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INFLUENCE OF ABIOTIC FACTORS ON THE BIOLOGICAL ACTIVITY OF WHEAT GRAINS

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Abstract

The article examines the effect of the main abiotic factors: temperature, wheat grain moisture content and carbon dioxide (CO_2) concentration on the biological activity of grains. Biological activity, which is assessed by the intensity of respiration and the amount of CO_2 released during it, is one of the most important indicators that allows assessing the condition of grains and the storage process. During grain respiration, organic matter is decomposed, accompanied by mass loss, emissions of metabolic products and, most importantly, the resulting heat flows, which directly affect the storage process and its success.

Experimental studies were carried out using wheat grains of different moisture content (15.4 ± 0.07%, 18.0 ± 0.1% and 20.0 ± 0.06%), which were stored at temperatures of 4 °C and 12 °C in tightly closed containers. It was found that the biological activity of wheat stored at a temperature of 4 °C with the lowest humidity (15.4 ± 0.07%) was minimal – the emitted comparative carbon dioxide flux did not exceed 0.0783 ± 0.0099 mg/(kg·h), and the generated heat flux was very low (0.233 ± 0.0296 W/t). The highest biological activity was found in grains that were 20 ± 0.06% humid and stored at a temperature of 12 °C. Their emitted comparative carbon dioxide flux reached 3.07 ± 0.128 mg/(kg·h), and the generated heat flux was 9.13 ± 0.382 W/t. An increase in temperature from 4 °C to 12 °C in all cases intensified grain respiration and metabolic processes. Meanwhile, CO_2 gas, reaching a certain concentration in the environment, reduced the viability of wheat and acted as a factor inhibiting its biological activity. However, the greatest influence was exerted by the grain moisture content, which determined the intensity of respiration, while temperature and carbon dioxide were factors that enhanced or inhibited this effect.

Keywords: wheat, biological activity, moisture content, temperature, carbon dioxide, heat flow.

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1. Introduction

Wheat grains are one of the most important agricultural products, used both in food production and in animal husbandry. Since grains are consumed throughout the year, preserving their quality during storage is extremely important. It has been established that grain losses during storage can reach 1-2% and more, depending on storage conditions, applied technologies and their management [1, 2].

Grains placed in a warehouse form an ecosystem that is alive and breathing. During respiration, oxygen is used, carbon dioxide (CO_2) and heat are released. This is directly related to changes in the condition of the grains. The intensity of respiration is one of the main indicators that allows assessing the biological activity of grains, their condition and the storage process, and predicting possible quality changes during storage [3, 4].

The biological activity of grains is determined by both abiotic and biotic factors. Grains form a very favorable environment for the development of microorganisms, especially mold fungi. Under favorable conditions of humidity and temperature, they can colonize the surface and internal tissues of grains [5]. Most scientists confirm that a sample of wetter grains is characterized by higher biological activity, as well as more favorable conditions for the development of microorganisms. For these reasons, grain moisture is considered one of the most important indicators determining the stability of grain storage and the extent of potential losses [2, 3, 13]. Significant mechanical, biological and sanitary damage can also be caused by the activity of pests (arthropods and vertebrates). Grain damaged by pests is a more favorable medium for the spread of microorganisms. In addition, they are characterized by higher respiratory intensity and deteriorate faster [5, 6].

The risk and impact of biotic factors are closely related to abiotic factors. These are components of the non-living environment that directly affect the physiological state and biological activity of grains during storage. The most important abiotic factors in the grain storage environment are temperature, humidity and gas composition. These factors and their interaction determine changes in grain quality, nutrient losses, self-heating processes and overall storage stability [11, 12].

Temperature is one of the most important abiotic factors regulating the rate of biochemical and microbiological processes. As the temperature increases, respiration intensifies and CO_2 release increases [1, 7]. In addition, temperature irregularities in the grain layer can cause condensation phenomena, which further increase humidity and expedite degradation processes [6]. Grain humidity is a critical factor determining their biological activity. Water is necessary for biochemical reactions to occur and for the development of microorganisms. Therefore, with increasing humidity, respiration is activated, CO_2 release and heat generation increase. At high humidity, these processes can cause self-heating and spoilage of grains [2, 8]. The gas composition in the intergranular space is no less important. During storage, due to respiration, the oxygen concentration naturally decreases and the CO_2 content increases. In certain cases, a higher carbon dioxide content can act as a natural preservative [1, 9]. However, a more intense increase in the CO_2 concentration at the same time indicates a higher biological activity of the grain and warns of a higher risk of changes in its quality.

Biotic and abiotic factors in the grain storage space form an artificial ecosystem and act in a complex way. They interact with each other, determining each other's viability, as well as the overall biological activity of the grain and its storage stability. It has been established that even small changes in temperature or humidity can significantly affect the metabolism of the grain, and the changed gas composition can both stimulate and inhibit biological processes in the stored product. Given the importance of temperature, grain moisture and gas composition, it is necessary to study their mutual interaction and impact on the biological activity of wheat [4, 10, 11, 12].

The aim of the research is to assess the effect of temperature, humidity and carbon dioxide on the respiration intensity, CO_2 release and heat generation of wheat grains under different storage conditions.

Objectives:

1. To investigate the biological activity of wheat grains of different humidity, determining the carbon dioxide and heat flux released by them.
2. To assess the influence of temperature on the biological activity of wheat grains.
3. To assess the influence of carbon dioxide concentration on the biological activity of wheat grains.

2. Object and methods

The research was carried out at the Mechanical, Energy and Biotechnology Engineering Department of the VMU Agricultural Academy. In order to simulate the real state of wheat after threshing, wheat grain samples with moisture content of 15.4 ± 0.07%, 18.0 ± 0.1% and 20.0 ± 0.06% were used during the research. The selected moistures also allowed to evaluate the biological activity of wheat grains of different moisture content, including both relatively dry and sufficiently moist grains, the storage of which is associated with an increased risk of microbiological contamination and spoilage. The samples were stored in hermetically sealed desiccators in a Feutron KPK 600 climate chamber (Germany) and a Memmert ICP 450 incubator (Germany). Therefore, during the entire research period (35 weeks), moisture exchange with the environment was avoided and a stable moisture level and temperature of wheat grains was ensured. Grain moisture was determined by the reference method according to the standard LST EN ISO 712 "Cereals and their products. Determination of moisture content. Reference method": grain samples were dried at a temperature of 105 °C in a drying cabinet "Memmert UFP 700" (Germany) to a constant mass.

The studies of biological activity of grains were carried out using glass desiccators and periodically recording the concentration of carbon dioxide in them with a gas analyzer "Kane Auto 2-2" (Great Britain) (Fig. 1). Depending on the volume of the desiccator, 1.2 kg or 2.4 kg of wheat were poured into them, forming a layer of test grain about 7 cm high. By applying different desiccator opening strategies, aerobic or anaerobic conditions are created for the grains in the desiccators. When storing grain under aerobic conditions, the desiccators were periodically opened in order to ventilate the grain there, avoid oxygen deficiency and maintain aerobic conditions. During these experiments, the flow of carbon dioxide emitted by grains and the flow of generated heat were determined. Another group of desiccators was kept without opening them. The aim was to create anaerobic conditions and to study the effect of increasing carbon dioxide concentration on the biological activity of grains.

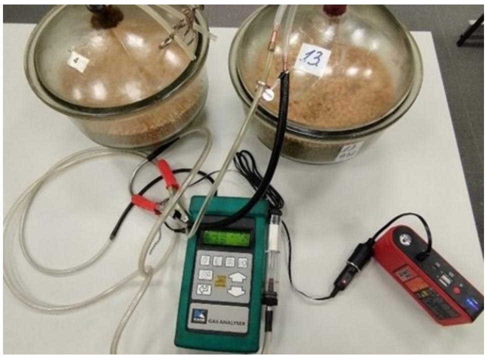


Fig. 1. Measurement of carbon dioxide (CO_2) concentration in desiccators with grains

Fig. 2. Desiccators with wheat samples in a climatic chamber

Desiccators with grain samples were stored in an incubator "Memmert ICP 450" and a climatic chamber "Feutron KPK 600" (Fig. 2), where temperatures of 12 °C and 4 °C were maintained, respectively. These conditions reflected the storage conditions of cooled grains and uncontrolled or insufficiently controlled storage. The carbon dioxide concentration in the desiccators was measured using a gas analyzer "Kane Auto 2–2", connected to the desiccator by hoses. Measurements were performed periodically, taking into account the intensity of the biological activity of the grains. Then, using the measurement results, the comparative carbon dioxide (CO_2) flows released by the grains and the generated heat flows were calculated according to the methodology presented below:

$$m_1^* = \frac{m_{CO_2}}{m_2^* \cdot t}; \quad (1)$$

$$m_{CO_2} = V_{CO_2} \cdot \rho_{CO_2} \cdot 10^6; \quad (2)$$

$$V_{CO_2} = V_{oro} \cdot \frac{CO_2\,\%}{100}, \quad (3)$$

where m_1^* – amount of carbon dioxide formed during respiration of products, mg/(kg·h); m_2^* – mass of products in the desiccator, kg; t – time, h; m_{CO_2} – mass of CO_2 released, mg; ρ_{CO_2} – density of carbon dioxide, kg/m^3; V_{CO_2}– volume of carbon dioxide in the desiccator, m^3.

Heat flux released during grain respiration:

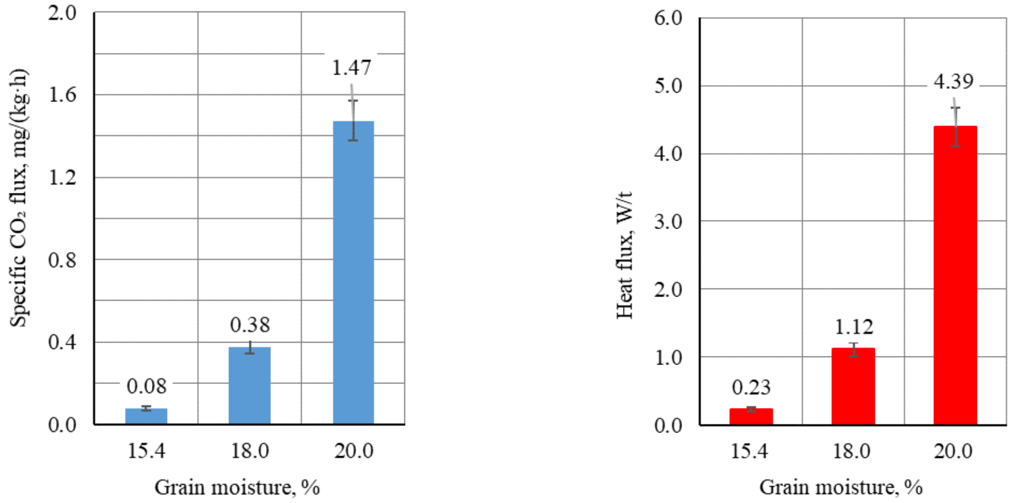
$$q_k = m_1^* \cdot 0.00298, \quad (4)$$

where q_k – heat flow, W/kg.

Data analysis was performed using MS Excel, calculating mean measurements and confidence intervals.

3. Results and discussion

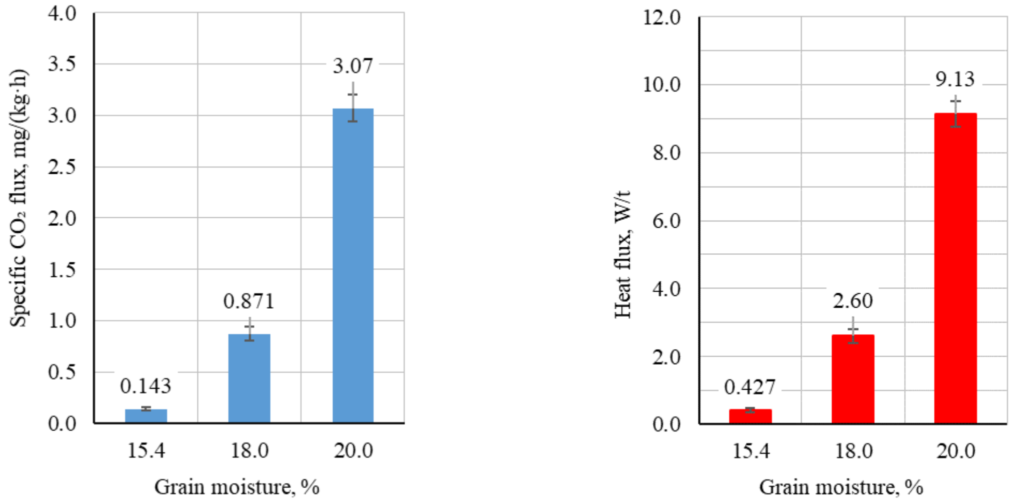
The biological activity of wheat grains was assessed according to the metabolic process – respiration intensity during storage. The amounts of released carbon dioxide (CO_2) quantities, the intensity of its concentration increase in the storage space (desiccators) were determined and the heat fluxes generated by the grains were calculated. The results obtained confirmed clear dependencies between the respiration intensity of wheat grains and the main abiotic factors – humidity, temperature and carbon dioxide concentration in the environment. At a temperature of 4 °C, the biological activity of wheat grains was relatively low. However, the results of the studies (Fig. 3) confirmed that with increasing humidity, the respiration intensity of grains and the released heat flux also increase. The comparative carbon dioxide flux released by grains with a humidity of 15.4 ± 0.07% was only 0.0783 ± 0.0099 mg/(kg h), and the generated heat flux was 0.233 ± 0.0296 W/t. However, the biological activity of grains with a moisture content of 18.0 ± 0.1% was 4.81 times higher, and that of grains with a moisture content of 20.0 ± 0.06% was even 18.8 times higher. The comparative carbon dioxide and heat fluxes released by wheat determined during the studies were 0.376 ± 0.0344 mg/(kg h), 1.12 ± 0.103 W/t and 1.473 ± 0.0963 mg/(kg h), 4.39 ± 0.287 W/t, respectively. The sharp increase in biological activity between 15.4 ± 0.07% and 18.0 ± 0.1% moisture is due to the transition from a safe storage state to a biologically active state. Mold fungi and other microorganisms develop only with sufficient water activity. At 15.4 ± 0.07% humidity, their development is severely restricted, but at 18.0 ± 0.1%, conditions become much more favorable for microbial colonization [5].



a) b)

Fig. 3. Biological activity of wheat at 4 °C temperature: a – specific carbon dioxide (CO_2) flux; b – heat generation flux

The biological activity of wheat grains stored at 12 °C was on average 2.08 times higher than when stored at 4 °C. The largest change in respiration intensity (2.32 times) was recorded in grains with a moisture content of 18.0 ± 0.1% (Fig. 4). The relative carbon dioxide flux released by them increased to 0.871 ± 0.0690 mg/(kg h), and the generated heat flux – to 2.6 ± 0.206 W/t. The biological activity of grains with a moisture content of 20.0 ± 0.06% increased even more: the values of relative carbon dioxide and heat fluxes reached 3.07 ± 0.128 mg/(kg h) and 9.13 ± 0.382 W/t, respectively.



a) b)

Fig. 4. Biological activity of wheat at 12 °C temperature: a – specific carbon dioxide (CO_2) flux; b – heat generation flux

The obtained results confirmed the statement of H. Kibar [3] that the rate of wheat respiration increases with increasing temperature and grain moisture content. Although this study assessed respiration rates at lower temperatures (4–12 °C), the same trend was observed – biological activity was significantly higher in wetter grains. In the Kibar study, the highest carbon dioxide flux was 12.38 mg CO_2/(kg h) at 35 °C. This suggests that higher temperatures may further accelerate metabolic processes in grains [3].

It was found that moisture content had a greater influence on the respiration rate of wheat grains than temperature. At a temperature of 12 °C, the difference between the comparative carbon dioxide fluxes released by grains with 20.0 ± 0.06% and 18.0 ± 0.1% moisture content, as well as the generated heat fluxes, reached 3.51 times. An even more pronounced difference was found when comparing grains with 18.0 ± 0.1% and 15.4 ± 0.07% moisture content. The comparative carbon dioxide flux released by the latter was only 0.143 ± 0.0208 mg/(kg h), and the generated heat flux was 0.427 ± 0.0621 W/t: the biological activity of wheat with a moisture content of 15.4 ± 0.07% was 6.09 times lower than that of grains with a moisture content of 18.0 ± 0.1% and even 21.3 times lower than that of grains with a moisture content of 20.0 ± 0.06%.

The biological activity of wheat grew extremely rapidly with increasing moisture content from 15.4 ± 0.07% to 18.0 ± 0.1%. Meanwhile, the effect of temperature was recorded to be weaker: when the temperature of 15.4 ± 0.07% moisture grains was increased from 4 °C to 12 °C, their emitted carbon dioxide and heat fluxes increased only 1.83 times, respectively from 0.0783 ± 0.00993 mg/(kg h) to 0.143 ± 0.0208 mg/(kg h) and from 0.233 ± 0.0296 W/t to 0.427 ± 0.0621 W/t.

An equally important factor is the gaseous composition of the environment. As biochemical processes occur, the gaseous composition in a sample of non-ventilated grains naturally changes - oxygen decreases in the inter-grain space and carbon dioxide (CO_2) concentrations increase. Studies using non-opening desiccators made it possible to assess the effect of increasing carbon dioxide concentration on the dynamics of wheat respiration intensity during storage. The results obtained were consistent with the conclusions presented by Ramachandran and Singh that monitoring CO_2 concentration is one of the most sensitive indicators of biological activity of stored grains. The authors indicated that the increasing concentration of carbon dioxide reflects the intensification of respiratory processes and can be used for early diagnostics of grain condition [1]. In this study, the highest CO_2 concentrations were determined in wheat samples with a moisture content of 20.0 ± 0.06%, in which the highest respiratory intensity was also recorded. The subsequent slowdown and stabilization of the growth of CO_2 concentration reflects the inhibitory effect of the increased CO_2 concentration on the biological activity of grains.

At a temperature of 4 °C, in desiccators with 15.4 ± 0.07% moisture content of grains, the CO_2 concentration remained low throughout the observation period (Fig. 5). The values did not exceed 0.05%. Thus, the respiratory processes of wheat grains proceeded slowly, biological activity was minimal, and the conditions created were favorable for long-term grain storage.

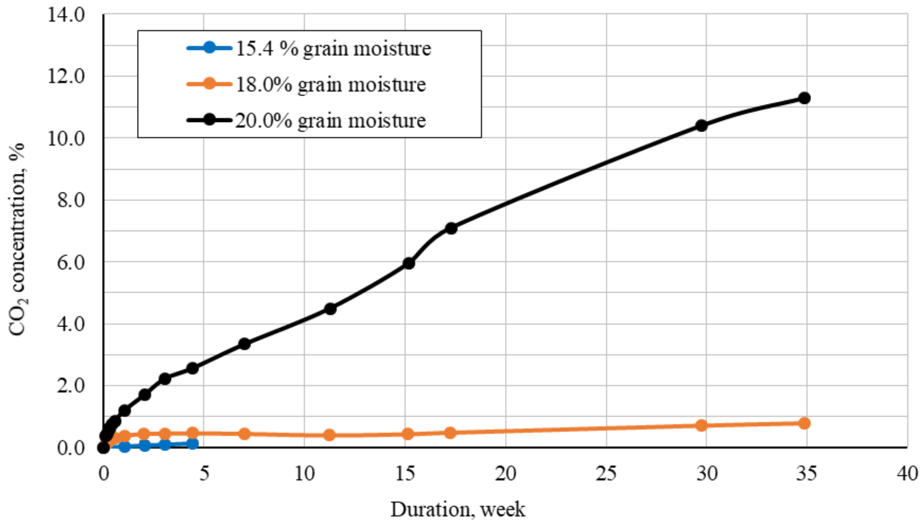


Fig. 5. Variation of carbon dioxide (CO_2) concentration during wheat storage at 4 °C temperature

A similar, although less stable, environment also formed in the bulk of wheat with a moisture content of 18.0 ± 0.1% stored at 4 °C. The carbon dioxide concentration in the desiccators was higher than in the case of grains with 15.4 ± 0.07% moisture content, indicating more intensive biological activity. However, after the CO_2 concentration increased to 0.38% within one week, the conditions stabilized. Higher moisture content resulted in a higher CO_2 concentration required to temporarily stabilize the state, as well as a higher overall concentration in the storage environment. A further increase in CO_2 concentration was observed only after 15 weeks from the beginning of the experiment. By week 35, the CO_2 concentration in the desiccators with grains reached 0.80%. The highest CO_2 concentration was observed in wheat with a moisture content of 20.0 ± 0.06%. Over 35 weeks, the CO_2 concentration in the desiccators increased logarithmically to 11.30%. Grain respiration was most intense during the first 17 weeks, when the CO_2 concentration increased on average by 0.42% per day, reaching 7.10% by the end of this period. Subsequently, the rate of increase slowed: from week 17 to week 30, the CO_2 concentration rose by only 3.3 percentage points, from 7.10% to 10.40%. During the final five weeks, the increase was minimal, from 10.40% (week 30) to 11.30% (week 35). This indicates the onset of a transition to a period of relative dormancy. However, a stable state during this period was not achieved. The wheat grains remained biologically active until the end of the experiment. A temperature of 4 °C was insufficient to stabilize the condition of high-moisture (20.0 ± 0.06%) wheat grains and to create a stable storage environment. Even a CO_2 concentration of 11.30% was not sufficient to slow the biological activity of wheat, which was driven by high grain moisture.

Storage at a higher temperature (12 °C) resulted in a more intensive increase in CO_2 concentration. The highest CO_2 values and the fastest growth were recorded in desiccators containing grains with a moisture content of 20.0 ± 0.06% (Fig. 6). The most intensive respiration occurred during the first 7 weeks, when the CO_2 concentration increased on average by 1.97% per day, reaching 13.80% by the end of this period. This was followed by a sharp decrease in biological activity. From week 7 to week 30, the CO_2 concentration increased by only 5.15 percentage points (to 18.95%), which is 2.68 times less than during the initial period. During the final five weeks, the CO_2 concentration slightly decreased, from 18.95% (week 30) to 18.80% (week 35). This indicates the onset of a dormancy, or stable state, period in the grain bulk.

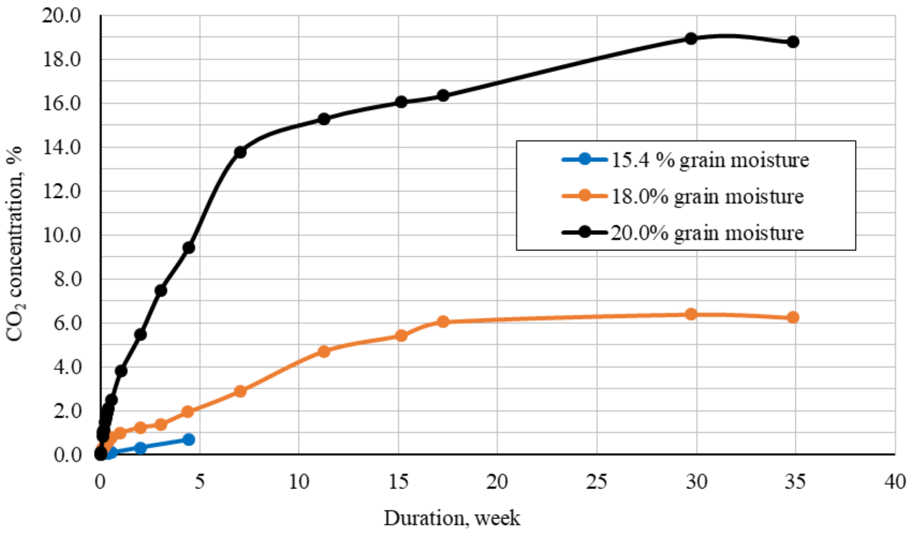


Fig. 6. Variation of carbon dioxide (CO_2) concentration during wheat storage at 12 °C temperature

The biological activity of grains with a moisture content of 18.0 ± 0.1% was lower; however, the period of intensive respiration at the beginning of storage lasted longer, up to week 15. During this period, the CO_2 concentration increased at an average rate of 0.36% per day, which is 5.47 times slower than in desiccators containing grains with 20.0 ± 0.06% moisture content. Subsequently, the increase in carbon dioxide concentration slowed significantly: CO_2 levels rose from 4.45% (week 15) to 6.4% (week 30), i.e., by 1.95 percentage points. During the final five weeks, a slight decrease in concentration to 6.25% was recorded. Thus, to stabilize the biological activity of wheat grains with 18.0 ± 0.1% moisture content, approximately three times lower CO_2 concentration was sufficient compared to grains with

20.0 ± 0.06% moisture content. A reduction in temperature to 12 °C alone was not sufficient to slow the respiration intensity of wheat grains with either 20.0 ± 0.06% or 18.0 ± 0.1% moisture content, nor to create a stable grain bulk.

Meanwhile, a temperature of 12 °C had no significant effect on the biological activity of grains with 15.4 ± 0.07% moisture content. The CO_2 concentration remained low throughout the entire experimental period and did not exceed 0.1%, indicating weak respiration intensity and low biological activity. This differed little from wheat grains stored at 4 °C. Therefore, a temperature of 12 °C was sufficient to create favorable conditions for the long-term storage of grains with 15.4 ± 0.07% moisture content under non-ventilated conditions.

4. Conclusions

1. The biological activity of wheat grains ranged from the lowest, observed in grains with a moisture content of 15.4 ± 0.07% at 4 °C (specific CO_2 emission rate – 0.0783 ± 0.00993 mg/(kg·h), generated heat flux – 0.233 ± 0.0296 W/t), to the highest, recorded in grains with a moisture content of 20.0 ± 0.06% at 12 °C (specific CO_2 emission rate – 3.07 ± 0.128 mg/(kg·h), generated heat flux – 9.13 ± 0.382 W/t).
2. It was determined that moisture content is the most important factor influencing the biological activity of wheat grains: when it increased from 15.4 ± 0.07% to 20.0 ± 0.06%, the respiration intensity of wheat increased up to 18.8 times at 4 °C and more than 21 times at 12 °C. However, the greatest change in biological activity was observed in the moisture range from 15.4% to 18.0%.
3. Increasing the temperature from 4 °C to 12 °C raised the biological activity of wheat grains by an average of 2.08 times, with the greatest effect (2.32-fold) recorded for grains with a moisture content of 18.0 ± 0.1%.
4. Unlike 12 °C, a temperature of 4 °C suppressed the biological activity not only of relatively low-moisture (15.4 ± 0.07%) but also medium-moisture (18.0 ± 0.1%) wheat grains; however, it was insufficient to stabilize the condition of high-moisture (20.0 ± 0.06%) wheat.
5. In a closed storage environment, increasing carbon dioxide (CO_2) concentration suppressed the biological activity of wheat; however, the effectiveness of this effect depended on the storage temperature and, in particular, the grain moisture content.

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