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RESEARCH ON THE INFLUENCE OF WARM AIR FLOW ON THE DRYING KINETICS OF WALNUTS

Vitalii YAROPUD, Candidate of Technical Sciences, Associate Professor
Petro LAVRENIUK, Recipient of the Third Educational and Scientific Level
Vinnytsia National Agrarian University

ЯРОПУД Віталій Миколайович, к.т.н., доцент
ЛАВРЕНЮК Петро Петрович, здобувач третього освітньо-наукового рівня
Вінницький національний аграрний університет

Walnuts are at high risk of oxidative spoilage during storage, transportation and sale. The speed of this process is affected by the chemical composition of the nuts, which varies depending on the variety and region of cultivation. This means that each batch of nuts has a different storage potential. The problem is exacerbated by the lack of an effective system for tracking batches of nuts at all stages: from production to sale. There is also a lack of objective methods for assessing the shelf life of nuts. Because of this, manufacturers and sellers often incorrectly set expiration dates. As a result, according to statistics, more than 30% of walnuts sold in stores have signs of bitterness, which indicates their spoilage.

Preservation of the quality of walnuts depends on a number of key factors, among which the level of humidity, temperature, humidity of the ambient air, access of oxygen, condition of the nuts, packaging materials, storage method and technological processing (peeled, in shell, roasted, etc.) play an important role. Although walnuts are considered a product with a long shelf life, maintaining optimal conditions is critical to maintaining their freshness and flavor.

The aim of the research is to study the kinetics of drying walnuts under the influence of a warm air flow in laboratory conditions.

The results of laboratory studies of the kinetics of drying walnuts with a warm air flow demonstrate that the main process parameters – initial humidity w_0, air temperature T, air flow velocity v and drying duration t – significantly affect the drying rate Vt and the final moisture level wt.

The change in nut moisture wt with time t in all studied conditions occurs gradually. The drying rate V_t is the highest at the initial stages and decreases with time due to the depletion of surface moisture. Similarly, with increasing air flow velocity, the drying rate increases. In general, optimization of the drying process involves adjusting the temperature and air flow velocity depending on the desired drying time. High temperature and optimal air flow rate ensure efficient drying. It was found that the delay in temperature change becomes shorter with increasing temperature. Thus, it can be considered that at the initial stage (5 h) of walnut drying, it is advisable to apply high-temperature treatment (80 °C) to improve the heat transfer effect and drying performance, which will further increase the drying rate. Subsequently, it is desirable to reduce the drying temperature to (50 °C).

Key words: *process, parameters, kinetics, research, drying, walnut, convection, dryer, air, flow.*
Eq. 6. Fig. 6. Table. 2. Ref. 16.

1. Problem formulation

Walnut is a valuable food product and an important component of the agro-industrial complex of Ukraine. Its cultivation has long traditions in our country, and natural and climatic conditions contribute to obtaining high-quality products. However, despite its significant potential, the industry faces a number of problems that hinder its development [1].

The food industry uses walnut kernels, which are distinguished by their exceptional taste: 1 kg of walnuts provides more than 8,500 calories. Walnut fruits are used in many industries: in confectionery (fillings, candies, cakes, cookies, etc.), in canning, fruit and vegetable, and butter production [1].

Walnut oil, which is used in the food industry, has particularly high taste properties: it is used to extract highly valuable aromatic compounds – rose, violet, and lemon essential oils. Walnut pulp is used for animal feed. Jam is made from unripe fruits.

Walnut kernels contain a variety of organic and mineral compounds: fats, proteins, carbohydrates, tannins and aromatic substances, vitamins. Unripe fruits contain more than 3000 mg% of vitamin C, ripe ones - 35 mg%.

Walnuts are harvested in September – October, after they fall to the ground. The green shell is removed from the collected nuts, dried in the sun or in drying chambers at a temperature not exceeding 60 ° C. The humidity of the dried nuts should not exceed 10%. Using calibration machines, the nuts are sorted, checked for quality and placed in paper or fabric bags weighing 30-50 kg [2].

The shelf life is two to three years. The leaves are collected in spring and early summer. They are picked and placed in baskets or bags, then dried in the sun or under tents, spreading a thin layer (23 cm) on paper or cloth.

Store in dry, cool rooms. Dry in dryers at a temperature of 30…40°C. However, their storage life is limited due to high lipid activity, fat oxidation, development of microbiological and fungal infections, as well as damage by pests. Ensuring the quality of nuts during storage is an important task for agriculture and the food industry [3].

2. Analysis of recent research and publications

Hot air drying is one of the most commonly used technologies for drying food products due to its relatively easy operation and low operating costs [4]. In [5], the drying characteristics of walnuts in shell were investigated using a laboratory hot air dryer at different temperatures (32 °C and 43 °C), air velocities (1 m/s and 3 m/s), and varieties (Serr, Pedro, Z67, K82). They found that walnut drying mainly occurred during the period of decreasing velocity, and all three factors significantly affected the drying time and kinetics. Higher drying temperature and air velocity resulted in shorter drying times.

Radiofrequency heating has been studied and used for food processing in recent years. Radiofrequency drying is a technology for rapid dehydration of food and agricultural products. In [6], a hot air RF approach (HARF) (at 27.12 MHz, 6 kW) was developed and tested in a pilot dryer for drying walnuts in shell. The results showed that, to reduce the moisture content of walnuts from 20.0% to 8.0% on a dry basis, radiofrequency heating with an electrode gap of 18.0 cm combined with HA at 50 °C resulted in a significantly shorter drying time (100 min) compared to HA drying at 80 °C (240 min). Furthermore, they found that the radiofrequency drying process exhibited two distinct stages: at the beginning, an accelerated drying stage was observed (from 0 to 40 min), when the sample temperature gradually increased; from 40 to 100 min, the drying process went through a deceleration stage, when the temperature remained relatively stable.

However, the application of infrared, vacuum and radio frequency drying methods in industry is still rare, and deep drying with a warm air flow is still the most widely used drying method due to its advantages in high processing capacity and relatively low operating costs [4]. As one example, walnuts with different moisture contents are mixed, shelled, washed in water, and then transported to cross-flow drying bins [7], and then dried with a constant air flow temperature of 43 °C until an average moisture content of 8% is reached. This temperature standard was established based on a drying test that stated that drying walnuts with an air flow above 43 °C resulted in a “cooked taste” after drying and a “rancid taste” after 4 months of ambient storage. Therefore, the conventional drying method can meet the needs for drying capacity and processing productivity of walnuts.

As mentioned, the walnut shell has a higher moisture content than the kernel at harvest, which creates a moisture gradient inward and hinders the diffusion of moisture from the kernel during the drying process. Therefore, if the moisture from the shell can be removed quickly at the initial stage of drying, it will promote the removal of moisture from the kernel, increase the overall drying rate and shorten the drying time. In [7], the drying characteristics of walnut shell and kernel under the action of warm air flow were studied and it was found that the moisture content of the shell decreased below that of the kernel after the first 6 hours of drying, and in [8] it was shown that the moisture removal from the walnut shell dominated at the initial stage of drying. In addition, since the thermal conductivity of the walnut shell is higher than that of the kernel [9], the heat conduction through the kernel is relatively slow. Due to this unique property, using a rapid heating method with controlled high temperature at the initial stage of drying can partially remove moisture from the shell while maintaining a relatively low temperature in the core. This drying strategy should reduce overall drying time and energy consumption while maintaining product quality.

The authors of [10] showed that drying grain with a gradual change in air temperature contributed to energy savings. Scientists [11, 12] investigated the drying characteristics and product quality of banana slices under temperature profiles of gradual increase and gradual decrease. They found that using a gradual temperature change with an appropriate initial temperature and cycle duration, it is possible to significantly reduce the drying time and improve the product quality.

In order for nuts to last a long time and not become bitter, they need to be dried immediately after harvest. Unfortunately, research into the drying process of nuts is not as widespread as for other products. Therefore, it is important to develop and describe in detail a system for drying nuts to ensure their highest quality.

3. The purpose of the article

The aim of the research is to study the kinetics of drying walnuts under the influence of warm air flow in laboratory conditions.

4. Results and discussion

Studies of the kinetics of drying walnuts with a warm air flow were conducted in laboratory conditions at the Faculty of Engineering and Technology of Vinnytsia National Agrarian University.

Samples of fresh walnuts of the Chandler variety were provided by the private enterprise "YAFK- VITON" (Vinnytsia region, Mohyliv-Podilskyi district, village of Velyka Kisnytsia) from the 2024 harvest. To avoid moisture loss, all nut samples were packed in polyethylene bags using a Comshop vacuum packer, each weighing 2.00±0.01 kg, and stored in a ventilated room at a relative humidity of 58±2% and a temperature of 25±2 °C. The moisture content (w) in the nut samples was measured using a SENCOR SFD6601BK drying oven at a temperature of 105±1 °C for 24 hours, according to the equation [13]:

$$w = 100\frac{m_0 - m_1}{m_0}\,; \tag{1}$$

where, m_0 – initial mass of the sample, g; m_1 – mass of dry sample after 24 hours of drying, g; w – moisture content in walnuts, %.

Figure 1 shows a diagram of the equipment. The experimental setup consisted of a modernized SENCOR SFD6601BK drying cabinet with a d-0030/2KW dimmer for regulating the air flow rate, a TM- 32/H-5T temperature recorder, and DS18B20 temperature sensors.

Since walnuts are spherical solids, the temperature at one point cannot represent the overall temperature. Therefore, three temperature measurement points were selected for monitoring and recording, and the average temperature of these points was used to characterize the temperature of the walnut. Specifically, one temperature sensor was fixed on the surface of the walnut with a heat-conducting tape, the second was inserted inside one of the nuts, and the third was in the middle of the drying chamber.

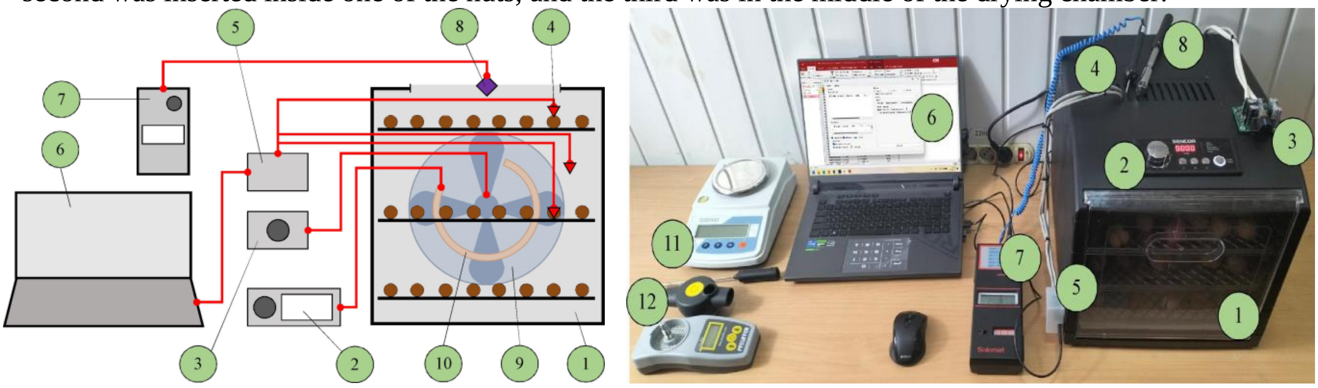

Fig. 1. General view of laboratory equipment:

1 – drying cabinet SENCOR SFD6601BK; 2 – temperature control unit; 3 – dimer d-0030/2KW; 4 – temperature sensors DS18B20; 5 – temperature recorder TM-32/H-5T; 6 – personal computer; 7 – multifunctional device Solomat MPM 500E; 8 – air speed sensor; 9 – fan; 10 – heater; 11 – digital scales TBE-0.3; 12 –hygrometer He Lite

Four temperature measurement points of walnut samples were determined: surface temperature, temperature inside the nut and cabinet temperature (Fig. 2). The drying cabinet was provided with the possibility of changing the air flow rate by controlling the voltage of the fan motor using a potentiometer. The air flow rate was controlled using a multifunctional device Solomat MPM 500E.

Fig. 2. Placement of nuts and temperature sensors in the drying oven

During the harvest season, the moisture content of nuts varied. During the experiment, the total moisture range of nuts was 34–46%, and this range was evenly divided into 4 groups with an interval of 6.0±0.2%. That is, the first factor in laboratory studies is the initial moisture content – w_0, % (in coded form – x_1). The second factor of the research is the temperature inside the drying oven – T, °C (in coded form – x_2),which varied in the range of 50–80 °C with an interval of 15 °C. The third factor of the research is the air flow velocity v, m/s (in coded form – x_3), which varied in the range of 1–3 m/s with an interval of 1 m/s. The fourth factor was time t, h (x_4),which was recorded every 120 min (2 h).

The research was conducted according to a full factorial design for three factors at three levels of variation with a total number of experiments – 27 with a repetition rate of – 20 (number of labeled nuts).

The drying cabinet was turned on for preheating, and after the system reached thermal equilibrium, the samples were placed on pallets. To track changes in the moisture content of walnuts during the drying process, 80 labeled nuts were quickly removed from the oven, the weight of each sample was measured on a TBE-0.3 digital scale and returned back to complete drying. This stage of the experiment was completed within 5 seconds to increase the accuracy of the research results.

A graphic diagram of the methodology for conducting a study of the kinetics of drying walnuts with a warm air stream is shown in Figure 3.

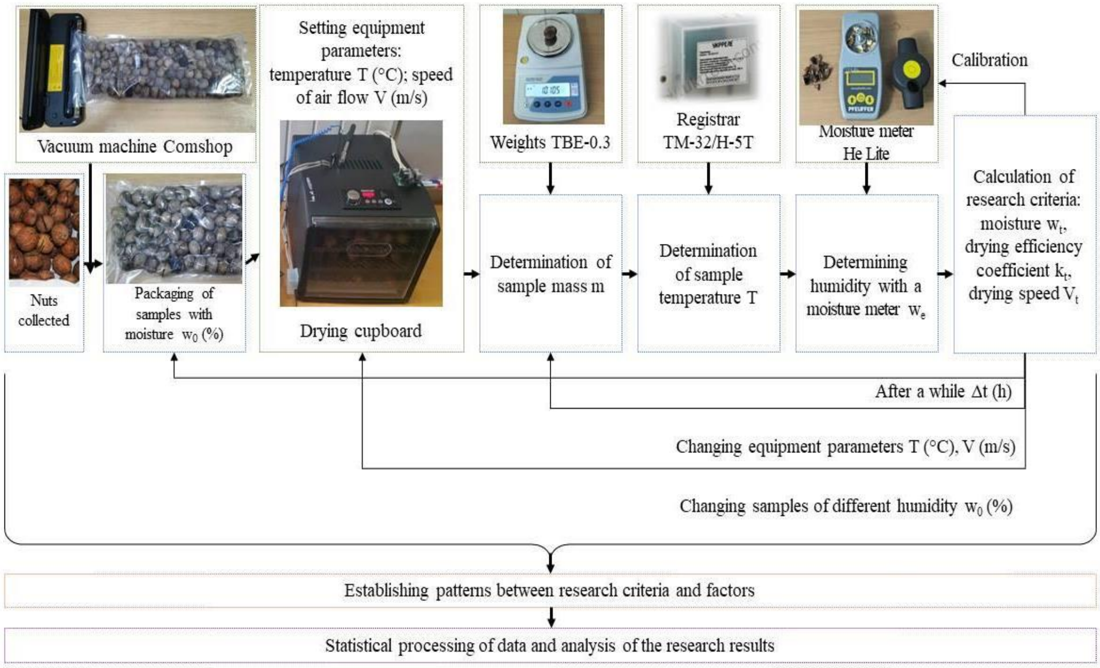

Fig. 3. Graphical diagram of the methodology for conducting a study of the kinetics of drying walnuts with a warm air flow

To assess the efficiency of drying, we will use the appropriate coefficient [14]:

$$k_t = \frac{w_t - w_l}{w_0 - w_l}, \tag{2}$$

where w_l, w_0, w_t – humidity at the end, at the beginning and at time t of drying, respectively.

Drying rate of nuts V_t (%/min) was calculated using the formula [15]:

$$V_t = \frac{w_{t+\Delta t} - w_t}{\Delta t}, \tag{3}$$

where $w_{t+\Delta t}$ – is the moisture content of the nuts at a given time t+Δt, %; w_t – is the moisture content of the nuts at a given time t, %.

The research criteria adopted were: the dependence of changes in humidity, temperature inside and on the surface of the nut, the drying efficiency coefficient, and the drying rate under different drying modes.

Due to the fact that there is no express moisture analyzer for nuts, a He Lite grain moisture meter (Pfeuffer, Germany) was used, which is set to the “corn” mode. To measure moisture, the nut was cracked and the kernel was placed in the moisture meter. Then, the data from the moisture meter were recorded and the moisture content was calculated using formula (1). After that, the He Lite grain moisture meter was calibrated for walnut.

According to the results of laboratory studies, data on changes in humidity for various combinations of factors during drying were obtained. For clarity, corresponding graphs of dependences were constructed (Fig. 4).

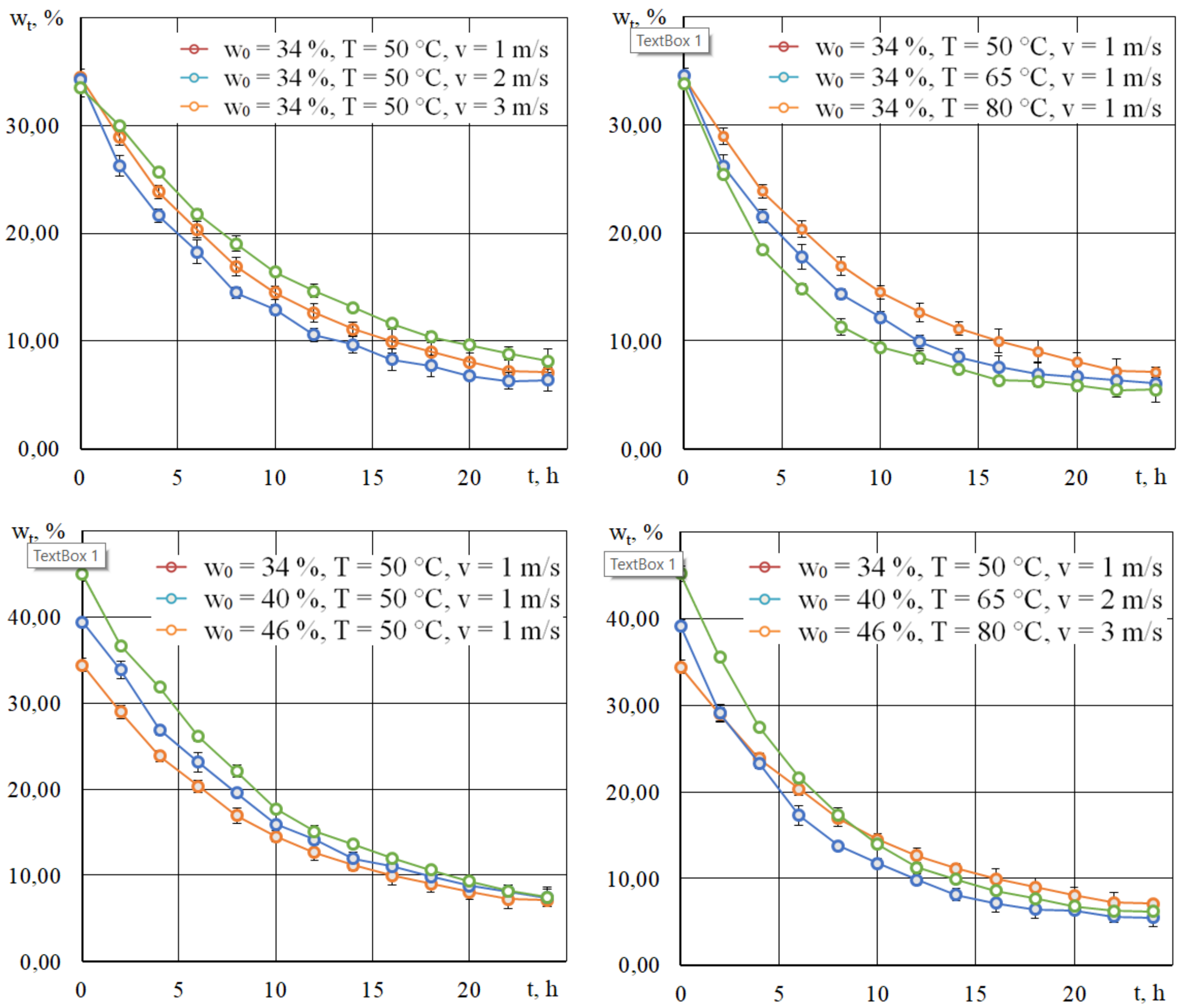

Fig. 4. Dependences of changes in nut moisture content during drying at different technological parameters

Analysis of changes in nut moisture content w_t during drying allows to assess the influence of the main process parameters: initial humidity w_0, air temperature T, air flow velocity v and drying duration t. The initial data show that these factors significantly affect the speed and final moisture level of the product.

The moisture content of nuts w decreases with time t in all studied conditions. At the initial stages of drying, intensive evaporation of moisture from the surface of nuts occurs, since the humidity gradient between nuts and the environment is maximum. Later, the process slows down due to the need to transfer moisture from the inner layers to the surface. For example, for nuts with an initial humidity of 34% at a temperature of 50°C and an air flow velocity of 1 m/s, after 2 hours the humidity decreases to 28.96%, after 10 hours – to 14.51%, and after 24 hours – to 7.1%.

Increasing air temperature significantly accelerates drying. This is due to the intensification of moisture evaporation from the surface due to an increase in the partial pressure of water vapor. For example, for nuts with w_0 = 34%at a speed of 1 m/s after 10 hours the humidity is: at T = 50 °C –w_t = 14,51%, at T = 65 °C – w_t = 12,17%, at T = 80 °C – w_t = 9,39%.

However, at excessively high temperatures, a surface crust may form, which makes it difficult for further evaporation of moisture from the inner layers of the nuts.

The air flow velocity also plays an important role. An increase in the air flow velocity v reduces the concentration of water vapor near the surface of the nuts, which increases the humidity gradient between the product and the environment. For example, for nuts with w_0 = 34% at T = 65 °C through 10 hours the humidity is: at v = 1 m/s– w = 12,17%, at v = 2 m/s – w = 10,17 %, at v = 3 m/s – w = 13,27%. The existing optimum can be explained by the fact that at higher temperatures the nut does not have time to heat up to the air temperature. This accordingly reduces the drying rate. At the same time, too high a flow rate can cause uneven drying or even damage to the product.

The higher the initial moisture content of the nuts, the longer it takes to reach the desired moisture level. This is due to the larger volume of water that needs to be evaporated. For example, when T = 50 °C, v = 1 m/s after 24 hours the moisture content of the nuts from w_0 = 34% is 7.1%, while for w_0 = 46% is 7,46%.

The fastest drying is achieved at high temperature (80°C) and air flow speed (2 m/s). For example, for nuts with w_0 = 34% Under these conditions, after just 10 hours, the humidity drops to the normalized value of 8.44%.

Having approximated the data in the form of an exponential dependence in the form [16]:

$$w_t = a_{000} + \left(a_{01} + a_1 x_1\right) \times \\ \times \exp\left[-\left(x_4\left(a_{02} + a_{20}x_2 + a_{22}x_2^{\,2}\right)\left(a_{03} + a_{30}x_3 + a_{33}x_3^{\,2}\right)\right) + a_{40}\right], \qquad (4)$$

where x_1 – encoded initial humidity value w_0; x_2 – coded temperature value inside the drying oven T; x_3 – coded value of air flow velocity v; x_4 – coded value drying timet; a_{01}, a_1, a_{11}, a_{02}, a_{20}, a_{22}, a_{03}, a_{30}, a_{33}, a_{40}, a_{000} – equation coefficients.

Having calculated the coefficients of the equation in the Wolfram Cloud software package using the "NonlinearModelFit" function, by the method of minimizing the sum of squares of deviations between the observed data and the model values, Table 1 was obtained.

Table 1

Results of calculating the coefficients of equation (4)

Coefficient	**Value**	**Standard error**	**Student's t-test**	**Significance assessment**
a_{01}	2,23039	0,021412	104,166	$4{,}89331\cdot10^{-260}$
a_1	0,382176	0,0215277	17,7528	$2{,}32084\cdot10^{-50}$
a_{02}	3,86533	0,00185609	2082,52	0,0
a_{20}	–0,125002	0,0264909	-4,71869	$3{,}47296\cdot10^{-6}$
a_{22}	–0,0182815	0,0451726	-0,404704	0,68595
a_{03}	0,431504	0,0142687	30,2413	$2{,}05796\cdot10^{-98}$
a_{30}	0,00445503	0,00294437	1,51307	0,131192
a_{33}	0,0146604	0,00528213	2,77547	0,00581711
a_{40}	1,03889	0,0464177	22,3812	$7{,}77504\cdot10^{-69}$
a_{000}	5,19541	0,318665	16,3037	$1{,}4698\cdot10^{-44}$

Discarding the insignificant coefficients of equation (4), comparing them with the tabulated value of the Student's t-test $t_t(0,05;\ 351) \approx 1,648$, we have:

$$w_t = 5,19541 + \left(2,23039 + 0,382176 x_1\right) \times \\ \times \exp\left[-\left(x_4\left(3,86533 - 0,125002 x_2\right)\left(0,431504 + 0,0146604 x_3^2\right)\right) + 1,03889\right]. \quad (5)$$

In decoded form, equation (5) can be represented as:

$$w_t = 5,1954 + \left(2,2456 + 0,06413\left(w_0 - 40\right)\right) \times \\ \times \exp\left[1,03206 - \left(0,0833t - 1\right)\left(3,856 - 0,008313\left(T - 65\right)\right) \times \\ \times \left(0,432537 + 0,014695\left(v - 2\right)^2\right)\right], \quad (6)$$

where w_0 – initial humidity, %; T – temperature inside the drying cabinet, °C; v – air flow speed, m/s; t – drying time, hours.

For greater clarity, graphs of dependence (6) are plotted in a three-dimensional coordinate system (Fig. 5).

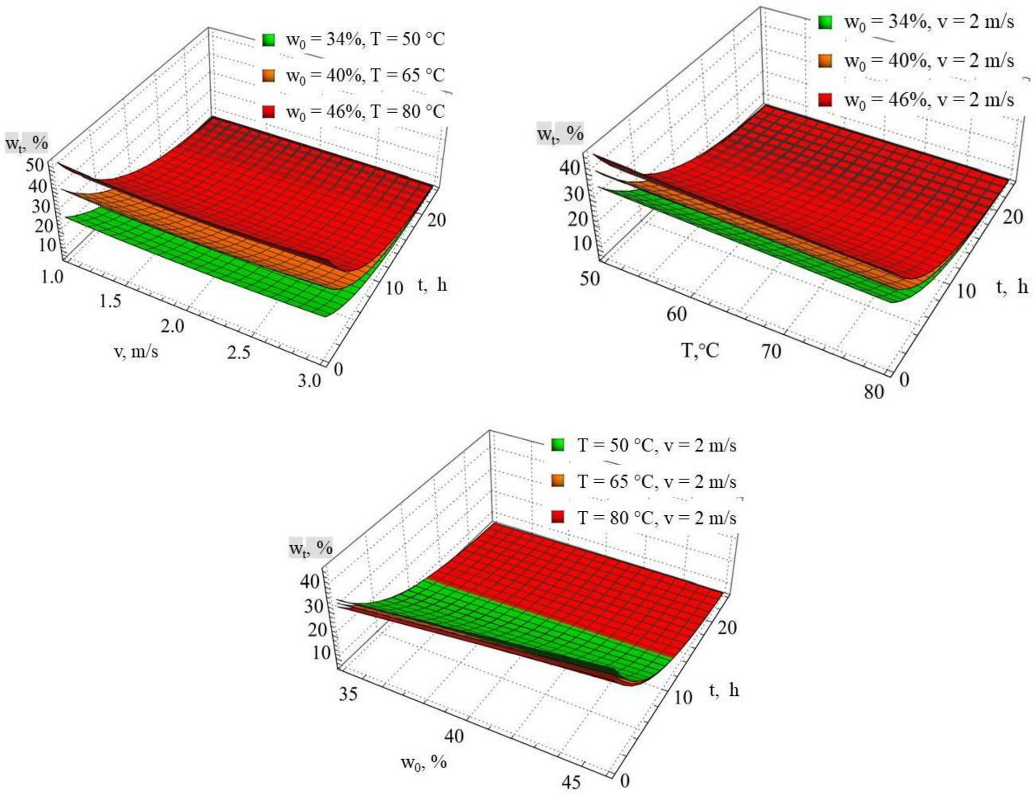

Fig. 5. Dependencies of the change in the moisture content of nuts during drying according to equation (6)

The results of the analysis of variance (ANOVA) comparing equation (6) with the original data are shown in Table 2.

Table 2

Results of the analysis of variance (ANOVA) of equation (6)

	DF (degrees of freedom)	SS (sum of squares)	MS (mean square)
Model	10	123814	12381,4
Error	341	1599,14	4,68956
Not Corrected Amount	351	125414	–
Corrected amount	350	38985	–

Calculated Fisher's exact test $F \approx 2640,6$ is very large, which may indicate the significance of the model (6) ($F > F_t\ (0,05;\ 10;\ 341) \approx 1,859$).

Based on the obtained data on the change in the moisture content of nuts during drying, the drying efficiency coefficient was calculated using formula (5) for each variant of the experiment. For clarity, the corresponding graphs of dependencies were constructed (Fig. 6).

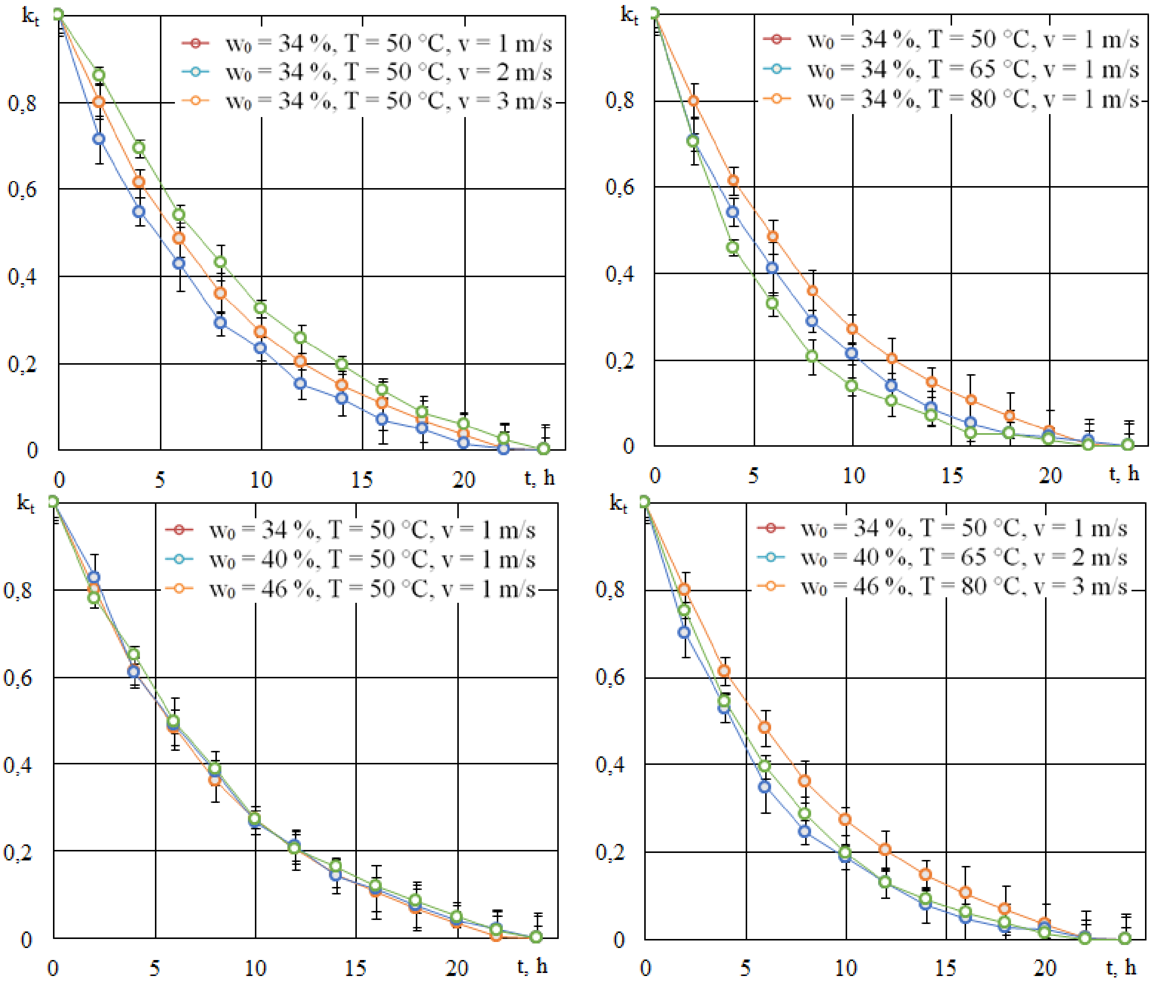

Fig. 6. Dependences of changes in the moisture content of nuts during drying at different technological parameters

Analysis of the drying efficiency coefficient change table k_t nuts shows that its value decreases with increasing drying time for all conditions. Thus, for the initial moisture content w_0 = 34%, temperatures T = 50°C, and air flow rate v = 1 m/s, value k_t decreases from 1 at the beginning of drying to 0.0037 after 22 hours. This is explained by the fact that moisture from the surface of the nuts evaporates faster in the initial stages, and over time the process slows down due to the need for moisture diffusion from the inner layers to the surface.

Increasing the air temperature T leads to an increase in drying efficiency, especially in the initial stages. Thus, for w_0 = 34%, v = 1 m/s, at six o'clock k_t constitutes 0,484 at T = 50°Cand only 0.205 at T = 80 °C. This is because higher temperature increases the rate of moisture evaporation, reducing the time required for drying. Similarly, increasing the air flow velocity v also contributes to an increase in k_t. For example, for w_0 = 34%, T = 50 °C, at six o'clock k_t = 0,484 at v = 1m/s, k_t = 0,426 at v = 2m/s and k_t = 0,429 at v = 3 m/s. Higher air flow speeds ensure more efficient removal of water vapor from the surface of the nuts into the environment, which speeds up the process.

Initial Humidity w_0 almost no effect on the efficiency ratio k_t, which confirms its generalizing properties. In general, optimization of the drying process requires adjusting the temperature and air flow rate depending on the desired drying time. Reduction k_t over time indicates that the drying process is multiphase, and its parameters should be adjusted depending on the drying stage.

It was found that the preheating time of nuts decreases with increasing drying temperature. This is because higher temperatures provide a greater amount of thermal energy, thereby reducing the preheating time. On the other hand, since the thermal energy of the drying medium is transferred from the surface to the interior, an increase in temperature causes significant temperature gradients, which accelerates the heat transfer.

It is found that the delay in temperature change becomes shorter with increasing temperature. Thus, it can be considered that at the initial stage (5 h) of walnut drying, it is advisable to apply high-temperature treatment (80 °C) to improve heat transfer efficiency and drying performance, which will further increase the drying rate. Subsequently, it is desirable to reduce the drying temperature to (50 °C).

5. Conclusion

The results of laboratory studies of the kinetics of drying walnuts with a warm air flow demonstrate that the main parameters of the process are the initial humidity w_0, air temperature T, Air flow rate v and drying duration t – significantly affect the drying rate $V_t$and the final humidity level w_t (6).

Change in nut moisture content w_t with time t in all studied conditions occurs gradually. Drying rate V_t is the highest at the initial stages and decreases with time due to the removal of surface moisture. Similarly, with increasing air flow rate, the drying rate increases. In general, the optimization of the drying process involves adjusting the temperature and air flow rate depending on the desired drying time. High temperature and optimal air flow rate ensure efficient drying. It has been established that the delay in temperature change becomes shorter with increasing temperature. Thus, it can be considered that at the initial stage (5 h) of walnut drying, it is advisable to apply high-temperature treatment (80 °C) to improve the heat transfer effect and drying performance, which will further increase the drying rate. Subsequently, it is desirable to reduce the drying temperature to (50 °C).

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ДОСЛІДЖЕННЯ ВПЛИВУ ТЕПЛОГО ПОВІТРЯНОГО ПОТОКУ НА КІНЕТИКУ СУШІННЯ ВОЛОСЬКИХ ГОРІХІВ

Волоські горіхи мають високий ризик окислювального псування під час зберігання, транспортування та продажу. На швидкість цього процесу впливає хімічний склад горіхів, який відрізняється залежно від сорту та регіону вирощування. Це означає, що кожна партія горіхів має різний потенціал зберігання. Проблема посилюється відсутністю ефективної системи відстеження партій горіхів на всіх етапах: від виробництва до продажу. Також бракує об'єктивних методів оцінки терміну придатності горіхів. Через це виробники та продавці часто неправильно встановлюють терміни придатності. В результаті, за статистикою, понад 30% волоських горіхів, що продаються в магазинах, мають ознаки гіркоти, що свідчить про їх зіпсованість.

Збереження якості волоських горіхів залежить від ряду ключових факторів, серед яких важливу роль відіграють рівень вологості, температурний режим, вологість навколишнього повітря, доступ кисню, стан горіхів, матеріали упаковки, спосіб зберігання та технологічна обробка (очищені, в шкаралупі, смажені тощо). Хоча волоські горіхи вважаються продуктом з тривалим терміном зберігання, дотримання оптимальних умов є критично важливим для збереження їх свіжості та смакових якостей.

Метою досліджень є вивчення кінетики сушіння волоських горіхів під впливом теплого повітряного потоку в лабораторних умовах.

Результати лабораторних досліджень кінетики сушіння волоських горіхів теплим повітряним потоком демонструють, що основні параметри процесу – початкова вологість w_0, температура повітря, швидкість потоку повітря і тривалість сушіння – суттєво впливають на швидкість сушіння і кінцевий рівень вологості.

Зміна вологості горіхів із часом у всіх досліджених умовах відбувається поступово. Швидкість сушіння є найбільшою на початкових етапах і зменшується з часом через вичерпання поверхневої вологи. Аналогічно, зі збільшенням швидкості повітряного потоку зростає швидкість сушіння. Загалом, оптимізація процесу сушіння передбачає регулювання температури та швидкості повітряного потоку залежно від бажаного часу сушіння. Висока температура й оптимальна швидкість повітряного потоку забезпечують ефективне сушіння. Було виявлено, що затримка у зміні температури стає коротшою зі збільшенням температури. Таким чином, на початковому етапі (5 год) сушіння волоських горіхів доцільно застосовувати високотемпературну обробку (80 °С) для покращення ефекту теплопередачі та продуктивності сушіння, що в подальшому підвищить швидкість сушіння. В подальшому температуру сушіння бажано зменшити до 50 °С.

Ключові слова: *параметри, кінетика, дослідження, сушіння, ефективність процесу, волоський горіх, конвекція, сушарка, повітря, потік, вологість, енергоефективність.*

Ф. 6. Табл. 2. Рис. 6. Літ. 16.

INFORMATION ABOUT THE AUTHORS

Vitalii YAROPUD – Candidate of Technical Sciences, Associate Professor, Dean of the Faculty of Engineering and Technology, Vinnytsia National Agrarian University (St. Soniachna, 3, Vinnytsia, Ukraine, 21008, e-mail: yaropud77@gmail.com, https://orcid.org/0000-0003-0502-1356).

Petro LAVRENIUK – Recipient of the Third Educational and Scientific Level of the Department of machinery and equipment for agricultural production of Vinnytsia National Agrarian University (3 Soniachna Street, Vinnytsia, 21008, Ukraine, e-mail: lavreniuk.petro.1239@gmail.com, https://orcid.org/0000-0002-2480-7365).

ЯРОПУД Віталій Миколайович – кандидат технічних наук, доцент кафедри машин та обладнання сільськогосподарського виробництва Вінницького національного аграрного університету (вул. Сонячна, 3, м. Вінниця, Україна, 21008, e-mail: yaropud77@gmail.com, https://orcid.org/0000-0003-0502-1356).

ЛАВРЕНЮК Петро Петрович – здобувач ІІІ освітньо-наукового рівня кафедри машин та обладнання сільськогосподарського виробництва Вінницького національного аграрного університету (вул. Сонячна, 3, м. Вінниця, 21008, Україна, e-mail: lavreniuk.petro.1239@gmail.com, https://orcid.org/0000-0002-2480-7365).