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Осциллирующая инфракрасная сушка кожуры яблок

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Аннотация. *Экспериментально исследована осциллирующая инфракрасная сушка кожуры яблок сорта «Гала». Продукт обладает ценными пищевыми свойствами и востребован в пищевой промышленности. На разработанной лабораторной установке для изучения процесса осциллирующей инфракрасной сушки и позволяющей поддерживать температуру высушиваемого материала на заданном температурном уровне* $\pm 3^\circ C$, *получены кривые сушки при трех средних температурах материала: t = 37°C; 47°C и 57°C. В качестве источников инфракрасного излучения использовались лампы «OSRAM Siccatherm». Кривые сушки содержали первый и второй периоды, критическое влагосодержание было равно* $\bar{u}_{кр} = 0{,}60$ *(кг влаги)/(кг сух. материала). В результате анализа кривых сушки было предложено продолжительность первого периода рассчитывать по скорости сушки, определяемую через коэффициент массоотдачи, а продолжительность второго периода путем обобщения кривых сушки по методу В.В. Красникова. Для исследованного материала найдено значение относительного коэффициента сушки (χ = 0,0624), позволяющее реализовать этот метод для исследованного материала. Получены данные по сохранности витамина С в яблочной кожуре, высушенной при различных температурах, что позволяет выбрать необходимый температурный режим.*

Ключевые слова: кожура яблок, сушка, инфракрасный подвод энергии, кинетика, сохранность витаминов

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Research article

Oscillating infrared drying of apple peels

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Abstract. *The oscillating infrared drying of Gala apple peel has been experimentally studied. The product has valuable nutritional properties and is in demand in the food industry. On the developed laboratory setup for studying the oscillating infrared drying process and maintaining the temperature of the dried material at a given temperature level, drying curves were obtained at three average material temperatures: t = 37 °C; 47 °C and 57 °C. OSRAM Siccatherm lamps were used as infrared radiation sources. The drying curves contained the first and second periods, the critical moisture content was equal to (kg moisture) / (kg dry material). As a result of the drying curves analysis, it was proposed to calculate the duration of the first period based on the drying rate, determined through the mass transfer coefficient, and the duration of the second period by generalizing the drying curves using the method of V.V. Krasnikov. For the studied material, the value of the relative drying coefficient (χ = 0.0624) was found, which allows implementing this method for the studied material. Data on the preservation of vitamin C in apple peel dried at different temperatures were obtained, which allows choosing the required temperature regime.*

Keywords: apple peel, drying, infrared energy supply, kinetics, vitamin preservation
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Introduction. When preparing apple puree, in particular in baby food technology, apples are peeled [1]. The peel contains a large number of vitamins and other nutrients, so it is advisable to process it into healthy food products. In recent years, the Federal State Budgetary Scientific Institution "Federal Scientific Center named after I.V. Michurin" in the science city of Michurinsk has been developing a technology for processing apple peel, which is a by-product of obtaining apple puree, into valuable food products. Within the framework of this technology, apple peel is dried to a moisture content of about 10% (at this moisture content, the dried product can be stored for a long time without spoiling) and then ground to a powder state [2]. The ground powder product can then be used in various food technologies. For apple peel, a two-stage convective vacuum-pulse drying is proposed in [2]: at the first stage, surface moisture is removed by convective means, at the second stage, internal moisture is removed by vacuum-pulse means, whereby pulsed vacuum effects facilitate the removal of internal moisture.

In recent years, much attention has been paid to infrared drying in the technology of drying food raw materials [3]. When drying heat-labile materials, oscillating (intermittent) infrared drying is used [4], since it allows not to overheat the dried material. When drying apple peel, due to exposure to elevated temperatures, there is a loss of vitamins and other heat-labile components, so it was advisable to study the loss of vitamin C during the drying process.

Experimental study. The basic diagram of the installation on which the study was conducted is shown in Fig. 1.

The unit has a drying chamber 1, in the lower part of which (flush with the bottom in a specially cut round hole) a metal grid 5 was located with the material to be dried on it - a thin layer of peel several mm thick. The grid was on a foam rubber stand, which, in turn, was installed on the scale pan 12, located under the drying chamber. We used electronic scales of the brand " Scale Cas MWP –300", which allowed weighing the samples to be dried with an error of 0.005 g. In the upper part of the drying chamber, symmetrically relative to the material to be dried, electric infrared emitters 2 – lamps " OSRAM Siccatherm », and between them - the sensor of optical pyrometer 3, with the help of which the temperature of dried peel was measured contactlessly. The installation was equipped with the automatic control system, including the sensor of optical pyrometer 3, electronic unit of pyrometer 8, power supply 9, automatic regulator TRM202 - position 10, resistance thermometer 11 for measuring air temperature in the drying chamber, humidity and temperature sensor 13, interface adapter 14 brand AC 4,15, through which the signal was transmitted to PC 15. Air from outside entered through air intake opening 4, with the help of axial fans 7 built into the side walls of the chamber it was blown through the drying chamber and removed through the outlet pipe 6.

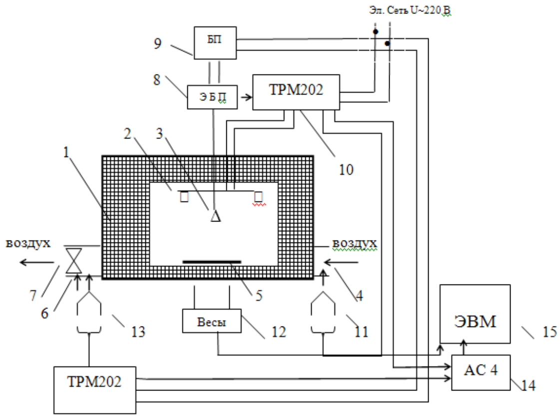

Figure 1 – Schematic diagram of the installation for oscillating IR drying

Materials and research methods. In this work, the kinetics of infrared drying of apple peel at different temperature conditions and the residual content of vitamin C in it were experimentally studied. The experiments were carried out with the peel of Gala apples.

The temperature of the material irradiated by the IR emitters was measured using an optical sensor of the Raytek non-contact pyrometer MID. Maintaining the temperature of the material being dried at a given temperature level was carried out using a 2-channel measuring and controller TRM202.

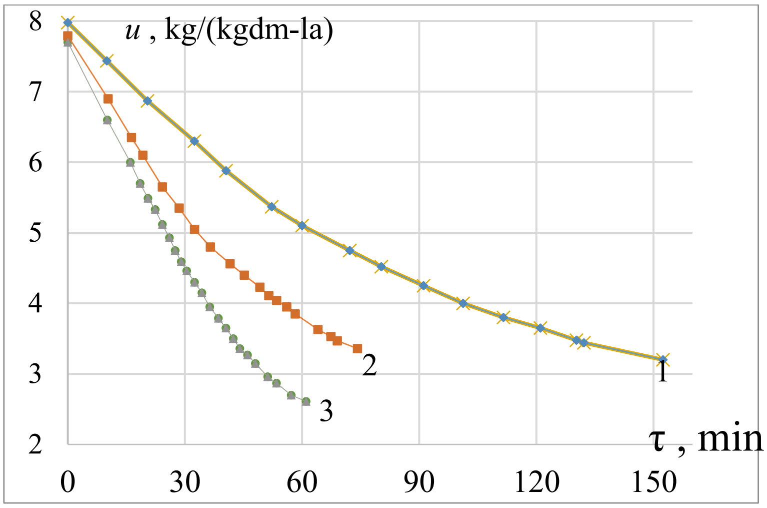

Figure 2 – Curves of infrared drying of apple peel: 1 - *t* = 37 º C; 2 - 47 º C; 3- 57 ° C

The studies were conducted while maintaining the average temperature of the material at three temperature levels: *t* = 37 º C; 47 º C and 57 ° C. The automatic control system maintained these temperature values with fluctuations relative to the specified average value. Periodically, after a certain time, the material was weighed. The experiments were carried out in triplicate, the results of weight measurements were averaged. At the end of the experiment , the moisture content of the material was determined - according to GOST 33977-2016 "Processed fruit and vegetable products. Methods for determining the total dry matter content" - by the ratio

$$\bar{u} = \frac{m_{\text{вл}}}{m_{\text{вл.м}} - m_{\text{сух.м.}}} . (1)$$

where is $\bar{u}$ – the moisture content of the sample, (kg moisture) /(kg dry material); $m_{\text{вл}}$ is the mass of moisture in the sample, kg; $m_{\text{вл.м}} - m_{\text{сух.м.}}$ is the mass of the sample before and after drying, respectively, kg.

Then, knowing the current values of the material weight, the moisture content of the material was calculated at different points in time and a drying curve was constructed.

Research results and their discussion. Fig. 2 shows the obtained drying curves $\bar{u} = f(\tau)$. The drying curves show both the first and second drying periods. The temperature of the material has a great influence on the drying rate, the drying rate increases especially significantly with an increase in temperature from 37 °C to 47 °C. The critical moisture content during drying of apple peel for all the studied drying modes can be taken as $\bar{u}_{\text{кр}} = 6.0$ (kg moisture) /(kg dry material). At, $\bar{u} < \bar{u}_{\text{кр}}$ the first drying period takes place, the rate of which is determined by external mass transfer. The drying duration in the first period τ_1 can be calculated using the ratio

$$\tau_1 = \frac{\bar{u}_{\text{н}} - \bar{u}_{\text{кр}}}{N} . (2)$$

where is the drying rate *N* (1/s) is related to the drying intensity i_1 (kg /(m ^{2} s) by the equation [5]

$$N = i_1 \frac{f}{\rho\ (1 - \varepsilon_{ck})}, (3)$$

Here *f* – specific surface area of the dried material in the layer, m2 / (m3 of layer); for apple peel of thickness δ we have: $f = 2(1 - \varepsilon_{sl})/\delta$; ρ– density of apple peel, equal to ρ= 796 kg/m ^{3} ; ε_{sl} – porosity of the layer, m ^{3} /(m ^{3} of the layer) (under experimental conditions it can be estimated as $\varepsilon_{sl} = 0.5$). At δ = 1 mm we obtain: *f* = 1000 m ^{2} /(m ^{3} of the layer).

The duration of the second drying period can be calculated using the drying coefficient *K* (1/s) according to the ratio [5]

$$\tau_2 = \frac{1}{K} \ln \frac{\vec{u}_{\text{кр}} - \vec{u}_{\text{р}}}{\vec{u}_{\text{к}} - \vec{u}_{\text{р}}}, (4)$$

where $\vec{u}_{\text{к}}, \vec{u}_{\text{р}}$ are the final and equilibrium moisture content of the material, respectively, kg /(kg of dry material). *K* is the drying coefficient, 1/s.

V. V. Krasnikov proposed a method for generalizing drying curves by relating the current drying rate in the second period $-(d\bar{u}/d\tau) = f(\bar{u})$ to the drying rate in the first period [6] using the parameter χ – the relative drying coefficient. In this case, the duration of the second drying period can be calculated using the equation

$$\tau_2 = -\frac{\ln(\bar{u}_{к} / \bar{u}_{кр})}{\chi N}. (5)$$

Analysis of the obtained curves of apple peel drying confirmed the possibility of such a generalization. For the process under study, it was found: $\chi = 0.0624$. Thus, for the process under consideration, it is possible to recommend calculating the time τ_1 according to equation (2), and the time τ_2 according to equation (5). Total drying time of apple peel: $\tau = \tau_1 + \tau_2$.

Determination of vitamin C content. The analysis of dried peel for vitamin C content was carried out on samples dried in experiments separate from the study of drying kinetics - by the oscillating infrared drying method on the setup described above, at average material temperatures of 37 °C and 47 °C (the maximum temperatures in the experiments were t_{max} = 40 °C and t_{max} = 50 °C, respectively). The vitamin C content in apple peel was determined according to GOST 24556–89 by the titrimetric method. The results of the analysis of dried samples for vitamin C content are presented in Table 1. As can be seen from the table, the vitamin C content significantly depends on the drying temperature regime; with an increase from temperature t_{max} = 40°C to temperature t_{max} = 50°C, the vitamin C content decreases from 0.54 mg/100 g to 0.39 mg/100 g, i.e. by 27.7%. Thus, from the point of view of drying speed, the drying mode at the average temperature of the material *t is preferable.* = 47 ° C, and from the point of view of preserving vitamin C - the regime at *t* = 37 ° C, mode at *t* = 57 ° C is not advisable to use, since it does not provide a large increase in drying speed (Fig. 2), but will be accompanied by a large loss of vitamin C and other valuable heat-labile components contained in the apple peel.

Table 1 – Vitamin C content in the peel of Gala apples dried at different temperatures

Drying temperature mode t_{max}, °C	Moisture content of samples, %	Vitamin C content, mg/100 g	Vitamin C (in terms of dry matter), /100 g
40 °C	11	0.54±0.04	0,607 ± 0,045
50 °C	10	0.39±0.03	0,433 ± 0,033

Conclusion.

1. The kinetics and preservation of vitamin C during oscillating infrared drying of Gala apple peels at different drying temperatures were experimentally studied.
2. It is recommended to find the drying duration in the first period by calculating the drying rate through the mass transfer coefficient, and the drying duration in the second period - by generalizing the drying curves using the method of V.V. Krasnikov. For the studied material, the value of the relative drying coefficient (χ = 0.0624) was found, allowing this method to be implemented.
3. Data on the preservation of vitamin C in apple peel dried at different temperatures was obtained, which makes it possible to select the required temperature regime.

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