USE OF OZONE IN OATS DRYING

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Abstract. The present article describes the drying of wet oats at different temperatures with ozonated and non-ozonated air. Experimental results show that moisture removal during drying of oats at temperature T = 21 ºC is higher using ozonated air than non-ozonated air. Moreover, after a 4-hour drying process, it amounts to 1.6 g per kg of oats. Using heated air, the difference in moisture removal decreases. At the beginning of the drying process, a decrease in the temperature of the drying agent can be observed in the layer, which is caused by the removal of moisture from the surface of grains. By increasing the air temperature from 21 ºC to 40 ºC, in the first hour of drying, 12.6 more $g \cdot kg^{-1}$ is removed than with unheated air, and in the second hour even more than 15 $g \cdot kg^{-1}$. By increasing the drying temperature from 40-60 ºC, this difference is much smaller -in the first hour only 3.5 $g \cdot kg^{-1}$, in the second already more than 7.3 $g \cdot kg^{-1}$. This could be explained by the fact that as the temperature increases, the thickness of the layer in which the drying process takes place increases. By processing the obtained experimental data, a relationship was obtained that connects the drying rate and temperature with the amount of moisture removed.

Keywords: drying, temperature, ventilation, ozone.

Introduction

Grain drying consumes about 60% of energy compared to other processes, so it is very important to look for solutions to make this process both more economical and faster [1]. Food security remains a major global problem, yet more than one-third of food is lost or wasted during post-harvest operations [2]. Many scientists have focused on researching the quality of oats and other cereals during drying and especially during storage. Thus, models were developed that relate quality losses of oats and toxin formation to different storage conditions [3; 4], The importance of lipase inactivation in the formation of oat rancidity was clarified by performing various degrees of heat treatment. A trend was found that the lower the residual lipase activity in whole kernels or kernel fractions, the higher the development of lipid oxidation and volatile oxidation products [5].

Ozone gas is used not only by living organisms (insects, mites, fungi and bacteria) and the breakdown of toxic compounds (pesticides and mycotoxins). Terms of use of ozone. and efficacy for various foods is also discussed [6]. It is emphasized that ozone is an effective green agent for combined multiple decontamination, thereby extending food storage and shelf life. It has no negative effect on the quality of the food.

Ozonation can be used to increase ethanol production. When evaluating the performance of ethanol production material, the fermentation efficiency of ozone-treated sorghum increases by more than 10% compared to the control. This indicates that ozonation is an effective way to increase the ethanol yield and shorten the fermentation process without reducing the ethanol yield [7].

The penetration of ozone into the grain layer with an ozone-air mixture has been studied [8-10]. It has been found that it depends on the initial ozone concentration in the supplied ozone-air mixture, the initial moisture content of the grain, the ozonation time and the thickness of the grain layer

For the pre-sowing treatment of seeds, in order to destroy the external and internal phytopathogenic microflora, to activate the vital activity processes of the seeds and to protect the plants during their vegetation period, chemical agents are widely used. However, in addition to the positive effect, chemical agents also have negative consequences: environmental pollution with pesticides and their accumulation in the soil and in the crop products themselves. From the middle of the 20th century, research began on the effect of ozone on grain - that ozone can both replace weed control and grain pickling chemicals, and improve the quality of grain in the drying and storage process [11-14].

Much attention is devoted to the destruction of various fungi in the grain layer. Thus, 1 hour of wheat and 2 hours of corn grain treatment with ozone was sufficient to reduce the total number of molds and inhibit the bioavailability of aflatoxins without producing toxic secondary compounds [15; 16].

The analysis of the research results made it possible to determine the feasibility of the initial ozonation of a wet grain pile in metal buffer storage tanks before feeding it to the grain dryer. Equipping buffer tanks for temporary storage of grain with an ozonation system, which, according to preliminary studies, will reduce the moisture content of a stack with one pass through a column grain mill to 8.3%. Currently, the percentage of moisture removed in one drying cycle does not exceed 6% [17].

Ozone is used to ensure a microbiologically safe product. One of the promising directions for increasing the energy efficiency of the grain drying process and saving energy resources is the improvement of grain threshing technology. The use of ozone can reduce the energy required in the milling process by reducing the amount of outer shell and damaged starch grains.

Investigate the efficiency of using ozonated air in drying oats at different temperatures and compare it with drying oats with non-ozonated air was aim of the research.

Materials and methods

For the research, an air flow supply device with two parallel air supply channels was made, which ensured the simultaneous performance of two experimental studies Fig. 1.

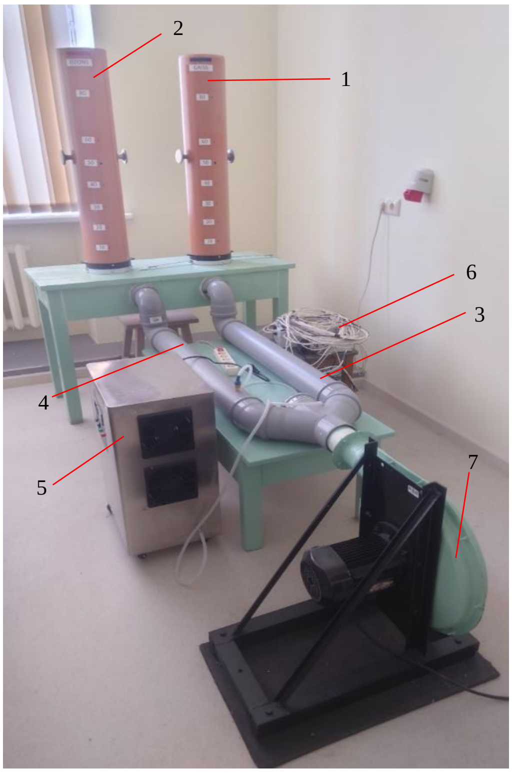

Fig. 1. **Experimental equipment for oat studies with ozonated air:** 1 – oat tank for ventilation with non-ozonated air; 2 – oat tank for ventilation with ozonated air; 3 – non-ozonated air supply pipe; 4 – ozonated air supply pipe; 5 – ozone generator DNA-20G; 6 – air temperature and humidity registration device; 7 – fan

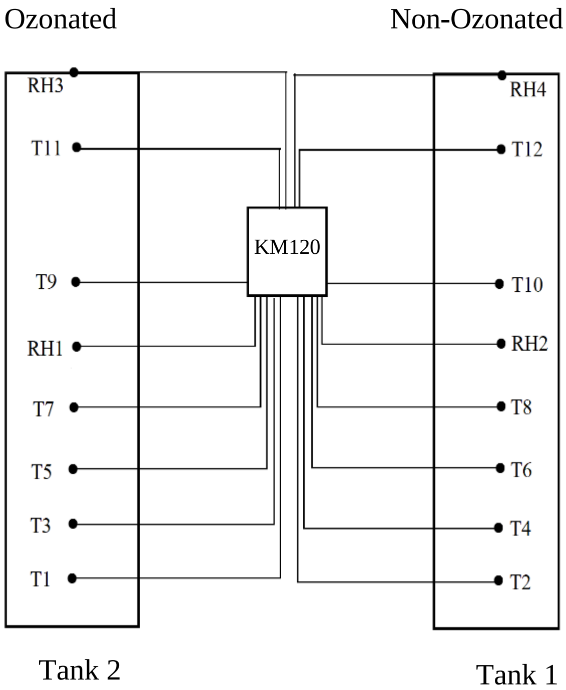

Fig. 2. **KM120 Loger sensors arrangement scheme**

In the research, identical oat ventilation is used to ventilate the tank with non-ozonized air 1 and with ozonated air 2. In the tanks, holes are made every 10 cm for a layer up to 60 cm thick and after 20 cm for a layer thickness of 80 cm for placing the KM120 Loger sensors of the registration device Fig. 2.

Artificially moistened oats were used for the experiments. Air temperature and humidity were determined with a recording device KM120 Loger. The device Supertech GM 2500 was used to determine the moisture content of moistened oats, the measuring accuracy is ±0.1%. Initial oat moisture was determined by taking 5 measurements from a total oat bin, after which oats are placed in drying bins of equal weight and height. The speed of the ventilated air flow at the exit from the oat tanks was measured with a measuring instrument Testo 417, the measurement range was 0.3...20 m·s^{-1} and the accuracy are ±0.1 m·s^{-1}. During the research, changes in the weight of oats were determined with OHAUS platform scales with an accuracy of ±0.005 kg. An ozone generator DNA-20G with an ozone concentration of 20 g·h^{-1} was used for ozone production. Experiments were performed with unheated room air (19.5-21.5 ºC) and heated air (40 ºC and 60 ºC). A Dania 9 kW electric heater was used to heat the air.

Each drying experiment was carried out for 4 hours, divided into 15 stages, respectively 6 stages of 10 minutes, 4 stages of 15 minutes, 3 stages of 20 minutes and 2 stages of 30 minutes. At the end of each stage, the ozone generator and fan were turned off, the sensors were removed, and both tanks were weighed to determine weight changes during drying. Changes in temperature and air humidity were recorded automatically and recorded in the data file of the KM120 logger. At the end of the experiments, oat moisture was determined in layers from the top of the tank at 65 cm, 45 cm, 25 cm and at the bottom of the tank with a Supertech GM 2500. The initial parameters of the experiment are shown in Table 1.

Table 1

Parameters of the experiments

Parameters	**Eksperiment 1**	**Eksperiment 2**	**Eksperiment 3**
Mass of oats in each container *m*, kg	12.73	12.44	12.29
Average moisture content of oats w_1, %	21.5 ± 0.8	20.1 ± 0.4	19.5 ± 0.3
Air flow speed on the surface of the layer, m·s^{-1}	0.55		
The temperature of the air entering the fan *T*, ºC	21	40	60
Oat layer thickness *h*, cm	83	81	80
Ozone concentration, g·h^{-1}	20		

Results and discussion

In all the following graphs, ozonated air data is marked in dark blue, and non-ozonated air data is marked in orange. The specified layer sizes are measured from the bottom of the tank. In an experiment with unheated atmospheric air (21ºC) after 4 hours of drying, the moisture removed when drying with ozonated air was 66.8 g per kilogram of oats, but when drying with non-ozonated air it was 65.2 g per kilogram of oats. The distribution of the amount of water removed by hours can be seen in Fig. 3.

When heating the drying agent (air), it can be seen that the amount of moisture removed increases in both cases, both when drying with ozonated air and without ozonation. After 4 hours of drying at an air temperature of 40 ºC, the moisture removed when drying with ozonated air was 101.3 g·kg^{-1}, while the moisture removed with non-ozonated air was 102.1 g·kg^{-1}. The amount of moisture removed can be seen hourly in Fig.4. There is no observable effectiveness of ozonated air during drying.

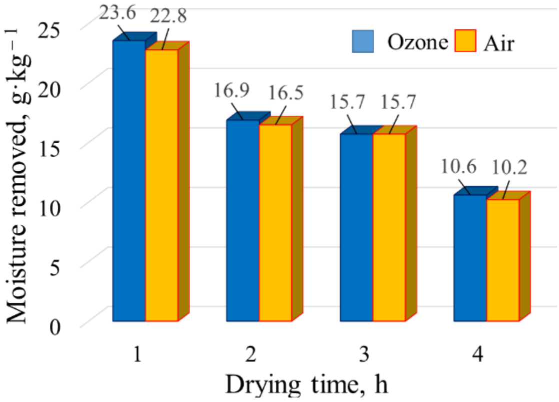

Fig. 3. **Amount of removed moisture per drying hours, drying with unheated air (21ºC)**

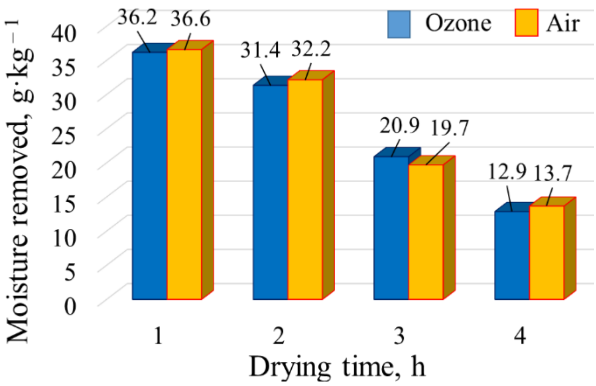

Fig. 4. **Amount of moisture removed per drying hours, drying with heated air (40 ºC)**

By increasing the temperature of the ventilated agent up to 60 ºC, the moisture removed during drying with ozonated air was 122.1 g·kg^{-1}, and with non-ozonated air 122.9 g·kg^{-1}. The distribution of the amount of moisture removed by hours can be seen in Fig. 5.

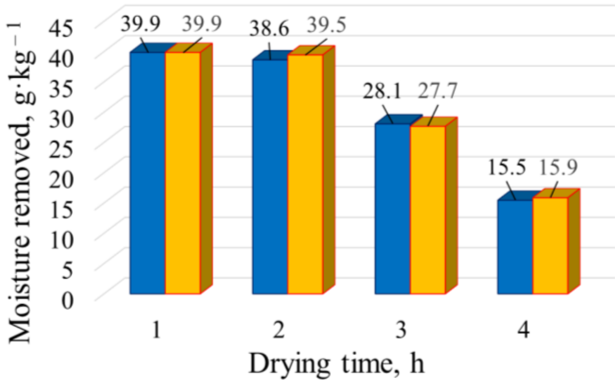

Fig. 5. **Amount of moisture removed per drying hours, drying with heated air (60 ºC)**

Comparing the experimental results of drying, it can be seen that increasing the temperature of the drying agent (air) increases the amount of moisture removed in the first hours with both ozonated and non-ozonated air.

By increasing the air temperature from 21 ºC to 40 ºC, in the first hour of drying, 12.6 more g·kg^{-1} is removed than with unheated air, and in the second hour even more than 15 g·kg^{-1}. By increasing the drying temperature from 40-60 ºC, this difference is much smaller – in the first hour only 3.5 g·kg^{-1}, in the second already more than 7.3 g·kg^{-1}. This could be explained by the fact that as the temperature increases, the thickness of the layer in which the drying process takes place increases.

Grain moisture in different layer thicknesses after 4 hours of drying at different drying temperatures is summarized in Table 2. The results of the experiment show that the oats at the bottom of the tank are about 3.5% drier than in the upper measured layer, i. e. 65 cm thick with an unheated drying agent, 2.3% – drier at a drying temperature of 40 ºC and within 0.3-0.5% using a drying agent with a temperature of 60 ºC.

It should be noted that the occupied volume of oats decreased by 10.8% when dried with unheated air, 13.6% when dried at 40 ºC and 16.3% when dried at 60 ºC.

Table 2

Grain average moisture (%) at different layer thickness after 4 hours of drying

Oat layer thickness, cm	**Drying temperature T = 21 ºC**		**Drying temperature T = 40 ºC**		**Drying temperature T = 60 ºC**	
	Ozonated air	**Non-ozonated air**	**Ozonated air**	**Non-ozonated air**	**Ozonated air**	**Non-ozonated air**
65	16.7	16.8	13.0	12.8	10.4	10.5
45	13.8	14.0	11.6	11.4	10.3	10.3
25	13.4	13.4	10.7	10.7	10.2	10.1
0	13.1	13.3	10.7	10.6	10.1	10.0

The temperature and humidity changes of the drying agent in the oat layer are shown in Fig. 6-7. Here we compare the situation when drying with unheated air and ozone-air mixture and heated 40 ºC heat agent.

At the beginning of drying, a drop in temperature can be observed, which stops in the lower oat layer already after the first 5 minutes and the temperature rises rapidly. This could be explained because at the beginning of drying, moisture is removed from the surface of the oats, which in turn causes the temperature to drop. Peaks on the graph curves occur when the fan and the drying process are stopped and measurements are taken. The total amount of moisture removed at different drying temperatures can be seen in Fig. 8.

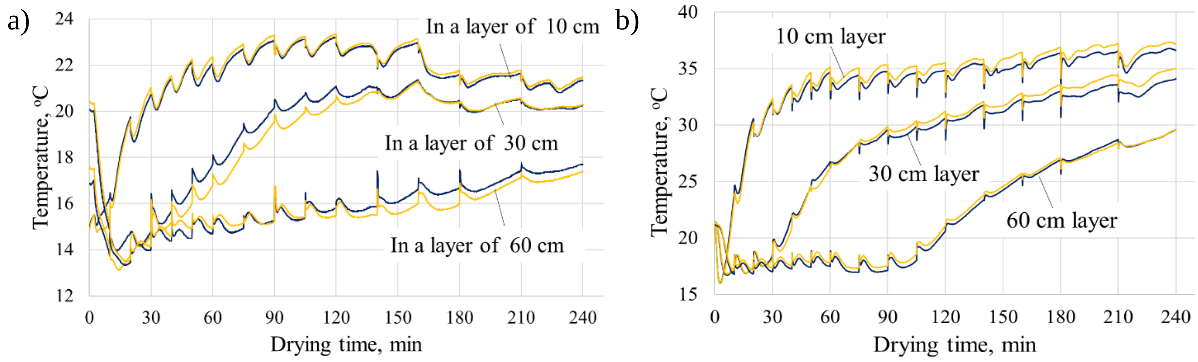

Fig. 6. **Ozonated and non-ozonated air temperature at different thickness of oats layers with drying temperature:** a – 21ºC; b – 40 ºC

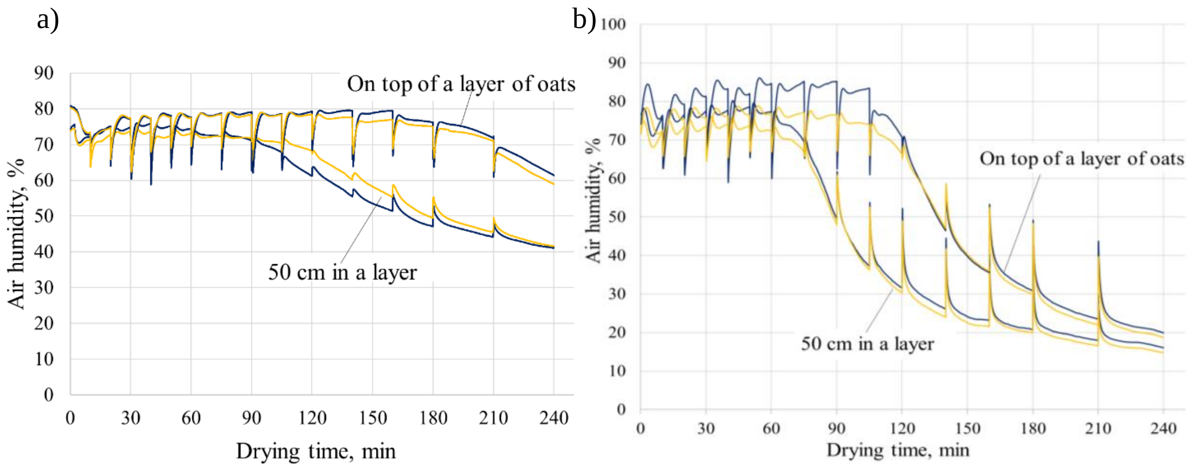

Fig. 7. **Ozonated and non-ozonated air humidity at different thickness of oats layers with drying temperature: a – 21ºC; b – 40 ºC**

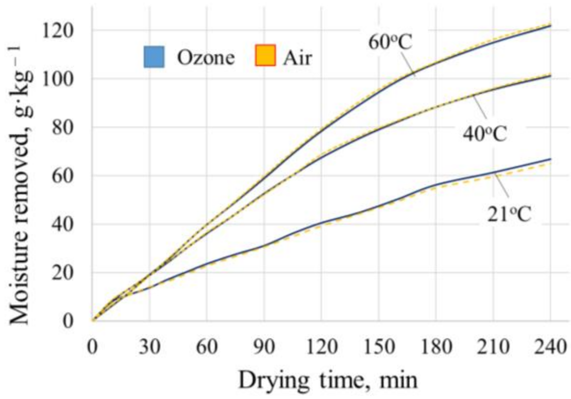

Fig. 8 **The total amount of moisture removed dependence on the drying time and temperature**

Using the experimental data and processing them statistically, an expression was obtained that characterizes the amount of moisture removed depending on the drying temperature and time under the given experimental conditions (1).

$$m = 0.2667 \cdot t - 0.8 \cdot 10^{-3} \cdot t^2 + 0.227 \cdot T - 4.25 \cdot 10^{-3} \cdot T^2 + 8.15 \cdot 10^{-3} \cdot t \cdot T, \quad (1)$$

where m – moisture removed, g·kg^{-1};
t – drying time, min;
T – drying temperature, ºC.

The correspondence of this relationship to experimental data is high, the coefficient of determination η^2 = 0.99. The graphical interpretation of the given relationship can be seen in Fig. 9-10.

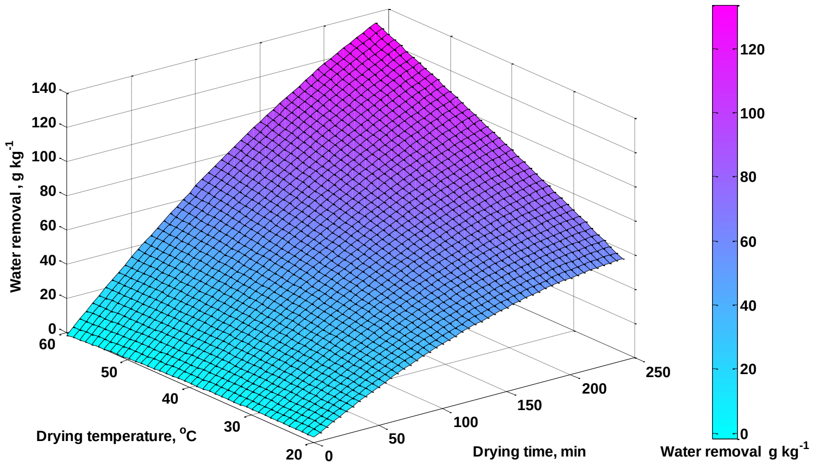

Fig. 9. **Water moisture removed dependence on the drying temperature and drying time**

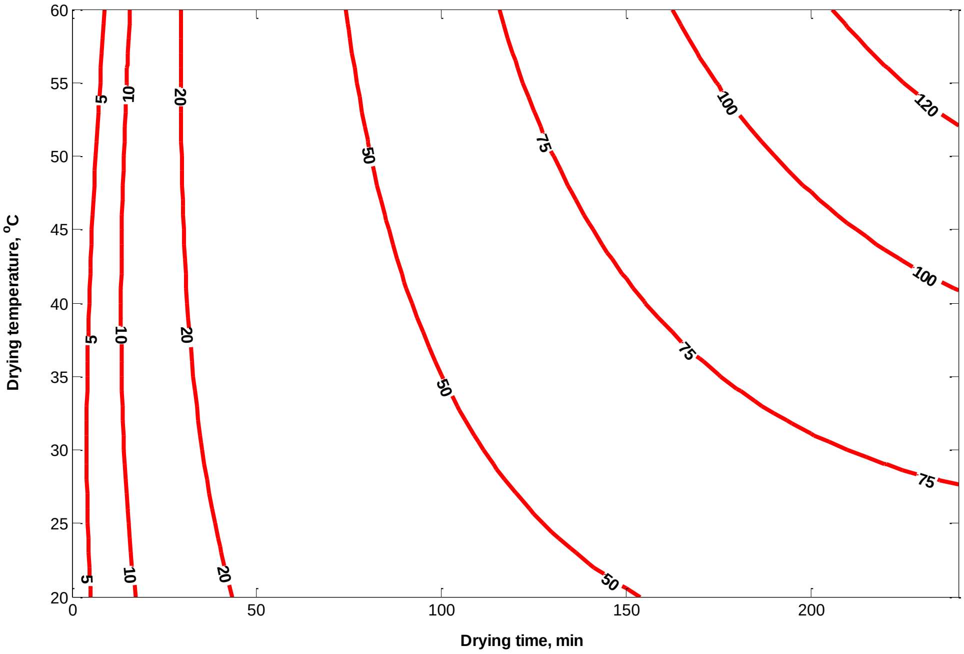

Fig. 10. **Contour representation of moisture removed (g·kg-1) dependence on the drying temperature and drying time**

Experimental data show that there is no significant difference in moisture removal when drying oats with ozonated and non-ozonated air, especially with heated air. It was observed that in drying process with ozonated unheated air, the amount of moisture removed is slightly higher than when drying with non-ozonated air.

Conclusions

1. Experimental results show that there is no significant difference in moisture removal when drying oats with ozonated or non-ozonated air, especially with heated air
2. Drying oats with unheated air (T = 21ºC), higher moisture removal was observed with ozonated air than with non-ozonated air. After 4 hours of drying, the total moisture output per 1 kg of oats was 1.6 g higher than without ozone.
3. By increasing the air temperature from 21 ºC to 40 ºC, in the first hour of drying, 12.6 more g·kg^{-1} is removed than with unheated air, and in the second hour even more than 15 g·kg^{-1}. By increasing the drying temperature from 40-60 ºC, this difference is much smaller -in the first hour only 3.5 g·kg^{-1}, in the second already more than 7.3 g·kg^{-1}. This could be explained by the fact that as

the temperature increases, the thickness of the layer in which the drying process takes place increases.

4. The study shows that the use of ozone in the drying of oats has a positive effect, especially when using unheated air for drying. It should also be taken into account that an ozonated environment kills microorganisms that are found in the oat layer and multiply quickly in a moist, warm environment.

Author contributions

All the authors have contributed equally to creation of this article.

All authors have read and agreed to the published version of the manuscript.

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