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DETERMINATION OF DIMENSIONAL AND MASS CHARACTERISTICS OF WALNUTS

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The article presents the results of comprehensive studies of the physical and mechanical characteristics of walnuts, which form the basis for constructing a mathematical model of the drying process in convective-vibration installations. The relevance of the work is justified by the need to increase energy efficiency and ensure high product quality amid growing demand for nuts on the global market. The current state of drying technologies is analyzed and the limitations associated with the thermolability of walnuts are emphasized: it is noted that at temperatures above 34–35 °C, the oil in the kernel degrades, which reduces the nutritional and biological value of the product.

To achieve the research objectives, a convective-vibration drying machine was developed, its design diagram and principle of operation are presented. A mathematical model of the drying process in a criterion form is proposed, which takes into account both external and internal factors of heat and mass transfer. Particular attention was paid to determining the dimensional and weight characteristics of the Ideal variety fruits. The average equivalent diameter of the nut (36.41 mm) and the sphericity index (89.71%) were experimentally established, which confirmed the possibility of approximating the shape of the fruit with a sphere. The bulk and actual density at different moisture levels (10–40%) were determined, which made it possible to estimate the change in the porosity of the nut layer within the range of 53.8–55.1%.

The results obtained made it possible to establish linear dependencies of density on moisture content and to substantiate the influence of the shape and mass parameters of fruits on the aerodynamic resistance of the layer. It has been shown that the use of vibration reduces the randomness of stacking, increases porosity, and reduces the resistance of the layer to the drying agent, which opens up prospects for intensifying the process without increasing the temperature. The conclusions confirm the scientific novelty and practical significance of the work, and further research is planned to assess the influence of fruit shape and size on the aerodynamic characteristics of the layer in the working chamber.

Key words: *walnut, drying, physical and mechanical characteristics, mathematical model, temperature, vibration impact.*
Eq. 5. Fig. 3. Ref. 10.

1. Problem formulation

Walnuts are a high-value agricultural product widely used in their pure form, as well as an ingredient in medicines and food products. Ukraine is one of the world's leading producers and exporters of this crop. However, the actual level of exports does not correspond to the existing production potential. This is due to the fact that about 70% of the harvest is produced in private households, where there are no opportunities for comprehensive processing of fruits using all their fractions. In addition to the kernel, the shell, partitions, and pericarp are also valuable and can be used in various industries. A full processing cycle is only possible in large farms equipped with technological lines.

Drying is a key operation in the storage and industrial processing of most types of plant products. It ensures long-term storage of the material and creates the necessary conditions for further technological operations. For walnuts, the optimal storage moisture content is considered to be 8–10%, while after harvesting, the fruits can have up to 40% moisture. For high-quality shelling, it is necessary to bring it to 10–15%. At the same time, the drying process remains the most energy-intensive stage, sometimes requiring up to 50% of the total energy consumption.

Modern methods of drying plant raw materials, in particular in convective dryers, involve various ways of intensifying the process. Their effective application requires a deep understanding of the physical and technological processes that occur both in the working areas of the drying chambers and directly in the material. In the case of walnuts, this requires a detailed study of their physical and mechanical characteristics, in particular dimensional and mass indicators. The determination of these parameters is the goal of this work, which emphasizes its scientific and practical relevance.

2. Analysis of recent research and publications

Modern scientific research is based on a systematic approach to solving the tasks at hand [1]. This usually includes a comprehensive theoretical justification, determining the relationships between the object and subject of research, creating a mathematical model of the process being studied, and developing a program and methodology for experimental research with subsequent verification of the adequacy of the developed model. To form a correct mathematical model, it is necessary to have prior knowledge of the physical and mechanical parameters of the material, in particular its geometric, dimensional, and mass characteristics.

In the course of studying the drying of walnuts in a convective-vibration dryer, a mathematical model was created that describes the change in the temperature of the nut kernel depending on time and spatial coordinates (kernel radius and drying exposure time) under various initial conditions and operating parameters [2, 3]. The significance of this model lies in its ability to ensure high quality of the finished product. This is due to the fact that walnuts are thermolabile materials: their consumer properties significantly depend on the drying temperature. It is known that when the temperature rises above 34–35 °C, the oil contained in the kernel begins to degrade [4].

A systematic approach to studying and improving the walnut drying process involves searching for and implementing ways to intensify it. Among the existing methods, several promising options stand out [5,6]. The results of our theoretical and experimental studies show that the most effective way to increase the drying intensity is to increase the heat transfer coefficient between the product and the drying agent by applying vibration to the layer of nuts in the drying chamber. Technically, this approach is more difficult to implement than, for example, simply increasing the temperature of the drying agent [7]. However, due to the thermolability of nuts, the use of high temperatures is limited.

Thus, the implementation of systematic research into the drying process requires a detailed study of the physical, mechanical, and thermophysical properties of the material. This determines the relevance of this work, which aims to determine the dimensional and mass characteristics of walnuts.

3. The purpose of the article

The aim of the research is to reduce energy consumption during walnut drying by creating a mathematical model of the process using data on the dimensional and mass characteristics of walnuts.

4. Results and discussion

A convective-vibration machine was developed to conduct experimental studies on the drying of walnuts. Its diagram is shown in Fig. 1.

Experimental studies aim to determine the functional patterns of the influence of input factors on the parameters of optimizing the walnut drying process. One of the conditions was to limit the core temperature in order to prevent a decrease in the oil content in the finished product. The created mathematical model allows determining the temperature of the nut core in space and time depending on input factors and external influences on the drying process. The mathematical model is an equation presented in a criterion form. The similarity criteria presented in the equation include all factors that characterize the drying process: physical, mechanical, and thermophysical properties of the material, intensity of internal heat sources, and process parameters. It is important to note that in most cases it is necessary to determine the dependence of the material characteristics on its moisture content. It is this parameter (i.e., moisture content) of the material that constantly changes (decreases), and its final value of 10% determines the end of the drying process. When considering the factors that influence the intensity of the drying process, it was noted that the physical and mechanical properties of walnuts, among other things, have a significant impact on the course of this process [5]. First of all, this concerns the shape, size, and density of the whole nut and its components.

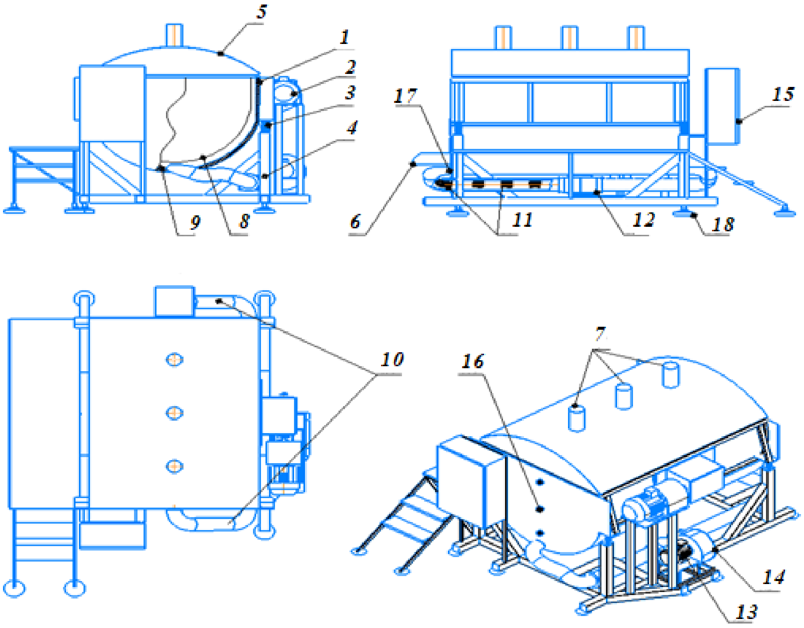

Fig. 1. Diagram of a vibrating machine for drying walnuts: 1 – U-shaped chamber; 2 – inertial vibrator; 3 – springs; 4 – springs; 5 – cover; 6 – discharge chute; 7 – air ducts; 8 – perforated bottom; 9 – tray; 10 – heated air supply line; 11 – electric heaters; 12 – air distribution device; 13 – electric motor; 14 – blower fan; 15 – automatic control system;16 – three-level sensors; 17 – temperature sensor; 18 – vibration supports

When considering the mathematical model of walnut drying, it was assumed that a walnut is a sphere within a sphere. The outer sphere is the nut shell and, accordingly, the inner sphere is the nut kernel together with the membrane [3]. Of course, an average nut can be considered a perfect sphere with a certain assumption. However, the degree of approximation of nuts of a certain variety to a perfect sphere can be determined using the method proposed in [8].

The equivalent diameter of the nut is determined by the formula:

$$D_e = (L \cdot B \cdot C)^{\frac{1}{3}}, \tag{1}$$

where L, B, C – are the length, width, and thickness of the nut, respectively, in mm.

The dimensions of the Ideal variety walnut are shown in Figure 2.

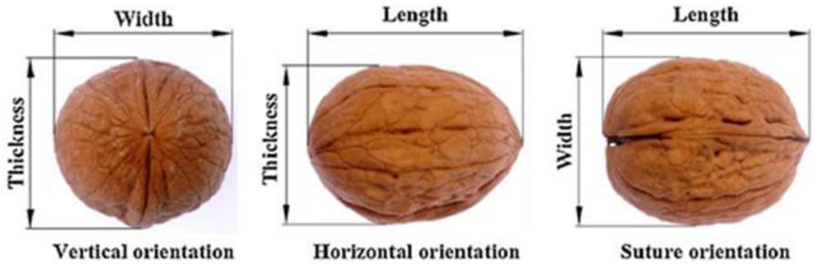

Fig. 2. Overall dimensions of the Ideal variety walnut in shell

The same work [8] provides an expression for determining the sphericity ndex of a nut, i.e., the degree of its approximation (in %) to a perfect sphere.

$$d_c = \left(\frac{D_e}{L}\right) \cdot 100\%, \tag{2}$$

The sphericity of a walnut fruit (%) is determined as the ratio of its equivalent diameter to its maximum overall size.

Density is one of the main physical and mechanical parameters of nuts. There's a difference between the actual density, which describes a single nut, and the bulk density, which shows the ratio of the mass of a certain number of nuts to the volume they take up. True density is one of a number of similarity criteria and is used to determine the thermophysical characteristics applied in the construction of mathematical models of the drying process.

In general terms, the density of an individual nut is the ratio of its mass to its volume. The average mass of the test samples was determined by weighing them on VL-200 laboratory scales. The volume of the fruits was determined by the method of displacing liquid from a 0.5-liter measuring vessel, known since the time of Archimedes. Although water is traditionally used, liquid toluene (C_7H_8) is used to determine the volume of walnuts. This is because, unlike water, toluene is not absorbed by the shell and, due to its lower surface tension, is able to penetrate even small cracks on its surface.

The bulk density was determined by filling a standard container measuring 0.2×0.2×0.15 m (volume 0.006 m³). After weighing the contents, the ratio of the mass of nuts to the volume of the container was taken as the bulk density value.

Another important characteristic of the layer of walnuts through which the drying agent flows is its porosity. The porosity index is determined using a special calculation formula:

$$\mathcal{E} = 1 - \left(\frac{\rho_n}{\rho_d}\right), \tag{3}$$

where $\mathcal{E}$ – porosity of the nut layer, dimensionless; ρ_n– bulk density of nuts, kg/m³; ρ_d – true (actual) density of nuts, kg/m³.

The actual and bulk density of walnuts varies depending on their moisture content. As the drying process progresses, these indicators naturally decrease, which is associated with a reduction in fruit weight. For correct calculations of similarity criteria, it is advisable to use the average value of the true density. This is consistent with the assumption accepted in the mathematical model of the walnut drying process in a convective-vibration dryer, according to which the physical properties of the material are considered unchanged throughout the process.

Density (both true and bulk) was determined for samples with moisture content of 10, 20, 30, and 40%. Fruits with the required moisture content were selected directly from the dryer container during laboratory experiments.

Experimental measurements of dimensional parameters were performed on fruits of the Ideal variety. For this purpose, the dimensions of 30 randomly selected nuts were measured (Fig. 3). Based on formula (3), the equivalent diameter of each sample was calculated and its average value was determined. As a result, the average equivalent diameter for the Ideal variety was obtained: D_e = 36.41 mm.

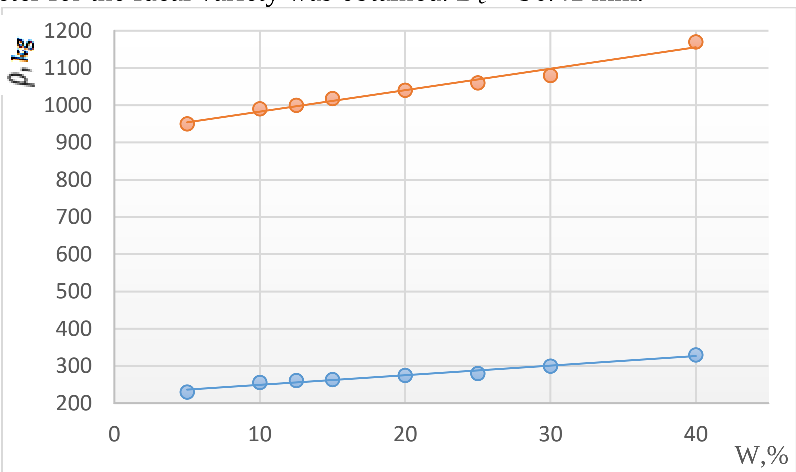

Fig. 3 – Dependence of the bulk and true density of walnuts on their moisture content: 1 – bulk density of nuts; 2 – true density of nuts

For the same sample, the sphericity index was determined to be d_c = 89.71%. This is a fairly high level, confirming the possibility of correctly reflecting the shape of the nut in a mathematical model in the form of a sphere.

An important parameter that was taken into account in the studies is also the density of the material. The graphical results of changes in the actual and bulk density of Ideal walnuts depending on their moisture content are shown in Fig. 3.

The bulk and true density of walnuts [kg/m^3] varies depending on their moisture content according to a linear law. In the moisture range of nuts W=5...40%, the change in their density is described by the following equations:

for bulk density:

$$\rho_n = 1{,}5 \cdot W + 241{,}8 \quad (4)$$

for actual density

$$\rho_d = 4{,}8 \cdot W + 942{,}75 \quad (5)$$

The porosity of the walnut layer directly affects its aerodynamic drag and, consequently, the energy efficiency of the drying process. Within the moisture range of 10–40%, this indicator was 53.8–55.1%. It is important to note that the porosity value is largely determined by the shape of the nuts and the method of layer formation (the geometry of the container in which they are located, the height of the filling, the nature of the stacking, etc.). To eliminate the influence of these factors, vibration is used to arrange the mutual position of the nuts, increase the porosity of the layer, and reduce its aerodynamic resistance.

It should be emphasized that other scientists who studied the physical and mechanical properties of walnuts [9, 10] did not pay attention to such a parameter as the sphericity of the fruits. For their experiments, this indicator was not of decisive importance. In our case, determining sphericity became an important confirmation of the correctness of the choice of geometric shape when constructing a mathematical model of the drying process.

5. Conclusion

An analysis of methods aimed at intensifying the walnut drying process has demonstrated that the application of vibration to the material layer is an effective means of enhancing heat and mass transfer. To determine the optimal parameters of this process, a mathematical model was developed that takes into account the geometric and mass characteristics of the walnut fruits.

Experimental studies of the Ideal variety established that the average equivalent diameter of a nut is 36.41 mm, the sphericity is 89.71%, and the porosity of the layer at a moisture content of 10–40% ranges from 53.8% to 55.1%. The high sphericity value confirms the validity of approximating the fruit as a sphere in the modeling of the drying process. Moreover, a linear dependence between the bulk and true densities of the nuts and their moisture content was determined.

Further research should be directed toward assessing the influence of fruit size and shape on the aerodynamic resistance of the nut layer within the working space of the drying chamber, which will contribute to improving the efficiency and uniformity of the drying process.

References

1. Tsurkan, O.V. (2021). A systematic approach to the study of post-harvest processing technology of pumpkin seeds. *Technics, Energy, Transport of AIC*, *4 (115),* 141–147. [in Ukrainian].
2. Kaletnik, G., Tsurkan, O., Spirin, A., Gudzenko, N., Prysiazniuk, D., Didyk, A. (2024). Substantiation of the operating parameters of walnut drying equipment. *Journal of Engineering Sciences*, *11(2),* 27–35. DOI: 10.21272/jes.2024.11(2).f4 [in English].
3. Tsurkan, O.V., Spirin, A.V., Gudzenko, N.M., Didyk, A.M. (2024). Mathematical model of the walnut drying process in a convective-vibrational dryer. *Vibrations in Engineering and Technology*, *4 (115),* DOI: 10.37128/2306-8744-2024-4-1 [in Ukrainian].
4. Martínez, M., Valdés, A., Garrido, I. (2020). Global trends in nut consumption and health implications. *Nutrients*, 12 (9), 2685. DOI: 10.3390/nu12092685 [in English].
5. Tsurkan, O.V., Spirin, A.V., Didyk, A.M., Bondarenko, M.P. (2024). Ways to increase the intensity of walnut drying process. *Vibrations in Engineering and Technology*, *4 (115),* 52–59. DOI: 10.37128/2306-8744-2024-4-7 [in Ukrainian].
6. Tsurkan, O.V., Spirin, A.V., Rutkevych, V.S., Didyk, A.M. (2024). Evaluation of the efficiency of the walnut drying process in a convective-vibrational dryer. *Vibrations in Engineering and Technology*, *3 (114),* 5–12. DOI: 10.37128/2306-8744-2024-3-1 [in Ukrainian].
7. Tsurkan, O.V., Rutkevych, V.S., Didyk, A.M. (2024). Theoretical studies of the walnut drying process using vibration technologies. *Herald of Khmelnytskyi National University. Series: Technical Sciences*, *4 (323),* 337–342. DOI: 10.31891/2307-5732-2023-323-4-337-342 [in Ukrainian].
8. Fashina, A.B., Saleh, A., Akande, F.B. (2015). Development and evaluation of a groundnut in-shell grader. *Agricultural Sciences*, *6 (2),* 217–223. DOI: 10.4236/as.2015.62021 [in English].
9. Polevoda, Yu.A. (2019). Study of the walnut shelling process between two parallel plates. *Vibrations in Engineering and Technology*, *3 (94),* 110–117. DOI: 10.37128/2306-8744-2019-3-14 [in Ukrainian].
10. Hoshko, V., Burtak, V., Shevchuk, R., Mahats, M., Barabash, R. (2022). Study of the physical and mechanical properties of walnuts. *Bulletin of Lviv National University of Environmental Management.*

Series "Agroengineering Research", *26*, 5–12. DOI: https://doi.org/10.31734/agroengineering2022.26.005 [in Ukrainian].

ВИЗНАЧЕННЯ РОЗМІРНИХ ТА МАСОВИХ ХАРАКТЕРИСТИК ВОЛОСЬКОГО ГОРІХА

У статті представлено результати комплексних досліджень фізико-механічних характеристик плодів волоського горіха, що є основою для побудови математичної моделі процесу сушіння у конвективно-вібраційних установках. Обґрунтовано актуальність роботи, зумовлену потребою підвищення енергоефективності та забезпечення високої якості продукції в умовах зростання попиту на горіхи на світовому ринку. Проаналізовано сучасний стан технологій сушіння та наголошено на обмеженнях, пов'язаних із термолабільністю горіха: зазначено, що при температурах вище 34…35 °С відбувається деградація олії ядра, що знижує харчову та біологічну цінність продукту.

Для досягнення мети досліджень розроблено конвективно-вібраційну сушильну машину, наведено її конструктивну схему та принцип дії. Запропоновано математичну модель процесу сушіння у критеріальній формі, яка враховує як зовнішні, так і внутрішні фактори тепломасообміну. Особливу увагу приділено визначенню розмірних та вагових характеристик плодів сорту «Ідеал». Експериментально встановлено середній еквівалентний діаметр горіха (36,41 мм) та показник сферичності (89,71%), що підтвердило можливість апроксимації форми плоду сферою. Визначено насипну і дійсну щільність при різних рівнях вологості (10…40%), що дало змогу оцінити зміну пористості шару горіхів у межах 53,8…55,1%.

Отримані результати дозволили встановити лінійні залежності щільності від вологості та обґрунтувати вплив форми і масових параметрів плодів на аеродинамічний опір шару. Показано, що застосування вібраційного впливу знижує хаотичність укладання, збільшує пористість і зменшує опір шару сушильному агенту, що відкриває перспективи для інтенсифікації процесу без підвищення температури. Висновки підтверджують наукову новизну та практичну значущість роботи, а подальші дослідження планується спрямувати на оцінку впливу форми й розмірів плодів на аеродинамічні характеристики шару у робочій камері.

Ключові слова: *волоський горіх, сушіння, фізико-механічні характеристики, математична модель, температура, вібраційний вплив.*

Ф. 5. Рис. 3. Літ. 10.

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