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аграрний університет****УДК 631.563:636.085.55****DOI: 10.37128/2306-8744-2026-2-3****RESEARCH INTO THE STORAGE  
PROCESS OF BEER GRAINS  
INTENDED FOR FEED PURPOSES**

*The article presents the results of a study of the storage processes of dry beer grains, which are used as valuable feed raw materials in animal husbandry. The relevance of the study is due to the need to reduce the share of grain components in the composition of compound feeds, as well as to increase the efficiency of using secondary resources in the brewing industry in the context of the development of a circular economy and resource conservation. It was established that the high humidity of native beer grains (up to 70-86 %) determines the need for its preliminary dehydration and drying to a level of 6-10 %, which ensures the stability of quality indicators during storage. Fermentation is considered as an alternative approach, which allows increasing the microbiological stability of the product.*

*Experimental studies were conducted on samples of dry beer grains, which were stored for three months under different temperature and humidity conditions. During the research, changes in humidity, acidity, hydrogen index (pH), as well as the level of microbial contamination were monitored. The patterns of influence of environmental parameters on the intensity of biochemical and microbiological processes have been established.*

*It has been proven that increased relative humidity of air (over 60 %) leads to secondary moistening of feed, which is accompanied by activation of microflora and deterioration of its quality. An increase in temperature above 30 °C intensifies the processes of acid accumulation, which indicates the development of spoilage. It has been established that the key factor of stable storage is the control of water activity ( $a_w < 0.85$ ), which limits the development of mold fungi and bacteria. Based on the results obtained, rational storage parameters have been substantiated: temperature not higher than 20 °C and relative humidity of air 40-50 %. The practical significance of the work lies in the possibility of using the obtained results in the development of feed storage technologies, optimization of feed resource logistics and increasing the efficiency of use of brewing by-products in animal husbandry.*

**Keywords:** beer grains; drying technologies; humidity regime; humidity dynamics; water activity; storage; temperature regime; feed stabilization; shelf life; mass transfer processes.

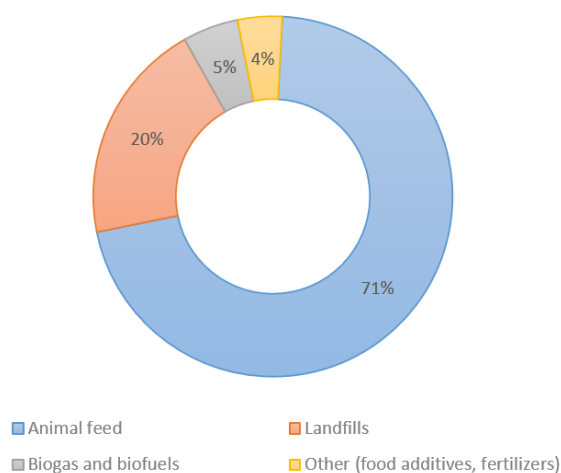
RESEARCH INTO THE STORAGE  
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**Introduction.** The issue of providing livestock, poultry and fish farms with feed is the main one in the meat production system and is decisive in shaping the structure of agricultural livestock farming and the pricing policy for meat and fish products. In the recipes of compound feeds made using traditional technology, the share of grain components is 60-80 % compared to the components suitable for human nutrition. At the same time, world grain reserves are constantly decreasing.

According to 2025 data, about 38 million tons of brewer's grains are produced annually in the world. This makes it one of the largest secondary resources in

the brewing industry. The main uses are animal feed, recycling and processing into biogas.

Modern feed production enterprises, in order to ensure competitiveness, need to reduce the grain components in feed and increase the share of processed products [1, 2, 4]. Therefore, there is a problem of developing effective methods of processing, storage and use of processed products that would allow preserving their feed benefits, extending their shelf life and including them in feed.



**Fig. 1. Global use of brewer's grains in 2025**

According to 2023, approximately 36.4 million tons of brewers' grains are produced annually in Europe, of which approximately 70% is used as animal feed, 10% is processed into biogas and 20% is landfilled. This highlights the potential of brewers' grains as a sustainable resource in a circular economy, where their recycling can reduce CO<sub>2</sub>

emissions by up to 500 kg/t compared to landfill disposal [1, 3, 11].

**Analysis of recent research and publications.** Beer grains are formed during the filtration of mash as a sediment after separation of the liquid phase (beer wort). From 100 kg of processed grain products, 125-170 kg of raw beer grains are formed. Depending on the equipment used, it contains 70-86 % moisture. Up to 75 % of protein substances and 80 % of fats contained in the initial composition of grain products used in beer production remain in beer grains. The nutritional and feed value of beer grains is given in Table. 1. Such a rich protein and mineral composition of beer grains determines its numerous advantages for use in various sectors of the national economy. In animal husbandry, raw (native) beer grains most often serve as an additive to milk and protein feeds for farm animals and poultry instead of meat and bone meal [2]. According to the results of the generalizations, Table 1 displays the nutritional value of beer grains, obtained based on the analysis of products of leading Ukrainian breweries, in particular «Obolon», «Slavutych», and «Carlsberg Ukraine».

**Table 1 – Average nutritional value of beer grains from Ukrainian breweries**

Indicators	Nutritional value indicators, %	
	native state	conversion to dry matter
Humidity	77.0	–
Dry matter	23.0	100
Crude protein	5.75	25.0
Crude fat	1.61	7.0
Raw ash	0.69	3.0
Crude fiber, g	3.91	17.0
Nitrogen-free extractives, g	10.54	45.8
pH	4.5	–
Feed units, in 1 kg	0.23	0.8
Digestible protein, g/kg	45	196
Calcium	0.05	0.22
Phosphorus	0.098	0.43

The data show that the native state of brewer's grains has a high moisture content (about 77%), which necessitates its prompt processing or preservation. In view of this, technological solutions for dehydration and stabilization of feed are gaining practical application, in particular technologies developed at the Institute of Animal Husbandry of the National Academy of Agrarian, which is confirmed by modern research in the field of feed production and feeding technologies [5]. The dry matter content is on average 23 %, while in terms of absolutely dry matter, a significant concentration of nutritional components is observed. The crude protein content reaches 25 % in dry matter, which indicates the high feed value of this type of secondary raw material.

Along with this, brewer's grains contain about 7 % crude fat, 17 % crude fiber and 45.8 % nitrogen-free extractives, which forms its energy nutritional value. The low pH value creates favorable conditions for natural preservation, but at the same time affects the storage stability in case of violation of technological conditions. The content of mineral substances, in particular calcium 0.22 % and phosphorus 0.43 % in dry matter, is sufficient for the use of the grain in animal diets as an additional source of macronutrients. Analysis of the obtained results confirms the feasibility of using beer grains as a valuable feed raw material.

In addition to its traditional uses, recent studies have shown the potential of brewer's grains as an



ingredient in functional foods (food supplements) such as plant-based breads, snacks, and yogurts. Fermentation methods with lactobacilli or yeasts are used to increase the bioavailability of minerals. Fermentation also extends shelf life by making brewer's grains more resistant to microbial spoilage [1, 3, 6, 7].

In our country, beer grains are mainly sold as livestock feed in their native form. However, when using wet beer grains, a number of problems arise. It contains a large number of microorganisms, which makes its long-term storage impossible (maximum 1-3 days). A large number of breweries were put into operation without taking into account the problem of waste disposal that is generated. That is why there is now a growing interest in the production of dry feed from beer grains. The

production of dry feed products from beer grains has a fairly high profitability. Dry beer grains are stable during storage and transportable.

In world practice (in Germany, the Czech Republic, Austria, etc.), dry feed production lines are an integral part of modern enterprises (Table 2). Drying technologies such as freeze-drying, superheated steam drying and vacuum microwave drying allow for better preservation of nutrients, antioxidants and phenolic compounds compared to traditional hot air. These methods reduce processing time and energy consumption, making production more cost-effective. For example, freeze-drying is the most effective method for preserving proteins and fibers, although more expensive [1, 12].

**Table 2 – Comparison of modern methods of drying beer grains**

Drying method	Drying time	Energy consumption	Nutrient preservation	Main advantages	Disadvantages
Hot air (traditional)	345 - 450 min	Low	Low (loss of phenols up to 63%)	Cheap, easy to set up	Significant quality degradation, loss of bioactive compounds
Lyophilization	18 - 24 hours	Very high	Highest (maximum preservation of proteins, phenols, flavonoids)	Best product quality	Very expensive, lengthy process
Drying with superheated steam	Twice as fast as traditional	Average	High (increases bioavailability of phenols)	Fast, does not oxidize the product	Requires precise control of parameters
Vacuum microwave	3 - 60 min	Very low ( $\approx 10\%$ from lyophilization)	High (good for thermo-labile compounds)	Fastest, low temperature ( $\approx 65\text{ }^{\circ}\text{C}$ )	More complex equipment
Refractance drying	5 - 60 min	Very low ( $\approx 0.04\%$ from lyophilization)	High	Energy-efficient, fast	Requires precise temperature calibration

Substantiating the relevance of the conducted research, it was assumed that ready-made dry feed from brewer's grains, after being packaged in bags, is often not used immediately, and for various reasons there is a need to store it until the moment of consumption by animals. Moreover, storage conditions in practice often differ significantly, which is due to the presence or absence of special premises, the season, etc. It is necessary to take into account that the investigated feed product is a biological object that requires compliance with scientifically substantiated storage parameters, the identification of which determines the feasibility of the conducted research. It is known that environmental factors that change during the storage period affect the rate of biochemical reactions, which affects the quality of feed preservation. Among those that have a direct impact, the temperature and humidity of the air are most often considered and studied [2, 5].

In addition to temperature and humidity, modern research also focuses on water activity. ( $a_w$ ), as a critical storage factor. It characterizes the degree of moisture availability for the course of microbiological

and biochemical processes. In contrast to total moisture, water activity reflects exactly that part of the moisture that can be used by microorganisms for development [6, 7, 9]. In general, it is defined as the ratio of the partial pressure of water vapor over the product to the saturated vapor pressure of pure water at the same temperature:

$$a_w = \frac{P}{P_0}, \quad (1)$$

where  $P$  is the partial pressure of water vapor above the product, Pa;

$P_0$  is the pressure of saturated water vapor above pure water at the same temperature, Pa.

Water activity can also be expressed in terms of the equilibrium relative humidity of the environment:

$$a_w = \frac{E_{Rh}}{100}, \quad (2)$$

where  $E_{Rh}$  is the equilibrium relative air humidity, %.

From a physical point of view,  $a_w$  it reflects not the total moisture content, but the proportion of free water capable of participating in the processes of mass



transfer, dissolution, and vital activity of microorganisms.

It has been established that with increasing water activity, the rate of microbiological and chemical processes increases, since the availability of water as a reaction medium increases. In particular, at values  $a_{1W}$  above 0.85, conditions are created for the development of most pathogenic microorganisms, which significantly reduces the stability of feed products during storage [6, 7].

For dry brewer's grains, it is recommended to maintain  $a_{1W}$  below 0.85 to inhibit the growth of microorganisms, including molds. At

$$a_{1W} = 0.88 - 0.91,$$

as in fermented brewer's grains products, the shelf life is extended, especially at sub-zero temperatures, which reduces the risk of spoilage [10, 11].

**Purpose of the study.** The purpose of the study is to establish the patterns of changes in the quality indicators of beer grains during storage depending on the temperature and humidity conditions of the environment, as well as to scientifically substantiate rational storage parameters that ensure maximum preservation of the nutritional value of the feed. Attention is paid to assessing the impact of air humidity, temperature and water activity on the intensity of microbiological and biochemical processes in the feed mass. The study is aimed at determining the permissible limits of changes in humidity, acidity and pH, which characterize the stability of the feed during long-term storage, as well as at developing practical recommendations for increasing the efficiency of using beer grains as part of compound feeds in modern agro-industrial production.

**Presentation of the main material.** The object of the study was dry beer grain feed, which was stored for 3 months at different temperatures and air humidity. The essence of the experiment was to study their impact on the quality of the stored feed. For this, a batch of fresh beer grain was dried using a technology developed at the Institute of Livestock Mechanization of the National Academy of Agrarian Sciences of Ukraine, which involves intensification of dehydration processes and ensuring the stability of the quality indicators of feed raw materials with a humidity of 6-10 % [8]. Then the samples were packed in bags and stored under different external conditions, which differed by season (winter, spring, summer) and conditions. For 3 months, daily monitoring of the temperature and humidity of storage of dry beer grain feed was carried out.

According to the research methodology, the following indicators were selected as indicators that characterize changes in the quality of dry feed from brewer's grains during storage: moisture content of the stored feed, pH value and acidity. Fig. 2 illustrates the change in feed moisture content under the influence of different storage conditions.

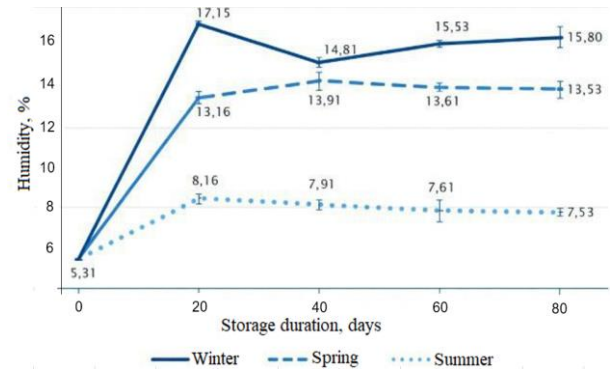


Fig. 2. Change in moisture content of dry feed from brewer's grains under different storage conditions

As can be seen from Figure 2, during storage, dry feed from brewer's grains is significantly affected by the humidity in the external environment (atmosphere). In the winter, when it is high (on average 85 %), the humidity of dry feed increased to 17.2 % in the first 20 days of storage, which contributes to the development of microflora in the stored feed. Therefore, taking into account the fact that feed from dry brewer's grains is able to absorb moisture from the air, according to the results of the conducted studies, high humidity of atmospheric air (more than 60%) causes an increase in its humidity by an average of 10%. This creates favorable conditions for the development of microorganisms in the feed, which are the main cause of its spoilage. Therefore, it is not advisable to store such feed in open areas and in damp rooms without ventilation, but it is recommended to store it in closed rooms with air humidity not exceeding 50% and using other modern methods of preservation [10].

Another indicator of the quality of feed preservation is the absence of oxidative processes in them. When dry feed spoils, carbohydrates, fats and proteins break down into substances, many of which have an acidic reaction (fatty acids, acetic, butyric, oxalic acids, amino acids). The more spoiled the feed, the more free acids it contains, therefore, it is by the degree of acidity that the degree of decomposition is judged, and accordingly, the good quality of the feed. Fig. 3 shows a histogram illustrating changes in acidity and pH in dry feed from brewer's grains under different storage conditions.

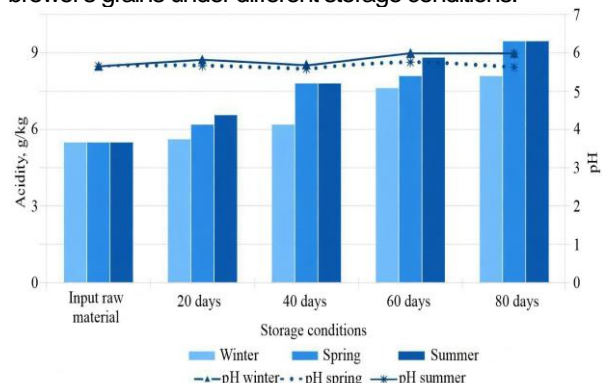
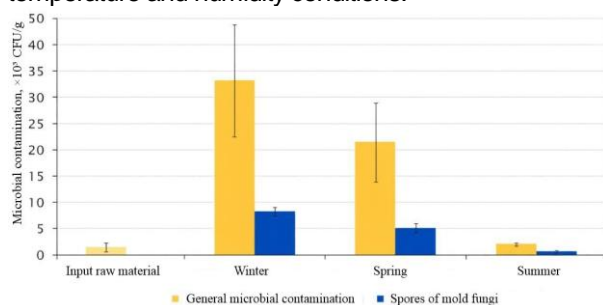


Fig. 3. Changes in acidity and pH in dry feed from brewer's grains under different storage conditions



It was found that at different combinations of temperature and humidity, dry feed from brewer's grains is stored differently. The negative impact on the quality of the studied feed is the increase in the moisture content of feed from brewer's grains, which increases under the influence of high air humidity (63-90%). It should also be noted that high ambient temperature (more than 30-35° C) leads to an increase in acidity, which indicates a decrease in the quality of the stored feed.

Fig. 4 graphically presents the results of bacteriological examination of samples of dry feed from brewer's grains, which was stored under different temperature and humidity conditions.



**Fig. 4. Total microbial contamination and number of mold spores in feed samples from dry brewer's grains, thousand in 1 g**

At the end of 3 months of storage, mold spores were detected in all samples examined. The largest number of mold spores – 8.3 thousand per 1 g – was found in feed samples stored under “winter” conditions, the smallest – 0.7 thousand per 1 g under “summer” conditions. According to the results of bacteriological studies, enteropathogenic types of *Escherichia coli*, salmonella, toxin-producing anaerobes were not detected. The tendency to increase the total bacterial contamination observed under “winter” conditions is explained by a significant increase in the moisture content of dry feed.

The practical implementation of the proposed recommendations will contribute to increasing the efficiency of using secondary raw material waste in compound feeds, reducing feed costs and developing resource-saving technologies in animal husbandry in a circular economy [5, 11]. Additionally, the use of brewer's grains as a raw material has economic advantages: processing reduces disposal costs and increases the value of the product in the direction of improving the quality characteristics and digestibility of feed. The environmental effect of this approach is manifested in reducing waste volumes and reducing emissions, which increases the overall sustainability of production processes.

**Conclusions and prospects for further research.** The study showed that dry beer grains are a hygroscopic material that actively absorbs moisture from the environment, which significantly affects its quality indicators during storage. It was established that the determining factors of feed stability are temperature, relative humidity and water activity. In particular, an

increase in relative humidity of air above 60% leads to secondary moistening of feed to a level of 15-17%, which creates favorable conditions for the development of microflora and deterioration of product quality. At the same time, an increase in temperature above 30 °C intensifies biochemical processes, in particular the accumulation of acids, which indicates the beginning of spoilage processes.

It has been proven that an important criterion for stable storage is the control of water activity at the level of  $a_w < 0.85$ , which allows to limit the development of mold fungi and bacteria and ensure the microbiological safety of feed. Based on the conducted experimental studies, rational parameters for the storage of dry brewer's grains have been substantiated, which provide for maintaining the temperature not higher than 20 °C and the relative humidity of the air within 40-50% in closed, ventilated rooms. It has been established that compliance with these conditions allows to minimize changes in humidity, acidity and microbial contamination throughout the entire storage period.

The results also confirm the feasibility of combining effective dehydration and drying methods with subsequent control of storage conditions, which ensures the extension of the shelf life of the feed and the preservation of its nutritional value. Further research should focus on the integration of brewer's grains into functional products, taking into account global sustainability trends.

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### ДОСЛІДЖЕННЯ ПРОЦЕСУ ЗБЕРІГАННЯ ПИВНОЇ ДРОБИНИ ПРИЗНАЧЕНОЇ ДЛЯ КОРМОВИХ ЦІЛЕЙ

У статті наведено результати дослідження процесів зберігання сухої пивної дробини, що використовується як цінна кормова сировина у

тваринництві. Актуальність дослідження зумовлена необхідністю зменшення частки зернових компонентів у складі комбикормів, а також підвищення ефективності використання вторинних ресурсів пивоварної промисловості в умовах розвитку циркулярної економіки та ресурсозбереження. Встановлено, що висока вологість нативної пивної дробини (до 70–86%) зумовлює потребу її попереднього зневоднення та сушіння до рівня 6–10%, що забезпечує стабільність якісних показників під час зберігання. Як альтернативний підхід розглянуто ферментацію, яка дозволяє підвищити мікробіологічну стійкість продукту.

Експериментальні дослідження проводилися на зразках сухої пивної дробини, які зберігали протягом трьох місяців за різних температурно-вологісних умов. У процесі досліджень контролювали зміну вологості, кислотності, водневого показника (pH) а також рівень мікробного обміління. Встановлено закономірності впливу параметрів навколишнього середовища на інтенсивність біохімічних і мікробіологічних процесів. Доведено, що підвищена відносна вологість повітря (понад 60%) призводить до вторинного зволоження корму, що супроводжується активізацією мікрофлори та погіршенням його якості. Підвищення температури понад 30 °C інтенсифікує процеси кислотонакопичення, що свідчить про розвиток псування.

Встановлено ключові фактори стабільного зберігання є контроль активності води ( $a_w < 0,85$ ), що обмежує розвиток пліснявих грибів і бактерій. На основі отриманих результатів обґрунтовано раціональні параметри зберігання: температура не вище 20 °C та відносна вологість повітря 40–50%. Практичне значення роботи полягає у можливості використання отриманих результатів при розробці технологій зберігання кормів, оптимізації логістики кормових ресурсів та підвищенні ефективності використання побічних продуктів пивоваріння у тваринництві.

**Ключові слова:** пивна дробина; технології сушіння; режим вологості; динаміка вологості; активність води; зберігання; температурний режим; стабілізація корму; термін зберігання; процеси масообміну.

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