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Original scientific paper

EQUIPMENT AND SCIENTIFIC STUDIES OF EXPERIMENTAL DATA ON STORAGE OF WHEAT GRAIN

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ABSTRACT

A complex of technical solutions is presented which makes it possible to study the influence of external factors on changes in the indicator of fat acidity value (FAV) and a range of other parameters characterizing the quality of preservation of long-term stored wheat grains in South Russia. Storage conditions (natural climatic, model) and also the effect of dust suppression treatment of grain by oil glazing that is carried out in some grain terminals in the South of Russia were taken as controlled external factors. New data has been obtained on changes in parameters of food suitability of the wheat grains during storage under model conditions with varying degrees of severity of climatic conditions in South Russia. After 6 months of storage the most considerable changes in FAV value were found for 4th class of wheat stored in natural climatic conditions with intensive insolation, the increase was 1.7 mg KOH/1 g of fat (from 7.3 mg KOH/1 g of fat up to 9.0 mg KOH/ 1g of fat). Minimum changes in the same parameter for the same storage period were observed for the wheat of the 3rd class stored in a thermostat at a stable high temperature of 35 °C (from 11.6 mg KOH/1 g of fat to 11.5 mg KOH/1 g of fat). For wheat of the 4th class, the changes were 0.7 mg KOH/1 g of fat (from 7.8 mg KOH/1 g fat to 8.5 mg KOH/1 g of fat). Analyzes of stored wheat grains subjected to dust suppression by the oil glazing showed similar results, which allows us to state the absence of a significant effect of oil glazing on changes in wheat properties during its storage.

Based on the results of the experimental analysis and a generalization of the data obtained an assumption was made on the possible reasons for the lack of pronounced trends in the data for the expected increase of FAV value in food suitability of the wheat grain when it is stored under typical model conditions of South Russia. The likely reason for this is the corresponding moisture state of grain, the water activity of grain was about 0.45. Such a low value was due, in particular, to the fact that samples of model-stored grain had a limited volume and do not reproduce the mass transfer processes that involve deep layers of the grain mass (because of the mass absence), which takes place during storage of grain in an industrial environment.

The tools were proposed for the operational monitoring of the moisture state of wheat grain during storage. Moreover, a plan has been developed to expand the field of modelling storage processes in terms of varying the moisture state of the stored wheat grain samples with an assessment of the influence of moisture state on the dynamics of changes in the parameters to be controlled.

1. Introduction

For wheat grains, as a raw material used for obtaining the corresponding grain products, standards of validity and freshness have not yet been defined. Also there are no systematized data on the nature of FAV changes in wheat grain stored under the various climatic conditions, which justifies the relevance of the current studies. The parameter of acid fat value is used to assess the freshness and shelf life of grain products, in particular, wheat flour — here the relevant standards have been established [1].

At the current period such studies were performed in laboratory conditions.

The methodological approaches during the research investigations consist of the laboratory modelling of grain storage processes and regular monitoring of the state of stored grain. This laboratory modelling for climatic conditions of the South Russia is performed in special laboratory storage boxes. It is laboratory conditions that allow deterministic sampling of the stored grain with appropriate analyzes and selective monitoring of the storage conditions.

The data obtained at this stage in the climatic conditions of South Russia will allow drawing of certain preliminary conclusions.

The additional study requires an understanding of degree of FAV nature changes influence on the wheat grains treated with the special dust-suppressing oil glazing during storage. Such oil glazing is widely used for grain export shipment in the Black Sea grain terminals in South Russia to increase the efficiency of transportation processes [2]. In particular, more than 10 million tons of Russian grain treated with such oil glazing has been shipped annually for more than six years. The indicated technology of oil processing of grain came to Russia from the USA, where it has been generally used for more than 25 years [3].

For the full implementation of the experimental part of these studies the appropriate equipment is required. Partially, in this capacity we use well-known standard tools. In particular for the determination of FAV [4].

The need for the laboratory modelling of storage conditions of grain in South Russia including the operational monitoring of crucial parameters over long time intervals as well as the need to prepare wheat grain samples subjected to variable oil glazing has resulted in the development and application of a range of special technical solutions. Such solutions will find their application also at the subsequent stages of research. In particular, in case of large volumes of stored grain in far spread distances delivery while monitoring of the grain condition.

Thus, the aim of the research is to study the change of the fat acidity value (FAV) in the grain of food-grade wheat under storage conditions of South Russia. The FAV characterizes the lipid complex in terms of its content in unsaturated and free fatty acids.

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2. Materials and methods

Storage was carried out in conditions as close as possible to the real climatic conditions of South Russia. The grain samples were placed into four containers. Two containers were installed in specially equipped boxes on the territory of the Kuban branch with slightly different conditions: in the shaded area under the influence of low-intensity natural insolation; and the other was installed in the area exposed to intense insolation. Two more containers were placed in a zone with active thermostatic control: inside a thermostat with a stabilized temperature of 35 °C with temperature deviations within the range of 0.5 °C. In these thermostatically controlled containers two samples were placed: a sample treated with oil glazing, and an untreated sample.

To ensure the most accurate temperature in the thermostatically controlled zone without dynamic fluctuations during regulation the special technical solutions were applied. The inner surface of the thermostatically controlled volume was separated from the external environment by a jacket filled with water coolant, inside of which there were thermal electric heating elements. The applied digital temperature controller provided dual-circuit temperature stabilization: stabilization of the coolant temperature in the jacket taking into account the temperature of the thermostatically controlled volume.

The general list of monitored parameters of wheat grain samples: FAV, moisture, quantity and quality of gluten, vitrescence, germination and sprouting energy. The determination of these parameters is carried out according to the relevant domestic standards that have foreign analogues.

The frequency of monitoring the state of the stored wheat samples: FAV — 1 month, commodity classification parameters and additional parameters — 3 months.

The dust-suppressing oil glazing of grain in industrial conditions mentioned in the introduction was carried out by spraying of vegetable (sunflower) or mineral (food additive E905) oil into the grain stream in the beginning of grain transport line in the works. The concentration of oil in the grain during this treatment is less than 0.02 %. As a result of this treatment, the volatility of grain dust was significantly reduced, which ensures a reduction in losses, improvement in the environmental and sanitary condition, increase of explosion safety level in the works, and reduction of power and waste disposal costs. The oil glazing agent sprayed in this way essentially belongs to the category of technological aids according to TR TS029/2012 «Safety requirements for food additives, flavors and technological aids». In the domestic interpretation, only sunflower oil — refined, deodorized, frozen out — has so far been used as a glazing agent in this technology. This is optimal item in its cost; it does not change the organoleptic and quality properties: grain safety, and allows processing at low ambient temperatures.

Our studies were also intended to identify the possible impact of sunflower oil introduced into the grain mass on the change of FAV index during storage of wheat grain in conditions of South Russia. To ensure the introduction of a variable dose of sprayed oil into the grain sample, a special laboratory stand for grain glazing was used, its scheme is shown in Figure 1. The stand, on the one hand, provides atomizer spraying oil aerosol into the grain sample, and, on the other hand, has measurement tools of the concentration of dust floating in the air overflow chamber. Monitoring of the oil aerosol dosage was carried out by changing the oil level in the capacity of the atomizer.

The main purpose of the stand was to assess the effectiveness of dust suppression by oil glazing of grains with different concentrations of sprayed oil and various types of glazers.

There is a detailed description of the specified stand [5]. The overflow chamber 5, in which the studied sample of grain was placed, is made in the form of a vertical section of pipe with a diameter of 100 mm. In the upper and lower part of the chamber 5 there are covers 3 and 15, through one of which a grain sample is loaded (and unloaded) into the chamber. The overflow chamber 5 has a cross-shaped joint with a horizontal section of pipe of the same diameter, which serves as the supporting body 6, mounted on sliding bearings 16 and rotating around the longitudinal axis with the help of electric drive 8. The electric drive itself is mounted on a fixed support 14. On the same fixed support 14 is fixed the opposite the end face of the housing 6, connected to the rotating part of the housing through an annular slip clutch 17. In order to prevent the exit of grain beyond the vertical cut of the pipe (chamber) 5 during its transverse rotation the restrictive diaphragms are installed in the interface between the housing 6 and the chamber 5.

The dust sensor 10 is mounted on the bracket and is located in the area of the dust exit from the chamber 5. The passage through the measuring channel of the dust sensor has a vertical orientation for unimpeded passage of soaring dust through it.

A solid-state laser emitter 9 and a digital video camera 1 are mounted on a fixed end of the housing. The laser beam 11 penetrates the entire horizontal space of the housing, passing through the overfill chamber and forming a light point on the boundary partition — the screen. The viewing sector of the video camera 2 covers the entire area of the backlight of the laser beam.

With the help of the electric drive 8, the housing 6 rotates around its longitudinal axis. In this case the overflow chamber 5 rotates around its transverse axis. At the same time, the grain sample 13 located in the chamber 5 performs periodic reciprocating movements, permanently pouring from one end of the transversely rotating chamber to its opposite end.

In the process of such pouring the dust present in the grain sample is released off from the grain sample into the inner space (5, 6). This dust floating in the air of the working space (5.6) passes through the restriction diaphragm 4 and enters the control passage of the dust sensor, which measures the concentration of dust in the air. In parallel, the video camera 1 is used to register an image of the space section (5, 6) through which the laser beam 11 passes.

Dust particles floating in the air are illuminated by a laser beam, which makes it possible to observe the density of dust particles in the laser beam illuminated by a light cord and the nature of the movement of these particles. Self-focusing the laser beam, due to its coherence and monochromaticity gives a clear visualization of the dust density distribution along the entire length of the spatial coordinate of the camera viewing sector.

The technique of grain sample processing at the described laboratory stand is as follows. A grain sample is loaded into the overfill chamber. The drive is started, the dust sensor readings are recorded and the laser dust visualizer is video-recorded. The rotation is carried out until stationary values of the measured parameters are reached.

Further, a dust-suppressing reagent is introduced into the grain sample with a spray nozzle-gun accompanying this rotation of the chamber and pouring of grain. As a result, a uniform processing of the entire grain sample by dust-suppressing reagent is achieved. Monitoring the dosage of oil aerosol was carried out by changing the oil level in the atomizer capacity.

After that the measurements of dust within the control interval were carried out. The experiments were performed in

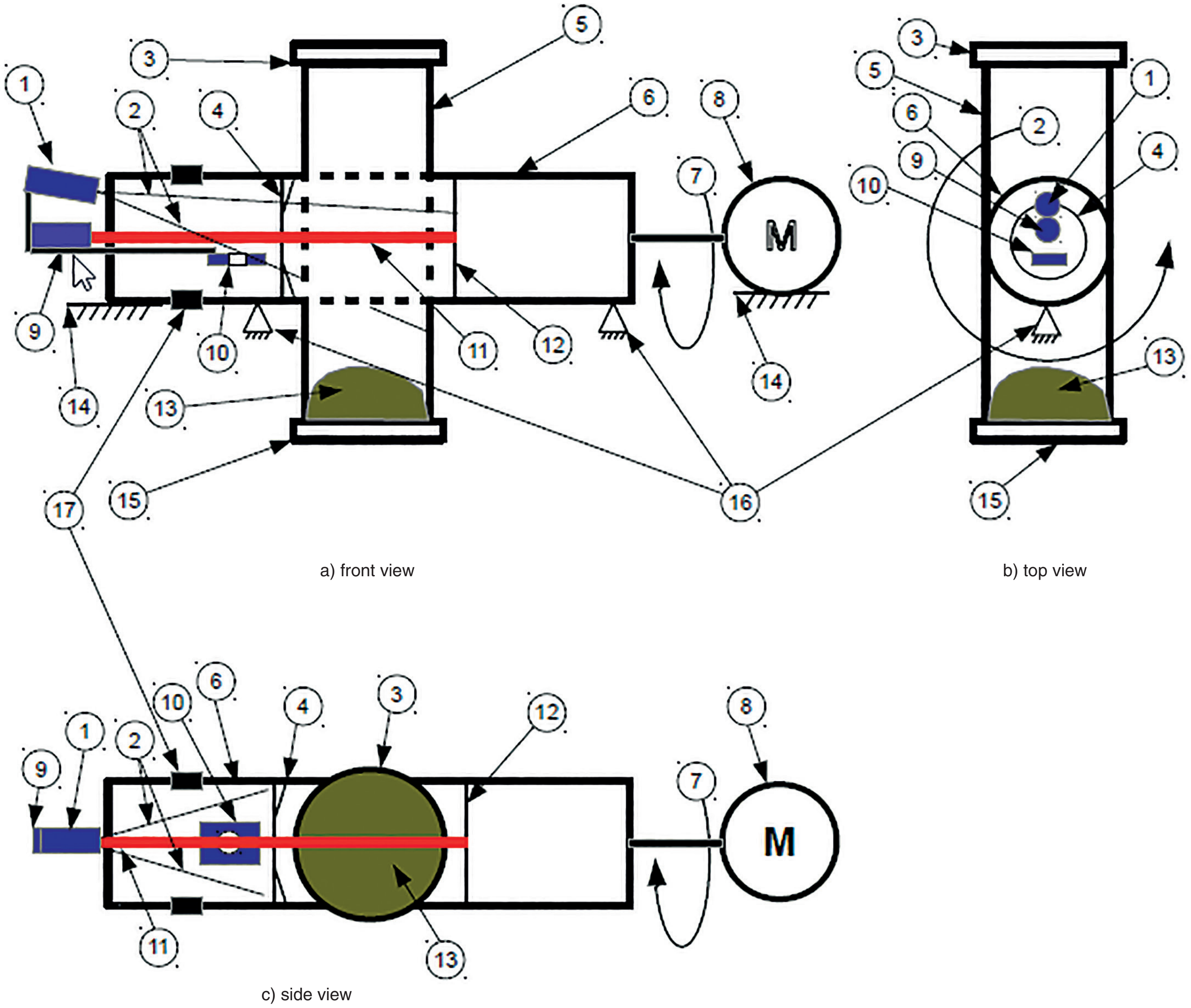

Figure 1. Diagram of a laboratory stand for grain glazing
where: 1 — digital video camera; 2 — camera review sector; 3 — top cover of the overflow chamber; 4 — restrictive diaphragm; 5 — overfill chamber; 6 — carrying case; 7 — direction of rotation; 8 — rotation drive; 9 — solid state laser; 10 — dust sensor; 11 — focused laser beam and the axis of the spraying torch oil atomizer; 12 — restrictive screen; 13 — grain test zone; 14 — fixed support; 15 — bottom cover of the overflow chamber; 16 — sliding support; 17 — slip clutch

several replications to verify reproducibility. As a dispenser and oil atomizer the laboratory atomizer of the compression type was used.

The SCADA system «MasterScada» was used as a data collection and registration system. At the same time, a data exchange protocol in ModBus format with data transfer via the RS-485 serial interface line was implemented in the secondary electronic unit of the dust sensor. Data transfer was carried out through the OPC server «LectusOPC».

Along with wheat grain samples that underwent laboratory oil glazing, a sample of grain that has passed oil dust glazing for suppression under industrial conditions at the Novorossiysk grain terminal was laid for experimental storage.

Laboratory modelling of storage conditions cannot fully reproduce storage conditions in an industrial volume grain terminal. The reason of it is an insufficient knowledge of the distributed and combined physical processes occurring in a large volume grain terminal under the influence of variable external conditions with heterogeneous initial conditions and, as a result, the complexity of their full formalized description. In this regard it is planned in the future to develop methods, prepare tools and conduct a similar kind of research on industrial volumes of stored grain.

To enable remote monitoring of the parameters of grain mass during experimental storage, a special set of measuring instruments has been prepared, which can be used both for research purposes and for arrangement of monitoring of the grain state in industrial production conditions. The composition of this set includes: thermic probes, hygro-thermic probes, wireless and wired data transmission modules, data collectors, special software. Instruments for hygro-thermic control allow determining the water activity of grain mass thus characterizing the stored grain mass from the point of view of its moisture state [6].

3. Results and discussion

Table 1, Table 2, Table 3 and Table 4 show the data obtained during the experimental storage of wheat grain samples.

Table 1

The results of soft wheat grain storage of harvest of 2018 in an actively thermostatically controlled zone with a maintained temperature of 35 °C (stated in June 2019)

Period of storage, month	FAV, mg KOH per 1 g of fat	Gluten		Moisture, %	Vitrescence, %	Sprouting energy, %	Germination, %
		quantity, %	quality, cu, IDC				
			3rd class				
Starting material	11.5	25.6	62.5	13.4	68	66	92
1	11.6						
2	11.4						
3	10.9	25.8	60	8.8	68	65	94
4	9.6						
5	11.7						
6	11.5	25.4	60	7.8	67	66	93
			4th class				
Starting material	7.3	22.0	85	11.8	60	93	97
1	7.8	22.0	85	11.3	60	87	96
2	7.5						
3	8.2	22.2	80	10.8	61	85	94
4	9.2						
5	8.6						
6	8.5	21.6	60	8.0	61	67	97
7	8.9						
8	8.9						
9	8.5	21.8	65	7.6	62	72	96
			4th class (treated with oil glazing)				
Starting material	7.3	22.0	85	11.8	60	93	97
1	7.4	22.2	85	10.6	59	86	95
2	7.4	22.4	80	9.9	60	86	95
3	8.5						
4	8.6	22.0	75	9.0	60	84	94
5	8.5						
6	8.7						
7	8.8	22.0	80	8.2	61	83	94

Table 2

The results of soft wheat grain storage of the harvest of 2018 under natural environmental conditions (in a box subjected to a regular exposure of direct sunlight, stated in June 2019)

Period of storage, month	FAV, mg KOH per 1 g of fat	Gluten		Moisture, %	Vitrescence, %	Sprouting energy, %	Germination, %
		quantity, %	quality, cu, IDC				
			3rd class				
Starting material	11.5	25.6	62.5	13.4	68	66	92
1	11.0						
2	10.8						
3	10.1	25.6	65	12.0	73	74	95
4	10.4						
5	10.7						
6	11.0	25.4	65	11.6	70	72	94
			4th class				
Starting material	7.3	22.0	85	11.8	60	93	97
1	7.2	22.2	85	10.8	60	88	96
2	7.1						
3	7.9	22.0	80	9.8	58	87	94
4	7.3						
5	8.9						
6	9.8	21.4	75	11.0	68	63	96
7	8.2						
8	8.8						
9	9.0	22.0	75	10.4	62	65	95

Table 3

Storage results of soft wheat grain of harvest of 2018 in natural environmental conditions (in a metal container not subjected to regular exposure of direct sunlight, stated in June 2019)

Period of storage, month	FAN, mg KOH per 1 g of fat	Gluten		Moisture, %	Vitrescence, %	Sprouting energy, %	Germination, %
		quantity, %	quality, cu, IDC				
3rd class							
Starting material	11.5	25.6	62.5	13.4	68	66	92
1	10.2						
2	12.5						
3	12.9	25.8	62.5	11.5	69	69	95
4	9.9						
5	13.1						
6	13.3	25.6	65.0	11.6	67	68	93
4th class							
Starting material	7.3	22.0	85	11.8	60	93	97
1	7.2	22.4	85	11.4	62	89	97
2	7.7						
3	8.1	22.0	80	10.9	63	87	95
4	8.3						
5	8.5						
6	10.9	22.0	70	11.2	59	63	96
7	8.7						
8	9.2						
9	9.4	22.2	75	10.4	60	64	97

Table 4

The results of the analysis of a wheat grain sample subjected to dust suppression by oil glazing in an industrial environment

FAV, mg KOH per 1 g of fat	Gluten		Moisture, %	Vitrescence, %	Sprouting energy, %	Germination, %
	quantity, %	quality, cu, IDC				
8.9	23.0	75	12.8	62	87	93

An analysis of the data presented in the tables allows us to preliminarily state the following: it is not possible to identify significant changes in the FAV parameter in experimental samples of wheat grain stored under conditions of South Russia for both subjected to oil glazing and stored since 2016 at stable high (35 °C) temperature.

So, as shown in Table 1, there were no significant changes in FAV value (11.6 mg KOH/1 g of fat) of 3rd class wheat stored for 6 months at a stably high temperature of 35 °C. Other parameters of product classification also remained practically unchanged. Wheat of the 4th class under the same conditions showed slightly different but close results: the value of the FAV parameter during storage increased from 7.8 mg KOH/1 g of fat to 8.5 mg KOH/1 g of fat, which increase can be considered insignificant. The situation here is similar to the other parameters of product classification.

Table 2 and table 3 show the data obtained during storage of wheat grain samples in natural climatic conditions in unshaded and shaded areas, respectively. Analysis of the data in these tables shows that the FAV values have a slight tendency to increase. At the same time changes of FAV of the 3rd class wheat stored in the zone with intensive insolation for 6 months were not recorded with the basic value of 11 mg KOH/1 g of fat, whereas such changes for wheat of the 4th class amounted as 2.6 mg KOH/1 g fat (from 9.8 mg KOH/1 g fat to 7.2 mg KOH/1 g of fat).

In the shaded zone the changes in FAV value were: 3.1 mg KOH/1 g of fat (with 10.2 mg KOH/1 g of fat and 13.3 mg KOH/1 g of fat) for the 3rd class, and 3.7 mg KOH/1 g of fat (c 7.2 mg KOH/1 g of fat to 10.9 mg KOH/1 g of fat) for the 4th class. Slightly higher moisture values were observed for the shaded zone.

What can serve as explanations for these preliminary conclusions? From our point of view, there can be several reasons for such results. In particular, one of the most probable reasons is that the grain is gradually dried (however it was initially in a dry state) under the conditions of increased temperature during the experimental storage inherent to the conditions of South Russia. As a result, moisture inside and on the surface of grain acquires a more bound state leading to a substantially slowing down of biochemical and microbiological processes, which are the initiators of the start stages of grain self-heating and spoilage including the oxidative processes leading to the formation of free fatty acids.

This situation significantly distinguishes the results of the planned modelling of South storage conditions from the results that could be obtained in real industrial grain storage conditions in South Russia. Here it is understood that one of the main factor which affects the potential deterioration in the quality preservation of grain mass under real industrial conditions is the redistribution of moisture inside the grain mass. This results in local drying of some zones and the concentration of moisture in other zones of the grain terminal capacity. However, such a redistribution of moisture is caused by the moisture transfer under the influence of external factors, mainly by the temperature gradient and condensation effects that occur on the inner surface shells, especially for metallic hoppers.

Moreover, it can be emphasized that the intensity of microbiological and biochemical processes in the grain is affected not by the mass fraction of moisture or moisture content in the grain as such, but by the amount of bound moisture or the moisture state of the grain. This parameter that uniquely characterizes the moisture binding of a material is the well-known as water activity or Aw, which is widely used in many branches of the food and pharmaceutical industries of the developed countries [7]. For grain, in particular, this parameter is numerically equivalent to the relative humidity expressed in fractions of unit or the relative humidity of intergranular air in thermodynamic equilibrium with grain. The practical implementation of this method does not cause technical difficulties. The procedure for determination of Aw actually comes down to measurement of the relative humidity of intergranular air under conditions of thermodynamic equilibrium.

$$Aw = Pw / Po = Pvv / 100, \quad (1)$$

where:

Pw is the pressure of water vapor in the food product system;

Po is the vapor pressure of pure water;

Rvv is a relative humidity in equilibrium in which the product does not absorb moisture and does not lose it into the atmosphere, %.

The indicated ratio is included in the basic thermodynamic equation for determination the binding energy of moisture with a material (Rebinder equation) [8]:

$$L = -R \cdot T \cdot Ln\,(Aw) \quad (2)$$

where:

L is the work of separation of 1 mole of water from the dry base of the material (without changing of the composition);

T is the temperature, K;

R is the universal gas constant.

From the literature data the general threshold values of *Aw* are known at which moisture is in a state accessible for the development of microbiological and biochemical processes in the products. These known threshold values are: $Aw < 0.65$ — moisture is completely inaccessible; $0.65 < Aw < 0.70$ — moisture is partially available; $Aw > 0.75$ — moisture is widely available [9].

With regard to grain, in particular wheat grain, such moisture categories can be defined as «dry grain», «medium dry grain», «wet grain».

In order to confirm the relation between the critical values of the «grain moisture content» category and the critical values of the «grain moisture state» category, we can provide known data on the equilibrium moisture content in grain and intergranular air in comparison with the data obtained from the normative documentation on the critical moisture values of various types of grain.

4. Conclusion

The two-year experimental storage of samples of food-grade wheat including the grain samples treated with oil glazing under modelling conditions of South Russia has not yet revealed the expected significant changes in FAV value. In order to establish the kinetic laws of this parameter change over a wide time range a continued experimental storage is required.

Uniform oil glazing of a grain sample with an adjustable norm in laboratory conditions can be performed effectively due to the interaction of a cyclically pouring of grain sample and its treating with an oil aerosol nozzled by an atomizer.

The state of moisture in grain is potentially a factor that affects the kinetic processes course during storage. Defining the degree of moisture state influence on the kinetics changes in FAV value requires an additional cycle of research.

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