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REVEALING THE INFLUENCE OF TEMPERATURE AND MOISTURE CONTENT ON ELECTROPHYSICAL PARAMETERS OF RAW APPLE MATERIALS

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Abstract

Additional heating of fruit raw materials in the drying process by direct passage of alternating electric current makes it possible to intensify the dehydration process by 3–5 times.

The amount of added thermal energy during direct electric heating depends, first of all, on the value of the specific electrical resistance of the raw material. Therefore, the list of necessary properties of the material must necessarily include the specific electrical resistance of the raw material as an integral indicator.

During drying with additional direct electric heating, the concentration of dry soluble substances, which directly depends on the moisture content of the studied raw material, and its temperature change throughout the drying time. This indicates a change in specific electrical resistance during the dehydration process. It was determined that the initial resistivity of apples before drying at a temperature of 20 °C and a moisture content of 8 kg/kg is within 195–220 Ohm·m, which indicates the high conductivity of the material.

With a decrease in moisture content from 8 to 6 kg/kg, the specific electrical resistance of the raw material decreases by 25–30 % compared to the initial values. With a further decrease in moisture content below 6 kg/kg, the electrical resistivity of the raw material begins to gradually increase.

At the same time as the temperature rises, there is a significant decrease in specific electrical resistance. When heating raw materials from 25 to 55 °C, the value of specific resistance decreases by 10–13 times.

The equation of the dependence of the specific electrical resistance of apple raw material on its moisture content and temperature for the studied apple varieties was obtained.

The obtained results of the change in the value of the specific resistance provide the necessary data for the development of an energy-saving technological device for drying fruits and the selection of optimal processing conditions in compliance with quality indicators.

Keywords: apple raw material, moisture content, direct electric heating, electrophysical parameters of apples, specific electrical resistance, power of direct electric heating.

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1. Introduction

Despite the modern technologies of storage of vegetable and fruit products, methods of long-term storage of dried raw materials with an unchanged content of useful substances remain in effect [1–3].

When harvesting a small amount of fruit and vegetable raw materials, natural air drying is most often used [4]. As a result, a high-quality dried product is obtained. However, the processing of large volumes of highly vitaminized vegetables and fruits presents increased requirements for technological processes and equipment:

– obtaining a product of the required quality at the output, which is primarily established by organoleptic inspection, is ensured by the limited temperature of the material during processing;

– the maximally reduced time of implementation of technological operations, which ensures an increase in labor productivity and a decrease in specific capital costs;

– reduction of thermal and electrical energy costs for removal of 1 kg of moisture.

In the drying industry, the convective method of drying with heated air is most widespread [3, 5]. However, the limited ratio of the surface of the sample and its mass, restrictions on the maximum temperature of the heat carrier lead to the fact that the duration of processing is very long. In the conducted studies of drying apple raw materials [6] under different technological regimes, the process of convective dehydration lasts 6–12 hours.

Intensification of drying is possible under the conditions of additional supply of thermal energy, in particular, infrared irradiation, acoustic ultrasonic treatment, heating in the microwave fields of the electromagnetic field, heating of the juice-containing material by direct passage of alternating electric current [6, 7].

The most appropriate is the use of direct electric heating, where joule heat is immediately applied without additional energy conversion. This ensures the highest efficiency, simplicity and cheapness of hardware design. The use of direct electric heating allows to shorten the process of convective drying of raw materials by 3–5 times [6].

During the drying of raw materials by the proposed method [8], the efficiency of the process is ensured by the following kinetic and technological parameters:

– temperature and consumption of drying agent;

– initial and final moisture content of the material to be dried;

– the temperature of the samples during processing;

– the magnitude of the applied electric field and the strength of the current passing through the raw material.

The list of necessary properties of the material must necessarily include the specific electrical resistance of the material as an integral indicator. The amount of added thermal energy during direct electric heating depends, first of all, on the value of the specific electrical resistance of the raw material.

A number of experimental works [9–13] were devoted to the study of electrophysical parameters of fruit raw materials, in particular, in the process of direct electric heating. However, due to the peculiarities of fruits (different degrees of maturity, chemical composition depending on the variety and fruits of the same variety), direct use of the obtained results of these works is impossible. In addition, most often this kind of experiments were carried out only at the stage of preliminary processing of raw materials without an in-depth study of the kinetics of dehydration and physical processes occurring inside the biological object during the drying process.

This allows to state that it is appropriate to conduct a study devoted to determining the influence of temperature and moisture content on electrophysical parameters, in particular, the electrical resistance of raw materials.

2. Materials and methods

Early summer and summer ripening apples of the Red Mac, Mantet and Helios varieties grown in the Sumy region (Ukraine) were chosen as objects of research.

Pre-prepared fruits were cut into cylindrical pieces with a height of 5 mm and a diameter of 28 mm. Later, these samples were dried at a room temperature of 20 °C to the set humidity, after which their linear dimensions were measured again.

The sample was then placed between two stainless steel mesh electrodes. By passing electric alternating current, the prepared apple samples were heated to a temperature in the range of 25–75 °C. At the same time, according to the readings of the milliammeter E536 (Ukraine), the magnitude of the current passing through the raw material was recorded.

The temperature inside the samples was determined by installed TXA (chrome-alumel) thermocouples (China) with thermoelectrode diameters of 0.2 mm connected to a VC61A type temperature indicator (China).

Based on the obtained data of the electrical resistance measured by the ammeter-voltmeter method, the values of the current specific electrical resistance were calculated according to the expression:

$$\rho = R\frac{S}{l}, \quad (1)$$

where ρ – current specific resistance, Ohm·m;

R – electrical resistance of the sample, Ohm;

l – current length (height) of the sample, m;

S – cross-sectional area, m^2.

The Statistica 12 (USA) standard program package was used to visualize the research results.

3. Results and discussion

During electrothermal processing, in particular, additional heating of high-moisture raw materials by direct passage of electric current through the material, the necessary electrophysical parameter is the specific volumetric capacity:

$$N_s = \frac{U^2}{RV}, \tag{2}$$

where N_s – specific volumetric power, W/m^3;

U – voltage, V;

V – volume of material, m^3.

Simultaneously:

$$U = E \cdot l, \tag{3}$$

$$R = \rho \frac{l}{S}, \tag{4}$$

where E – electric field strength, V/m.

Taking into account (3) and (4) and after appropriate transformations, the expression of the specific power (1) released in the material will have the form:

$$N_s = \frac{E^2}{\rho}. \tag{5}$$

It can be seen from the obtained expression (5) that the smaller the specific electrical resistance of the raw material, the more power can be added to the convective heat flows. In other words, the specific electrical resistance of the raw material is the main electrophysical parameter on which the efficiency of heating the raw material in the drying process depends.

Conducted studies of the electrical conductivity of fruit raw materials in [13] indicate that the electrical conductivity of fruit and vegetable juices is affected by the concentration of dry soluble substances (vitamins, minerals, sugars, etc.) and temperature.

During drying by the proposed method [8], the concentration of dry soluble substances, which directly depends on the moisture content of the studied raw material, and its temperature change throughout the drying time, which indicates a change in specific electrical resistance during the dehydration process.

The results of the study of the specific electrical resistance of sliced apples of the studied varieties at different values of their moisture content and temperature are shown in **Fig. 1–3**.

Analyzing the obtained dependencies (**Fig. 1–3**), it is possible to conclude that for the apples of the studied varieties, the values of their specific electrical resistances are practically the same. The initial specific resistance of apples at a temperature of 20 °C and a moisture content of 8 kg/kg is within 195–220 Ohm·m, which indicates the high conductivity of the material.

As the moisture content decreases from 8 to 6 kg/kg, the specific electrical resistance of the raw material decreases somewhat. With a decrease in the moisture content to 6 kg/kg at a temperature of 20 °C, the value of the specific electrical resistance decreased by 25–30 % compared to the initial values. This is explained by the internal movement of juice from the cells to the surface of the raw material, which increases the free moisture in the sample.

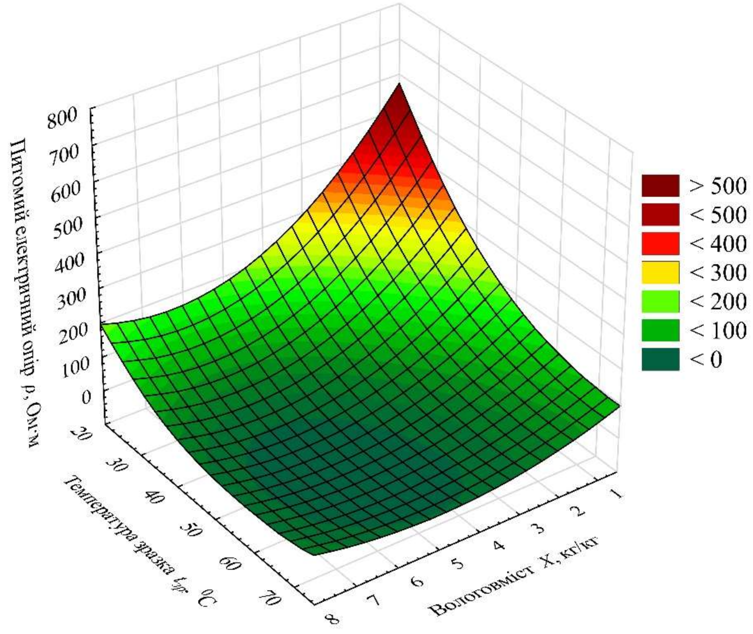

Fig. 1. The effect of moisture content and temperature on the specific electrical resistance of sliced apples of the "Helios" variety

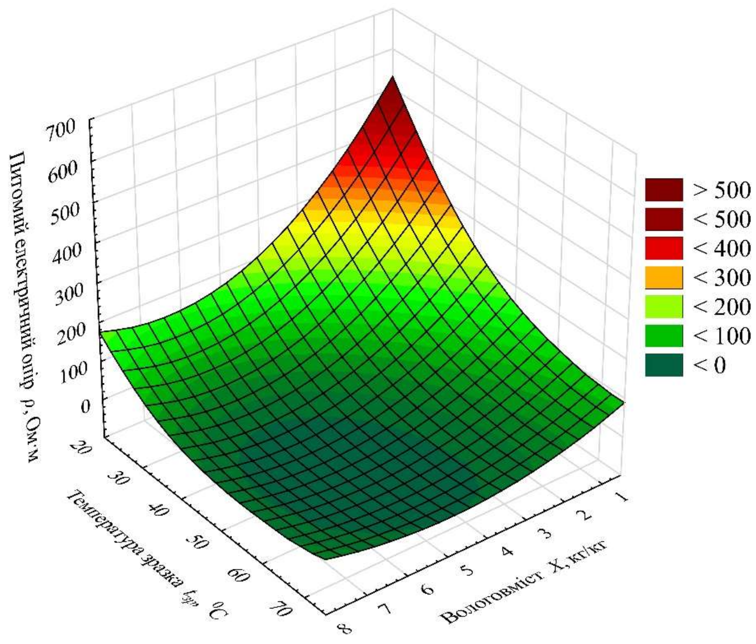

Fig. 2. The effect of moisture content and temperature on the specific electrical resistance of sliced apples of the "Mantet" variety

As the moisture content decreases below 6 kg/kg, the specific electrical resistance gradually increases. Obviously, this is explained by a decrease in the amount of free moisture in the samples, as well as an increase in the concentration of electrically neutral mono- and disaccharides (sugars), which significantly affect the decrease in the conductivity of the juice [14, 15].

At the same time as the temperature rises, there is a significant decrease in specific electrical resistance. Thus, in all cases, when the raw material is heated from 25 to 55 °C, the value of the specific resistance decreases by 10–13 times. The decrease in the resistance of the raw material is explained by the sharp release of cell juice as a result of increased permeability of cell membranes under the influence of temperature and the phenomenon of electroplasmolysis, which occurs when an alternating electric current is passed through plant objects [12].

It is an established fact that when heated to 60–65 °C, the specific resistance drops to a minimum value and practically does not change during further heating of the samples. This is explained by the complete destruction of cytoplasmic membranes and the lethal effect of high temperature on the vital activity of cells. Therefore, heating raw materials above 55–60 °C during drying can significantly worsen the quality of the finished product.

As a result of processing the obtained results in the Statistica 12 software environment, there are the following equations for the dependence of the specific electrical resistance of apple raw materials on its moisture content and temperature:

– for "Helios" apples:

$$\rho = 946.2556 - 129.2027\tilde{O} - 21.8327t_r + 7.7891X^2 + 0.8168X \cdot t_r + 0.1484t_r^2, \quad (6)$$

where X – moisture content, kg/kg;

t_r – the temperature of the raw material, °C;

– for "Mantet" apples:

$$\rho = 880.6729 - 121.4554\tilde{O} - 20.4984t_r + 7.337X^2 + 0.768X \cdot t_r + 0.1407t_r^2; \quad (7)$$

– for "Red Mac" apples:

$$\rho = 884.3821 - 115.8796\tilde{O} - 21.4133t_r + 7.011X^2 + 0.7374X \cdot t_r + 0.1519t_r^2. \quad (8)$$

The main technological parameter of drying, on which the quality of the finished product depends, is the maximum temperature of the product during the processing. At the same time, the maximum value of the heating temperature of the raw material during the drying process directly depends on the value of its specific electrical resistance. Therefore, specific resistance can also serve as an informative parameter for choosing a product processing mode.

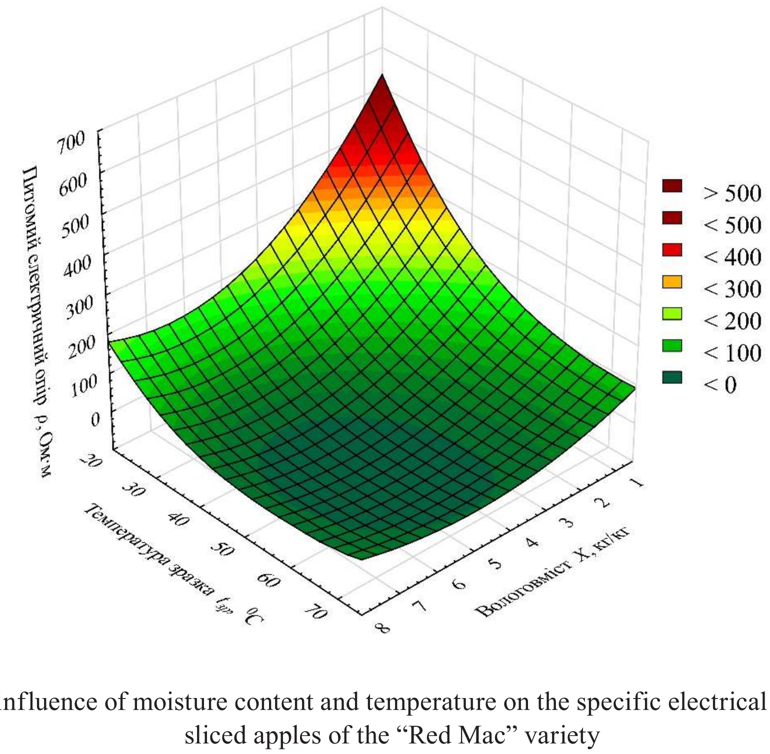

Fig. 3. The influence of moisture content and temperature on the specific electrical resistance of sliced apples of the "Red Mac" variety

The obtained mathematical expressions allow for regulation and control of the temperature regime in the process of drying apple raw materials by changing the intensity of the electric field of direct electric heating.

Low values of the specific resistance of juicy raw materials may indicate the feasibility of using direct electric heating to intensify the convective drying process.

The next stage of the conducted research is the development of an energy-saving device for drying fruits using direct electric heating of raw materials.

The main difficulties in solving this problem may be the lack of data in the literature on the electrophysical parameters of some types of fruits, which are necessary to determine the optimal modes of processing raw materials. However, this problem can be solved by conducting additional experimental studies.

4. Conclusions

Experimental studies of the dependence of the specific electrical resistance of apple raw materials on moisture content and temperature were carried out.

It was determined that the initial resistivity of apples before drying at a temperature of 20 °C and a moisture content of 8 kg/kg is within 195–220 Ohm·m. With a decrease in moisture content from 8 to 6 k/kg, the specific electrical resistance of raw materials decreases by 25–30 %, and with a further decrease in moisture content, it begins to increase.

With an increase in the temperature of the raw material, there is a significant decrease in the specific electrical resistance, in particular, when it is heated from 25 to 55 °C, the value of the specific resistance decreases by 10–13 times. Heating the raw material to 60–65 °C leads to a drop in the value of the specific resistance to minimum values, which practically does not change with further heating of the samples.

The equation of the dependence of the specific electrical resistance of apple raw materials on its moisture content and temperature for the studied varieties of apples was obtained, which will allow regulation and control of the temperature regime during the drying process.

Low values of specific electrical resistance indicate the feasibility of using direct electric heating for additional heating of raw materials during the drying process and create prerequisites for the development of an energy-saving device for drying fruits.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this study, including financial, personal, authorship, or any other, that could affect the study and its results presented in this article.

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The study was conducted without financial support.

Data availability

The manuscript has associated data in the data repository.

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