional drying step, offering a cost-effective and environmentally friendly way to increase the value of brewing industry waste.

Keywords:
Brewing Waste;
Feed Ingredients;
Extrusion; Moisture;
Feed Additives; Feed.

Article History:

Received:	10	July	2025
Revised:	19	September	2025
Accepted:	11	October	2025
Published:	01	December	2025

1- Introduction

In 2024, 603,546 million litres of beer were produced in Kazakhstan. By-products of this beer production were thousands of tonnes of organic wastes suitable for animal feed, specifically, wet brewers' grain (193.5 kt), hop residues (0.181 kt), protein sludge (1.81 kt), excess liquid brewers' yeast (7.0 kt), grain waste (2.07 kt), malted sprouts (3.4 kt), and grain combinations (1.51 kt) [1, 2]. In addition, brewing generates other types of residues. Waste dust from grain polishing is used to feed waterfowl in reservoirs. Mineral waste in the form of spent kieselguhr is used as mineral feed for birds because it contains abundant silicon [3].

Organic waste can be classified according to the generated volume and moisture content. The two main brewing waste components by volume are wet brewers' grain and brewers' yeast. Brewing waste components can also be categorized as wet or dry. Wet waste includes wet brewers' grain, hop residues, protein sludge, brewers' yeast, and grain raft. The shelf life of this type of waste is up to three days because of its high humidity; thus, it should be processed quickly. Dry waste includes grain waste and malted sprouts. This type of waste can be sold to consumers without processing. However, malted sprouts contain the alkaloid hordenine, which gives them a bitter taste. Hop residues and protein sludge also have a bitter taste. Therefore, when using these by-products to feed animals, they should be mixed with wet brewers'

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DOI: http://dx.doi.org/10.28991/ESJ-2025-09-06-021

grain or other roughage [4]. Wet brewers' grain is a valuable feed ingredient containing approximately 75%–80% water (after draining free moisture in a preliminary storage bin), 3.9% protein, 1.3% fat, 3.2% fibre, 8.0% BEV and 0.6% ash, as well as vitamins, macro- and microelements. Wet brewers' grain is most often used as feed for dairy cows (10–20 kg per head per day) and pigs (up to 5 kg per head per day) [2, 5].

To increase their nutritional value, wet brewers' grains are sometimes fermented, with Lesnov's starter, for example [6]. We conducted research and obtained positive results when testing fermented wet brewers' grains with Lesnov's starter on dairy cows [7-10]. Table 1 presents the results of treating wheat bran and brewers' grains with a mycelium-based preparation (Lesnov's starter).

Table 1. Results of treatment of wheat bran and brewers' grains with a mycelium-based preparation

Enzyme name	Name of raw material	% of enzyme input	Before processing		After processing	
			Protein, %	Fibre, %	Protein, %	Fibre, %
Sourdough Lesnova	Wheat bran	0.0003–0.0005	14.5	13.6	17.02	5.98
	Brewers' grains		20.06	14.4	24.7	5.1

It follows from the results in Table 1 that after processing, the protein content of wheat bran and brewers' grains with an enzyme increases and their fibre content decreases, which improves their nutritional value and quality. However, after fermentation, the product has a moisture content of 65% and therefore requires rapid feeding to animals or drying to a moisture content of 10–12%.

Wet brewers' grains have a short shelf life (no more than three days) because of their high moisture content, and therefore, their transportation to consumers is economically feasible within a radius of 100 km. In the republic, most breweries are located in regional centers (cities), and therefore, it is not always possible to use wet brewers' grains fully. When wet brewers' grains enter the environment, their decomposition releases toxic decay products (ammonia, skatole, indole, mycotoxins, etc.) that increase the load on the environment. The degree of environmental hazard of grains increases from class V to IV within a month [11]. To address this problem, it is recommended that dry wet brewers' grains be dried to a moisture content of 10–12%, which increases the shelf life to 3–6 months (up to 9 months for granulated grains). However, to date, brewers' grains have not been dried at the republic's breweries because of the significant financial costs involved.

Dry brewers' grains contain no more than 12% moisture, no less than 18% protein (up to 27.1%); 8.2% crude fat, 16.3% crude fibre, 3.9% crude ash, macro and microelements, carotene, and vitamins E, B1, B2, B4, and B5. It is a valuable raw material for the production of compound feed and can be fed to animals, poultry, rabbits, and fish, positively affecting their productivity [12, 13]. Many methods have been proposed for drying food and feed products, including conductive (contact), thermo-radiative (infrared), microwave, sublimation, acoustic, convective (air), and other methods [14, 15]. Most published sources contain information about drying with vibrating, aerodynamic, drum, and other types of dryers using conductive and convective drying methods [16-19]. The difficulty of drying brewers' grain is that the content of bound moisture in fresh brewers' grain is higher (60%) than the free moisture content (40%). Therefore, the efficiency of drying equipment is assessed primarily by its ability to evaporate bound water intensively.

Brewers' grain drying in vibration dryers occurs as a result of the particles being blown with a drying agent (heated air, steam), which comes from an external blower through the lower inlet pipes of the dryer base, passes through holes in the perforated sheet, and penetrates the layer of material moving under the influence of vibration. The disadvantages of vibration dryers include the use of a convective drying method, high energy costs, and the need to use drying agents such as heated air, superheated steam, and other heat carriers. When drying in an aerodynamic dryer, the particles of brewers' grain are also blown with a drying agent, which is heated by natural gas. Additional disadvantages of aerodynamic dryers include the inability to regulate the temperature and air flow speed and the need to use an energy-consuming drying agent. However, at breweries, drum dryers are most often used. In these, the brewers' grains enter the drum, are thrown around in it during the rotation of the drum, and are treated with a drying agent (steam, hot air, exhaust flue gases, etc.). In addition to the disadvantages mentioned above, the disadvantages of drum dryers include their large overall dimensions.

When the moisture content of raw materials is higher than 65%, it is unprofitable to remove water by evaporation, and therefore, equipment for preliminary dehydration of raw materials is used, such as centrifuges, squeezing presses, separators, and decanters. Removing water mechanically requires energy consumption that is almost two orders of magnitude less than evaporative moisture removal [20]. When using centrifuges, wet brewers' grain is dehydrated to a moisture content of 80–82%, which requires additional dehydration, reducing the efficiency of the process [21].

Therefore, for dehydration of wet brewers' grain before drying, it is recommended to use belt filter presses or screw separators, which remove moisture in the product to a moisture content of 60–65% [22, 23]. However, the disadvantage of mechanical dehydration of brewers' grain is the formation of a filtrate containing a significant amount (up to 15%) of soluble nutrients – sugars, amino acids, etc. – because of which the nutritional properties of brewers' grain are diminished. This creates a problem of disposal of the filtrate itself, which is mainly discharged into sewers [24].

Therefore, the aims of the research were to use a completely new method for removing free and bound moisture from wet brewing waste based on the extrusion method and to develop an extrusion technology for the complex processing of brewing waste into feed products, eliminating the disadvantages of existing drying methods.

2- Material and Methods

A structural diagram of the complex processing of brewing waste into feed products is presented in Figure 1.

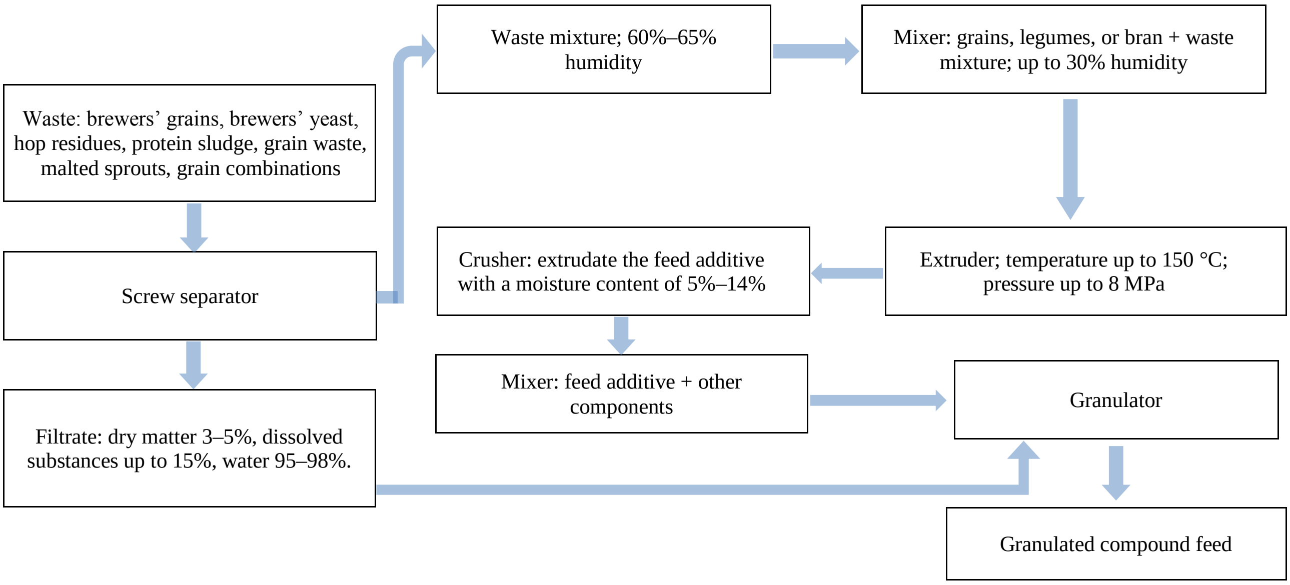

Figure 1. Structural diagram of the proposed complex processing of brewing waste into feed products

This study aimed to develop energy-saving technology for the complex processing of brewing waste into feed products and assess the effectiveness of the proposed technology. Wet brewing waste was obtained from Carlsberg Kazakhstan LLP and First Brewery LLP. Figure 2 shows the types of waste used, grain components of compound feed, extrudate, and granulated compound feed.

(a) (b) (c) (d) (e)

Figure 2. (a) Wet brewers' grain; (b) wet brewers' yeast; (c) grain component of compound feed; (d) dry extrudate (feed additive); (e) granulated compound feed

Sample selection and preparation were conducted according to GOST 13496.0. Materials were weighed on laboratory scales (VK-300) and electronic scales (TV-S-32.2-A2). The moisture content was determined by the thermographic method using an EVLAS-2M moisture analyser. Drying, crushing, mixing, extrusion, and granulation of raw materials and finished products were performed using a drying cabinet, crusher, mixer, extruder (PE 170), and granulator (SYS30-IV), respectively (Figure 3).

(a) (b) (c) (d) (e)

Figure 3. (a) Drying cabinet; (b) crusher; (c) mixer; (d) extruder; (e) granulator

The research methods comprised systems analysis and synthesis of technological processes, in particular, the extrusion of mixtures from wet brewing waste and the incorporation of dry ingredients into compound feed [25]. Systems analysis was used to identify the causes of problems hindering the use of wet brewing waste in the production of compound feed, set goals, develop solutions, and formulate a general scheme for solving problems. As a result, new technology for the complex processing of brewing waste into additives for compound feed was developed. The ratios of absolutely dry substances (ADS) in the brewing waste and compound feed, as well as the energy requirements of the proposed technology, were determined.

Dry brewers' grain is added in proportions of 6%–30% for cattle feed and 4%–8% for poultry [26–28]. Other dry components (e.g., grains, legumes, and bran) are present in amounts up to 50%–65%. However, in Kazakhstan, breweries do not dry wet brewers' grain but rather sell it raw at 10–13 tenge/kg. Thus, large product losses occur. Imported dry brewers' grain is offered on the feed market at 92–98 tenge/kg, making it an expensive feed component. Therefore, the challenge is to replace dry brewers' grain with wet brewers' grain without pre-drying to manufacture feed.

3- Results and Discussion

As the results of many studies have shown, extrusion of plant components of compound feed increases their nutritional value, digestibility, and taste and also improves storage conditions. The extrusion process breaks down complex carbohydrates (starch) into simpler ones, which facilitates their absorption; helps to increase the digestibility of protein and the availability of amino acids; gives the feed a pleasant smell and taste, which increases its palatability to animals; and destroys pathogenic microorganisms and toxins with high temperature and pressure, making the feed virtually sterile [29]. Therefore, there are no restrictions or potential risks when using extruded compound feed. Various parameters of the extruded product have been examined in many studies. The main factor examined in this study was the moisture content of the extruded product. In one previous study, the process for drying crushed plant material in a drum dryer was studied, and a graph was developed to show the dependence of the moisture content of the plant material and the air temperature inside the dryer on the drying time (Figure 4).

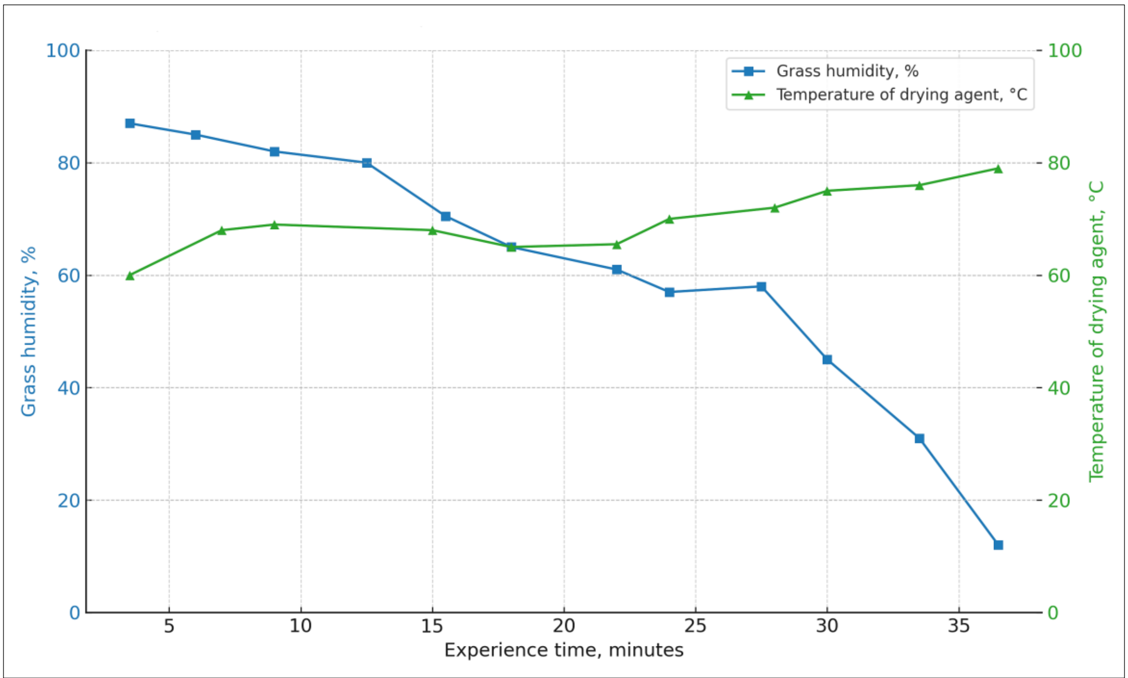

Figure 4. Graph of changes in moisture content in plant materials and temperature in the drying chamber of a drum dryer

According to the graph, after 27 minutes of drying, the rate of moisture release increases because of the end of the process of evaporation of free moisture, the loss of viability of the cells of plant materials, and the beginning of the process of evaporation of intracellular bound moisture [30].

Another study examined the issues involved in changing the moisture content of high-moisture materials during drying and presented a graph of the dependence of the moisture content of brewers' grains on the drying time at a drying agent temperature of 60 °C (Figure 5) [31].

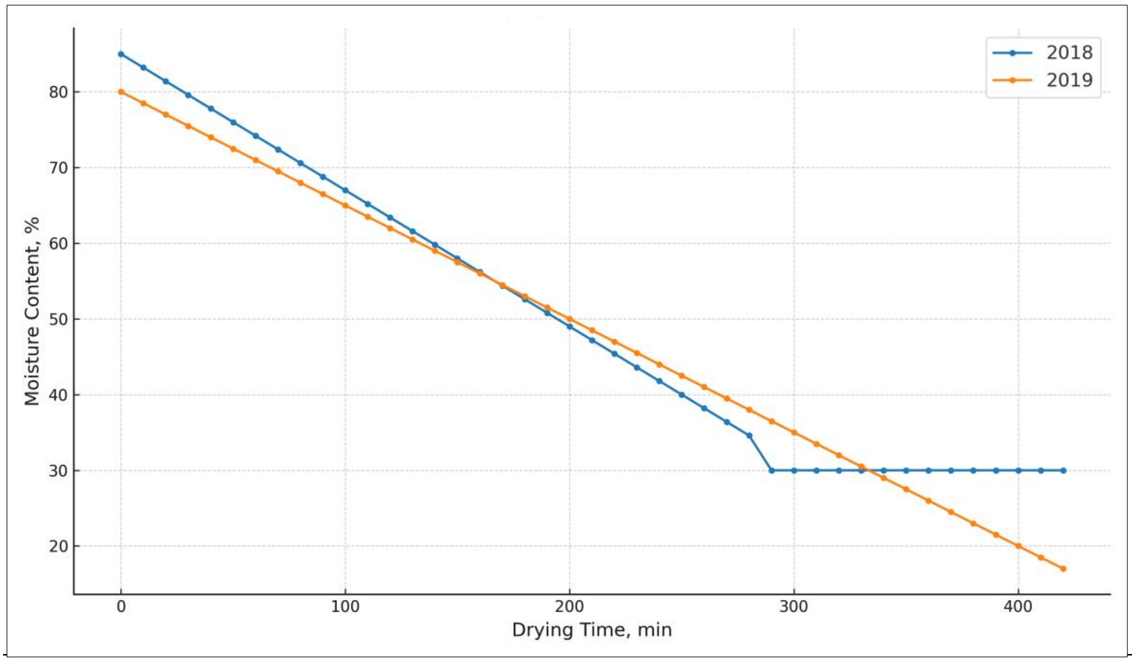

Figure 5. Dependence of the moisture content of brewers' grains on the drying time at a drying agent temperature of 60 °C

According to this graph, the removal of free moisture corresponds to two sections on the curve. The drying process in the second period proceeds similarly to the drying of materials with low humidity, when the drying rate is determined by the rate of internal diffusion of moisture from the depth of the dried material to its surface.

As these graphs show, during convective drying in, for example, a drum dryer, the drying time is extended for a certain amount of time, with free moisture evaporating first, and then bound moisture. A different picture is observed of the evaporation of free and bound moisture during the extrusion of plant products [32]. While the product is in the extruder barrel, the water in the product, under such thermal conditions (the temperature in the extruder can vary from 110 to 200 °C) and under very high pressure, exists only in a liquid state. After the product leaves the die holes, as a result of sharp drops in the temperature and pressure (between high-pressure zones from 6 to 25 MPa and atmospheric pressure), instantaneous (1.2×10^{-4} sec) evaporation of moisture occurs.

In this case, the energy accumulated by the product is released at a speed approximately equal to the explosion speed; water from the state of superheated liquid instantly turns into steam, releasing a significant amount of energy; and the product loses up to 50% of its moisture, i.e., the drying process occurs instantaneously. In this case, as a result of the 'explosion', the product acquires a porous structure, and deep transformations of its structure occur in it: rupture of cell walls, destruction, and hydrolysis. The following theoretical formula and value are proposed for the rate of water evaporation from the product during extrusion: $m = h \times A\ (C1 - C2) = 6.726 \times 10^{-5}$ kg/sec; where m is the rate of water evaporation; h is the coefficient of convective mass transfer, m / sec; A is the surface area, m^2; C1 is the mass concentration of moisture on the surface, kg/m^3; and C2 is the mass concentration of moisture in the surrounding area, kg/m^3 [33]. The drying rates of plant materials in a drum dryer and during extrusion are not comparable because, during convective drying, the process is carried out in stages. Free moisture evaporates first, followed by bound moisture, and during extrusion, the evaporation of free and partially bound moisture occurs almost instantly. It should be noted that the extrusion process takes less than 30 s, and during this time, the raw materials have time to go through several processing stages: heat, sterilization and disinfection, grinding and mixing, partial (up to 50%) dehydration, stabilization, texturing, expansion, and profiling [34].

Previously, we developed a method for the comprehensive processing of brewing waste into granulated feed [35]. This method involves mixing waste with a moisture content of 30–92% in a ratio based on the formation standards and then separating the resulting mixture by mechanical dehydration into a solid fraction 'cake' with a moisture content of 60–65% and a liquid fraction 'fugate' with a dry matter content of 3–5% (humidity 95–97%). The liquid fraction 'fugate' is then thickened by, for example, evaporation to a dry matter content of 35–40% (humidity 60–65%), and waste with a moisture content of 6-12% is added to the 'cake' in a ratio based on the formation standards. The resulting mixture is crushed to a particle size of 100–500 μm, dried to a moisture content of 10–12%, and then granulated using thickened 'fugate' with a dry matter content of 35–40% as a binder. This processing method is energy-intensive, and therefore, it has been improved in subsequent studies, taking into account the results of the theoretical and practical work mentioned above on drying plant products.

A structural diagram of the complex processing of brewing waste into feed products (Figure 1) presents a new extrusion dehydration method. According to this new method, brewing waste is mixed in a ratio based on the formation standards or mixtures are prepared with individual types of waste in combination with brewers' grains according to recipes developed.

The following are prerequisites for the development of such a waste disposal method. Brewers' grains and brewers' yeast are included in animal and poultry feed to increase the nutritional value of the diet and reduce feeding costs. Hop grain is a source of protein and other nutrients, but because of its bitter taste, it is fed to animals, poultry, and other animals in combination with other feeds, including brewers' grain. Protein sludge has high nutritional value, but because of its bitterness, it is used as feed in a mixture with brewers' grain. Grain waste is similar in composition to barley, and grain alloy contains very small barley grains; therefore, they can be grain components of compound feed. Malt sprouts are highly productive feed, but because of their bitter taste, they are fed to animals in a mixture with roughage and other feeds [36].

The proportion of each type of waste in the total organic waste mass was as follows: 91.0% wet brewers' grain (85%–88% moisture), 0.1% hop residues (84% moisture), 0.9% protein sludge (80% moisture), 3.3% brewers' yeast (85% moisture), 2.4% grain waste (up to 13% moisture), 1.6% malted sprouts (10% moisture), and 0.7% grain combinations (up to 32% moisture).

Thus, adding other waste to brewers' grains can slightly increase the product's nutritional value. Furthermore, the moisture content of the mixture decreases to 81%–84%. However, it is more profitable for brewers to sell dry grain waste, malted sprouts, and grain combinations at higher prices without mixing in brewers' grains. Therefore, brewers can use waste comprehensively for quick disposal or sell it separately, depending on its market value. Nonetheless, because of the small volume of perishable waste – hop grains and protein sludge – it is more profitable to incorporate it into brewers' grains during recycling.

The complex processing of brewing waste is carried out as follows. At the brewery, a mixture of all brewing wastes or a mixture of brewers' grains with a given type of waste is placed in a receptacle for partial separation of free moisture. From this point onward, the waste can be sold to customers, as it has a moisture content of up to 85%. Customers (feed mills, livestock farms, poultry farms, and others) place the product in receptacles from which the waste is taken as needed and dehydrated to 60%–65% moisture using a screw separator. The squeezed liquid filtrate, which on average represents 43% of the original mass of the waste mixture, is pumped into a temporary storage tank, and the partially dehydrated waste mixture is moved to another tank. The shelf life of the resulting wet waste does not exceed three days; thus, 1% propionic or formic acid is added to extend the shelf life to 14 days.

Next, a filler is selected to reduce the humidity of the waste mixture from 60%–65% to 28%–30% (the optimal range for extrusion). The filler comprises the dry components of the compound feed to be extruded. Rye or peas can be used as fillers; however, they contain harmful substances, including trypsin enzyme inhibitors, chymotrypsin, toxic resorcinol compounds, tannins, phytates, and lectins. Thus, such fillers should be pre-treated by heating (e.g., extrusion) to neutralize these harmful substances [37, 38]. The extrusion efficiency of grain, legumes, and other ingredients of compound feed (e.g., wheat, barley, corn, soybeans, rapeseed, lupine, and bran) has been evaluated in many studies. Soybeans, rapeseed, and lupine treated by extrusion play a special role [39]. Dry components with a moisture content of 10%–13% are added to the compound mixture at a ratio of 1:1.85–2 to reduce the moisture content of the mixture to 28%–30%. For example, 20 kg of crushed barley with a moisture content of 10% can be added to 10 kg of a mixture with a 65% moisture content. As a result, the moisture content of the mixture decreases to 28.3% (i.e., a ratio of 1:2 is obtained). If 18.5 kg of barley is added, the moisture content of the mixture decreases to 30% (i.e., a ratio of 1:1.85).

Then, the mixture of brewing waste and dry feed components is extruded to obtain an extrudate with a moisture content of 5%–14%. The final moisture content of the extrudate depends on many factors, including the brand, design, and size of the working parts of the extruder; the extrusion modes; and the type and composition of the processed material. The extrudate is crushed and introduced into the feed according to the formula. The feed is then granulated, and the filtrate is used as a moisturizer because it contains proteins, polysaccharides, and other substances with binding properties.

The extrudate – a dry feed additive obtained from, for example, crushed barley and organic waste from brewing – has, on average, the following nutritional values per 1 kg: ECU, 0.94 kcal; OE, 2,525 kcal. (10.56 MJ); and crude protein, 17%–19%.

Studies were conducted on the production of compound feeds using the proposed technology under laboratory conditions. Table 2 presents one of the compound feed formulations (starter KK-62-2-89 for calves) [40].

Table 2. **Formula for starter KK-62-2-89 for calves**

No.	Component name	Content in 10 kg	
		%	**kg**
1	Extruded barley	58	5.8
2	Feed fat	3	0.3
3	Sunflower meal	25	2.5
4	Grass meal	4	0.4
5	Feed yeast	6	0.6
6	Feed phosphate	1	0.1
7	Chalk	1	0.1
8	Salt	1	0.1
9	Premix (PKR-1)	1	0.1
	Total	**100**	**10**

The formulation in Table 1 uses 58% extruded barley. Thus, to increase the nutritional value of the compound feed, 6% of the extruded barley in the recipe was replaced with dry brewers' grain, which contains almost three times more protein than barley and is rich in B-complex vitamins and microelements. Dry brewers' yeast was also included instead of feed yeast. Table 3 presents the composition of the resulting feed.

Table 3. **New formula for starter KK-62-2-89 for calves**

No.	Component name	Content in 10 kg	
		%	**kg**
1	Extruded barley	52	5.2
2	Brewers' grain (dry)	6	0.6
2	Feed fat	3	0.3
3	Sunflower meal	25	2.5
4	Grass meal	4	0.4
5	Brewers' yeast	6	0.6
6	Feed phosphate	1	0.1
7	Chalk	1	0.1
8	Salt	1	0.1
9	Premix (PKR-1)	1	0.1
	Total	**100**	**10**

However, considering the above-mentioned conditions in Kazakhstan, we replaced dry brewers' grain and dry brewers' yeast with wet ones; thus, further calculations were necessary. In the recipe, 0.6 kg of dry brewers' grain and 0.6 kg of dry brewers' yeast with a 10% moisture contain 0.54 kg of dry matter each. Accordingly, wet brewers' grain and brewers' yeast with 85% moisture and 0.54 kg of dry matter have a mass of 3.6 kg each. As a result, the total mass of the mixture of brewers' grains and brewers' yeast with 85% moisture was 7.2 kg. After manual squeezing and drying to 65% moisture, the mass of the mixture was reduced to 3.08 kg.

Then, 5.8 kg of crushed barley and 0.36 kg of sunflower meal with 10% moisture were added to the wet mixture at a ratio of 1:2 (3.08 kg wet: 6.16 kg dry) to obtain the optimal moisture content for extrusion (28%). As a result, the total mass of the mixture was 9.24 kg, with a moisture content of 28.3%. The mixture was extruded using a single-screw extruder (PE 150) with a screw length of 500 mm, a diameter of 60 mm, and a die hole diameter of 8 mm. The extrusion mode parameters were as follows: the temperature in the extruder matrix zone was 140–150 °C, the pressure was 4–8 MPa, and the extruder screw rotation speed was 700 rpm. The mixture was in the extruder barrel for 4–5 s and had a temperature of 95–105 °C at the outlet. After extrusion, the product containing the barley extrudate had a mass of 7.3 kg with 10%–12% moisture. Given that previous research on extrusion of food and feed products has confirmed the virtual sterility of extrudates, microbiological or toxicological analysis of the wet waste before or after extrusion was not performed. After incorporating the extrudate, starter KK-62-2 had the following composition (Table 4).

Table 4. **Formula for starter KK-62-2-89 for calves containing the extrudate**

No.	Component name	Content in 10 kg	
		%	kg
1	Extrudate	73	7.3
2	Feed fat	3	0.3
3	Sunflower meal	16	1.6
4	Grass meal	4	0.4
5	Feed phosphate	1	0.1
6	Chalk	1	0.1
7	Salt	1	0.1
8	Premix (PKR-1)	1	0.1
	Total	**100**	**10**

Samples of starter KK-62-2-89 for calves were prepared according to this formula. The samples were then mixed with the filtrate obtained by squeezing the mixture from brewing waste at the beginning of the process to a final moisture content of 18%. Subsequently, the mixture was granulated to obtain particles with a diameter of 3 mm.

Brewers' grains are also useful in the manufacture of compound feed for laying hens, turkeys, guinea fowl, and especially geese and ducks [30]. In fact, 80% of the 4 million tonnes of compound feed produced annually in Kazakhstan is used for poultry. Therefore, a recipe for compound feed PK-1 for laying hens was developed using the following components: 25% wheat, 25% barley, 20% sunflower meal, 10% soybean cake, 10% dry brewers' grain, 2% brewers' yeast, 3% chalk, 3% shell, and 2% premix (P1-2). Dry brewers' grain and brewers' yeast were replaced with wet brewers' grain and brewers' yeast, according to the proposed technology. Table 5 presents the resulting formula.

Table 5. **Formula for PK-1 compound feed for adult laying hens**

No.	Component name	Content in 10 kg	
		%	kg
1	Extrudate	73	7.3
2	Sunflower meal	9	0.9
3	Soybean cake	10	1.0
6	Chalk	3	0.3
7	Shell	3	0.3
8	Premix (P1-2)	2	0.2
	Total	**100**	**10**

It should be noted that the recipes were developed using the computer program Coral, and therefore, at this stage of the research, no tests were carried out to assess the actual productivity of animals fed the new extruded compound feed.

The efficiency of the developed technology, which allows replacement of the convective drying of brewing waste – mainly in drum dryers using natural gas – with extrusion, was assessed based on the following criteria: energy costs, production cost price, market price, and feed quality.

When wet brewing waste is dried by convective means, the moisture in it acts as ballast. Evaporating this moisture in a drum dryer requires an average of 110 m^3·h/tonne of natural gas (per tonne of dry product), the price of which in Kazakhstan for legal entities is 51.7 tenge/m^3 with VAT. Hence, drying one tonne of waste costs 5,687 tenge. If one tonne of compound feed contains 12% (120 kg) dry waste (brewers' grains and brewers' yeast), the drying cost per tonne is lowered to 682.4 tenge.

In the proposed method, when replacing 12% of dry waste (brewers' grains and brewers' yeast) containing 10% moisture (120 kg) in one tonne of compound feed (starter KK-62-2-89 for calves) with 30.8% squeezed waste containing 65% moisture (308 kg), the moisture in the latter acts as a humidifier for the extruded dry components. In contrast, if extrusion were performed without squeezed waste, the dry components of the feed would have to be moistened with water or steam. Therefore, for the calculation, the mass of squeezed waste equals 108 kg, and the extrusion costs are calculated for 9 kWh, equivalent to 337.7 tenge (at a price of 37.53 tenge per 1 kW). Thus, when extruding wet waste from brewing together with the feed's dry components, the costs are half those of drying wet waste in drum dryers using natural gas.

In Kazakhstan, dry brewers' grain is offered on the feed market at 92–98 tenge/kg. Wet brewers' grain is sold by breweries at 9–13 tenge/kg. Thus, if we assume that 1 kg of dry grain is obtained from 4–5 kg of wet grain, replacing dry brewing waste with the wet product results in savings averaging 40–50 tenge/kg. The efficiency of extrusion for feed manufacturing has been proven in many studies. For example, the nutritional value of non-extruded barley is 1.15–1.2 k. units (per kilogram), whereas that of extruded barley is 1.24–1.35 k. units [41, 42]. Furthermore, extruded compound feeds are irreplaceable in fattening young cattle because 90% of cases of death of young animals occur due to gastrointestinal tract infections derived from contaminated feed. Feeding young animals with extruded feeds reduces deaths due to gastrointestinal diseases by a factor of 1.5–2 [43]. Using extruded compound feeds in poultry farming increases the number and size of eggs by 20%, reduces feed consumption by 30%, improves the taste of the feed, increases the digestibility of feed up to 90%, and lowers the death rate due to gastric diseases by 15% at a cost for the resulting product that is lower than the market cost [44, 45].

There are no small breweries in the republic, and large industrial breweries and feed mills are located in regional centers (cities) and equipped with modern equipment for the implementation of the proposed technology. Livestock farming and peasant farms located in rural areas have unlimited access to extrusion equipment, so in the republic, TOO 'Agrotekhservis 14' (Kostanay) produces affordable extruders for feed processing. It should also be noted that the structural scheme developed takes into account the logistics of handling waste from breweries on a large scale, since breweries operate around the clock throughout the year, constantly accumulating waste in preliminary bunkers, from where feed mills, also operating continuously throughout the year, can transport waste for processing [46, 47].

Many efforts have been devoted to the processing of wet waste from brewing into dry feed products. For example, a line for processing brewers' grains into a dry feed ingredient was developed. The line included a screw separator, a roller crusher, a decanter centrifuge, and a drum dryer, installed in series. Nonetheless, this line has disadvantages, including the multi-stage technology, the variety of installed equipment with high energy costs and the use of an energy-intensive drum dryer. In another study, a feed mixture was prepared from brewers' grains, malted sprouts, and brewers' yeast at a ratio of 50%:45%:5%, dried in a drum dryer [48, 49].

Studies have also reported compound feed for piglets aged 40–60 days, produced using the following components (proportion by weight): 20% green alfalfa, 21% wheat, 36% barley, 13% soybean meal, 2% fish meal, 2% vegetable oil, 3% feed yeast, 0.8% chalk, 1% calcium phosphate, 0.2% table salt, and 1% premix [50, 51]. The mixture of alfalfa (65%–70% moisture), wheat, and barley was extruded at 138–142 °C. The extrudate, at a temperature of 87–95 °C and a moisture content of 15.2% was then cooled, crushed, and added to the compound feed. The dry components had a moisture content of up to 14%; thus, the extrudate (moisture content of 15.2%) required additional drying. The moisture content of the extrudate at the outlet depends on many factors, including the design of the machine. Extruders with a device for extracting steam from the barrel of the extruder are used to reduce the moisture content [31, 52, 53].

Another report described a technology for preparing extruded feed based on bran and brewers' grain for ruminants. Brewers' grain with a moisture content of up to 70% was mixed with dry wheat bran (or crushed grain or straw), and the resulting mixture (moisture content of 24%–33%) was extruded. During this process, the mixture was heated up to 105 °C. The extrudate was cooled and dried [54-56]. However, that technology was used to produce only feed for ruminants, not compound feed. Thus, previous studies are lacking in technological advancements for producing compound feed based on wet waste from brewing, underscoring the novelty of the present work.

4- Conclusion

A technology has been developed that allows the use of wet brewery waste in the production of animal and poultry feed under the conditions in Kazakhstan, where breweries do not have the technology for drying wet waste and producing dry feed products. This new technology reduces by half the cost of producing animal and poultry feed. The proposed technology involves the extrusion of a mixture of brewing waste and dry components of compound feed with a moisture content of 10–14%, squeezed to a moisture content of 60–65%. This process occurs stably at a ratio of dry components to compound mixture of 1:1.85–2 and the following conditions: mixture moisture content of 28–30%, temperature in the extruder matrix zone of 140–150°C, pressure of 4–8 MPa, and extruder screw rotation speed of 700 rpm.

The research results may be of interest to breweries, the compound feed industry, and livestock and poultry farms in the agro-industrial complex.

However, certain limitations and potential risks may be encountered when using this method. In particular, if the extrusion temperature and time parameters are insufficiently controlled, partial destruction of heat-sensitive nutrients (e.g., B vitamins and some amino acids) is possible. The possibility of contamination of the raw materials with mycotoxins should also be taken into account, especially when wet waste is stored outdoors in unsanitary conditions, which requires preliminary quality control of the raw materials. To minimize these risks, it is recommended that the HACCP system be implemented and that regular microbiological and toxicological monitoring of raw materials and finished products be conducted.

5- Declarations

5-1- Author Contributions

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

5-2- Data Availability Statement

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

5-3- Funding

The presented research was conducted within the framework of Project No. AP19677701, 'Development of Technologies for Processing Fat-Moisture-Containing Waste from Food Production into Feed Products of the Agro-industrial Complex', financed by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan.

5-4- Acknowledgements

The authors express their gratitude to the leadership of Almaty Technological University.

5-5- Institutional Review Board Statement

Not applicable.

5-6- Informed Consent Statement

Not applicable.

5-7- 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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