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INVESTIGATION OF HYGROSCOPIC PROPERTIES OF THE SPELT GRAIN

Об'єктом дослідження є гігроскопічні властивості не обрушеного (з квітковими плівками) та обрушеного (зі знятими плівками) зерна спельти. Однією з проблем є те, що під час післязбирального оброблення та зберігання зерна спельти у різних умовах довкілля може відбуватись його зволоження, яке може призводити до погіршення якості зібраного врожаю. Для запобігання цьому необхідно знати гігроскопічні властивості спельти, зокрема її рівноважну вологість, в залежності від параметрів повітря – його температури і відносної вологості. Перспективним є прогнозування рівноважної вологості спельти відповідно умов її оброблення чи зберігання, що дозволить уникати небажаних наслідків. Для дослідження гігроскопічних властивостей не обрушеної та обрушеної спельти використовували поширений тензометричний метод визначення рівноважної вологості. Досліди проводили в діапазоні температур повітря 5...25 °С та його відносної вологості 33...70 %, які моделюють умови активного вентилювання та зберігання зерна у різні пори року. Отримано чисельні значення рівноважної вологості спельти сорту Зоря України 2016 р. врожаю за вказаних діапазонів температур та відносної вологості повітря. Рівноважна вологість не обрушеної спельти (в квіткових плівках) знаходиться в межах 9,35...13,78 %, обрушеної (без плівок) – в межах 9,98...14,58 %. Порівняно з не обрушеною спельтою, рівноважна вологість обрушеної вища на 0,42...0,74 %, що необхідно враховувати при зберіганні останньої. Встановлено характер залежності рівноважної вологості не обрушеної та обрушеної спельти від параметрів навколишнього повітря – температури та відносної вологості. Запропоновано емпіричне рівняння, яке дозволяє прогнозувати значення рівноважної вологості спельти залежно від параметрів довкілля. Це дозволяє обґрунтувати раціональні режими післязбирального оброблення спельти, насамперед активного вентилювання, прогнозувати терміни безпечного зберігання залежно від умов зовнішнього середовища та запобігати зниженню показників якості зерна.

Ключові слова: *зберігання зерна спельти, тензометричний метод, гігроскопічні властивості, рівноважна вологість, ізотерми сорбції.*

1. Introduction

One of the global problems of mankind is food. A big role in its decision is played by grain farming, which is a backbone for other sectors of agro-industrial production. The state of grain production and the position on the grain market in world practice are accepted as the main indicators of food security of the world in general and each individual country in particular.

Spelt, or film wheat, is a variety of wheat with a genomic composition similar to soft wheat. Increased attention to spelt in many European countries and in Ukraine in recent decades is due to a number of factors. Among them is the suitability for biological farming, popular in many developed countries, unpretentiousness to growing conditions, the ability to withstand soils depleted in batteries. It has high winter hardiness, resistance to excessive moisture during the tillering period. Some food and technological properties allow it in some cases to press the traditionally dominant soft wheat [1–3].

The constant use of spelt in food contributes to the rapid normalization of blood sugar levels in the blood, strengthens the immune system, improves the work of the endocrine, cardiovascular, digestive, nervous and reproductive systems [1, 4]. To a large extent, spelt products reduce the risk of developing infectious, oncological diseases and anemia. Also noteworthy is the use of this cereal for people who are allergic to gluten in wheat, barley and oat grains [5–7].

Nowadays, the issues of post-harvest grain processing remain insufficiently studied in the present spelt (first of all, of its active ventilation and drying), which could ensure its safe storage and subsequent technological processing into foodstuffs.

An important influence on the state of the grain mass during post-harvest handling and storage have sorption properties, that is, the ability to sorb (absorb) and desorb (emit) moisture vapor and various gases from the environment. This leads to a change in the moisture and odor of the processed or stored grain. Humidification of grain as a result of sorption during storage also creates conditions for increasing the vital activity of seeds, microorganisms and other living organisms [8, 9].

Thus, as a result of interaction with the environment, the moisture content of the grain continuously changes to achieve an equilibrium state (the so-called equilibrium moisture), the course of which is largely determined by the properties of the grain, which are called hygroscopic.

Considering that spelt is a little-studied culture, the study of its hygroscopic properties is an urgent task.

2. The object of research and its technological audit

The object of research is the hygroscopic properties of spelt grain.

The subject of research is not collapsed (with flower films) and collapsed (with removed films) spelt grain

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of varieties Zorya Ukrainy of 2016 harvest. The initial humidity of not collapsed spelt is 12.20 %, collapsed – 11.50 %.

In the characteristic of the hygroscopic properties of the grain, the basic concept is equilibrium moisture – a state of dynamic equilibrium, in which the partial pressure of water vapor in the air and above the grain is the same. The moisture content of the grain, which corresponds to this state, is called the equilibrium moisture. As it is known, such factors as temperature and relative humidity of air, type of grain crop and its initial humidity influence the equilibrium moisture of a grain [10].

The determining factor influencing the magnitude and speed of reaching equilibrium moisture is the relative humidity of the air – the larger it is, the faster the grain absorbs moisture and the greater the equilibrium moisture. The latter also depends on the air temperature: with the same relative humidity and higher temperature, lower equilibrium humidity corresponds and, conversely, a lower temperature leads to an increase in the equilibrium moisture content of the grain. This should be taken into account when daily temperature drops and temperature changes in granaries and the environment [9, 10].

Different grain crops, under the same conditions, absorb an unequal amount of moisture, which is associated with the structure and biochemical composition of the grain. The equilibrium moisture content of individual grains in the grain mass is also unequal. The reasons for the uneven distribution of moisture in the grain mass can be:

– uneven distribution of moisture in each individual grain;
– different sorption capacity of grains of different fullness and size;
– relative humidity of the ambient air of the grain mass;
– release of water and heat by all living components of the grain mass;
– state of granaries;
– change in temperature at various sites of the grain embankment and the phenomenon of thermal moisture conductivity associated with it [9].

For such insufficiently studied culture as spelt, hygroscopic properties are practically not studied, which determined the aim of research.

3. The aim and objectives of research

The aim of research is establishment of patterns of changes in the equilibrium moisture content of spelt grain depending on the temperature and relative humidity of the outside air. This will improve the efficiency of its post-harvest handling and storage.

To achieve this aim it is necessary to perform the following objectives:

1. To determine the value of the equilibrium moisture content of spelt at different temperatures and relative humidity.
2. To establish the nature of changes in the equilibrium moisture content of spelt depending on the temperature and relative humidity of the air.
3. To determine the empirical coefficients in the equation of sorption isotherms to predict the values of the equilibrium moisture content of spelt depending on temperature and relative humidity.

4. Research of existing solutions of the problem

An analysis of the literature on spelt gives some insight into this poorly studied culture. In them, the authors cite a number of characteristics of spelt, mainly agronomical, show the nutritional and biological value of products from it and their ecological purity.

Thus, the review [1] indicates that cereals represent the most significant group of crops in the structure of crop production from the economic, agronomic and consumer points of view. It is emphasized that spelt is an ancient kind of wheat, which is now rediscovered in Europe and North America and is becoming increasingly popular for its agronomic, nutritional and medical characteristics. In [11], it is emphasized that these «ancient grains» – wild precursors of wheat – made it possible to revive organic farming, due to which spelt and farro appeared in our rations and farms.

The physico-agronomic characteristics of spelt grown in an organic farmer system are given in [3]. The yield, nutritional value and biometric characteristics of spelt are investigated. The authors of [4] emphasize that spelt has a lower yield compared with modern wheat, but this is offset by better quality characteristics of the grain, in particular, a significantly higher content and quality of protein.

The importance of spelt for ecological management and the production of harmless organic food are considered in [11, 12]. The authors of studies [12] compare two varieties of spelt, including such technological indicator as the mass of 1000 grains. Other technological characteristics are not considered.

Separate technological properties of spelt grain, such as nature, glassiness, and grain hardness, are investigated in [13]. The biochemical composition, properties of gluten are also studied, the advantages of bread products made from spelt over traditional commercial types of wheat are shown. However, the obtained data are important for grain processing and baking enterprises, and do not provide the information necessary to substantiate the modes of post-harvest processing of spelt at grain-processing enterprises.

In [5], an assessment of the technological quality of spelt is also given, which includes studies of the content of raw gluten, its swelling, instability, enzymatic activity (number of falling), and the gluten index. It is noted that the use of spelt-based products can provide an increase in the consumption of minerals, vitamins and fiber, which will help to reduce the glycemic index of food products made from spelt. In the source [2] it is noted that some gliadines, present in the gluten of modern wheat, is missing in spelt gluten, which makes these grasses acceptable for people suffering from allergies through the individual intolerance of modern wheat species. The high quality of spelt bread is also confirmed by other authors in [4, 14].

As for the methods and techniques for studying the mass transfer characteristics of grain, in particular, hygroscopic properties, it is most fully described in [10]. However, regarding the spelt grain no data are given.

Thus, the results of the analysis allowto conclude that in the literature there are no data on the hygroscopic properties of spelt, which determines the above aim of this work.

5. Methods of research

The studies were carried out by the conventional tensometric method [10], which consists in the fact that weighed grain is placed in weighing glass cups, which are placed in hygrostats – a desiccator with a liquid having a certain elasticity of water vapor above the surface. Weighing the weighting cups with a certain frequency, it is possible to judge about the degree of moisture absorption by the grain.

The experiments were carried out in the range of air temperatures t=5...25 °C and its relative humidity φ=33...70 %, simulating the conditions of active ventilation and storage of grain at different times of the year.

To ensure the ambient temperature of 5 °C adopted in the studies, the desiccators were placed in a refrigerator, and for a temperature of 25 °C they were placed in a thermostat.

To create a certain relative humidity of the air, about 1...2 dm^3 of sulfuric acid solution of the required density was poured into the desiccators, which provided the above values, the relative air humidity of 33, 45 and 70 %. At the same time, to ensure more accurate results, the concentration of sulfuric acid solutions in a desiccator was prepared taking into account the dependence of its density on temperature [15]. The density of sulfuric acid and its solutions was controlled using a set of hydrometers.

In each desiccator, cups with a weighed grain of about 5 g were laid. Considering that the experiments were carried out in 2 parallels, the total number of the weighting cups with the weighed grain of not collapsed and collapsed spelt was 24 pieces.

Weighting cups with sample weights were periodically weighed. According to the obtained data, the changes in the mass of thesample weights in the weighting cups at each specific point in time were calculated by the intermediate grain moisture (%) using the formula:

$$w_i = 100 - \frac{m_1}{m_i}(100 - w_1), \qquad (1)$$

where w_i – the intermediate (current) moisture of the grain at the i-th instant of time, %; m_1 – the initial mass of the sample of grain (at the beginning of the experiment), g; m_i – the intermediate (current) weight of the sample of grain at the i-th instant of time, g; w_1 – intermediate (current) and initial moisture content of grain, %.

On the basis of the obtained data, sorption or desorption curves were constructed (depending on the initial moisture content of the grain). Upon reaching a constant mass of samples, the experiment was stopped and the achieved moisture content of the grain was determined, which was taken to be hygroscopic. The initial and final moisture content of the grain was determined according to DSTU GOST 29144:2009 (ISO 711-85) [16].

A further generalization of the experimental data was performed by statistical methods using the spreadsheet MS Excel 2007 processor.

6. Research results

The experiments have shown that the duration of the experiments to achieve the equilibrium state of the grain is within 20...40 days. At the end of the experiments their mathematical processing is carried out. In parallel experiments, to calculate the average values of the mass of grain in the weighting cups at each selected point in time, which is subsequently transferred to the current grain moisture content.

The obtained experimental values of the current moisture content of grain for averaging are approximated by empirical equations of sorption or desorption isotherms, in which the coefficients are determined by the least squares method. According to the obtained sorption and desorption isotherms, the equilibrium humidity of the non-collapsed and collapsed spelt is determined for each of the temperature values and relative humidity of the air in the desiccators.

The obtained calculated equilibrium moisture values of spelt are further compared with the achieved final moisture content of spelt samples in each of the desiccator. A test shows that the calculated and experimental values of the equilibrium moisture are within the experimental error. The obtained equilibrium moisture values are given in Table 1.

Table 1

Equilibrium humidity Zorya Ukrainy spelt (2016)

Conditions of experiments		The value of the equilibrium moisture content of spelt, %			
φ, %	t, °C	Not collapsed		Collapsed	
		parallel	average	parallel	average
33	5	10.87	10.79	11.64	11.52
		10.70		11.40	
45		11.36	11.40	11.70	12.06
		11.44		12.41	
70		13.84	13.78	14.73	14.59
		13.72		14.44	
33	25	9.51	9.35	10.12	9.98
		9.19		9.84	
45		10.39	10.52	11.21	11.06
		10.60		10.90	
70		12.79	12.66	13.14	13.08
		12.52		13.02	

From the data of Table 1 it is possible to see that the hygroscopic humidity of the not collapsed spelt in the investigated temperature range of 5...25 °C is higher by 0.42...0.74 % than in the collapsed one, which can be explained below by the ability of films to absorb water than in the grains. This is consistent with the literature data and means that even in conditions where the whole grain is in a state of hygroscopic equilibrium with the environment, there is a possibility for the exchange of moisture between the wetter core and the films [9].

From the source [10] it is known that the sorption isotherms of a grain can be fairly accurately described by an equation of the form:

$$w_e = A - B \cdot t + (C - D \cdot t)\left[\lg\left(\frac{1}{1-\varphi}\right)\right]^{0.5}, \qquad (2)$$

where w_e – the equilibrium moisture content of the grain, %; A, B, C, D – constant, depending on the form of the bond between moisture and the dry matter of the grain and the temperature of the grain; φ – the relative humidity of air, in fractions.

The values of the constants A, B, C, D are determined on the basis of the experimental data by the least squares method. For the practical implementation of the method of least squares, it is possible to use the procedure «Search for solutions» of the MS Excel 2007.

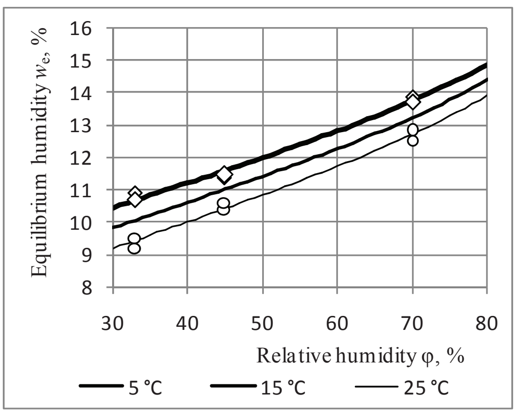
Using the above relation (2) at the final stage of processing experimental data, the empirical coefficients A, B, C, D are determined from the hygroscopic properties of the studied spelt samples:

– for not collapsed spelt A=6.864; B=0.07565; C=9.843; D=–0.0333;

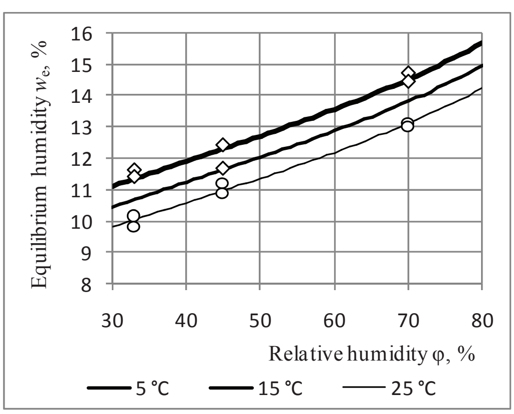
– for collapsed spelt A=7.324; B=0.05824; C=10.43; D=0.01684.

The standard deviations in the calculation of the equilibrium moisture content according to the obtained empirical equations are for not collapsed and collapsed spelt, respectively 0.045 and 0.055 %, and the relative error is within 0.21...2.04 %.

Using the obtained empirical equation (2) for the not collapsed and collapsed spelt, an isotherm of equilibrium humidity is constructed at temperatures of 5, 15 and 25 °C (Fig. 1). The given isotherms give a visual representation of the nature of the change in the equilibrium humidity, depending on the relative humidity of the air.



a



b

Fig. 1. Equilibrium humidity isotherms: *a* – not collapsed; *b* – collapsed spelt

Fig. 1 shows that in the range of relative humidity φ=30...70 % the equilibrium humidity w_e of both not peeled and peeled spelt grows almost in direct proportion law. And only after φ=70 % more rapid w_e growth is observed. This is also characteristic of other cereals [10]. It is also seen that the equilibrium humidity w_e of a collapsed spelt is slightly higher than the collapsed spelt, which can lead to a deterioration in the quality of the collapsed spelt during its storage.

7. SWOT analysis of research results

Strengths. The strengths of the research results are the ability to predict the equilibrium moisture content of not collapsed and collapsed spelt, which will help prevent the negative phenomena of its wetting during active ventilation in various climatic conditions and subsequent storage. This will help preserve the spelt quality. It is also shown that the equilibrium moisture content of anot collapsed spelt is above collapsed by 0.42...0.74 %, which creates the best conditions for storing the latter.

Weaknesses. The weak points of the studied hygroscopic properties are the insufficient range of the obtained data on spelt varieties, climatic zones of its cultivation, and crop years.

Opportunities. Opportunities for further research are the need to attract to research new and zoned varieties of spelt grown in different years in different agro-climatic conditions. This will allowto create an extensive database of the hygroscopic properties of spelt both in Ukraine and the world, more accurately predict its equilibrium moisture and avoid undesirable consequences during post-harvest handling and storage of spelt.

Threats. Threats are that the use of research results for other varieties of spelt, harvests of other years and spelt grown in other climatic conditions of Ukraine, the numerical values of hygroscopic properties will be somewhat different from the established ones and will need to be adjusted. Under some environmental conditions, spelt may become wet when ventilation is active or deterioration in quality during long-term storage.

8. Conclusions

1. The numerical values of the equilibrium moisture content of spelt of varieties Zorya Ukrainy at temperatures of 5...25 °C and relative humidity of air 33...70 % are determined. It is shown that the equilibrium humidity of not collapsed spelt (in floral films) is within 9.35...13.78 %, collapsed (without films) – within 9.98...14.58 %. It is also established that the equilibrium moisture content is higher by 0.42...0.74 % for not collapsed, which can lead to deterioration in the quality of the collapsed spelt during its storage.

2. The nature of the change in the equilibrium moisture content of spelt is determined depending on the temperature and relative humidity of the air. With an increase in relative humidity and a decrease in ambient temperature, the equilibrium humidity of spelt increases. In the range of relative air humidity φ=30...70 %, the equilibrium humidity w_e of both collapsed and not collapsed spelt grows almost in direct proportion law and only after φ=70 % a more rapid growth of w_e is observed.

3. Empirical coefficients are determined and an equation is proposed that describes the dependence of the equilibrium moisture content of a spelt on the parameters of the ambient air – temperature and relative humidity. The proposed equation allows to predict the values of the equilibrium moisture content of not collapsed and collapsed

spelt at different temperatures and relative humidity. The average deviation is for not collapsed and collapsed spelt respectively 0.045 and 0.055 %.

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