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THE MECHANISMS OF HEAT AND MASS TRANSFER THAT TAKE PLACE WITHIN RICE GRAINS DURING THE DRYING PROCESS

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Abstract

The information on the internal structure of rice grains has been studied and analyzed. Based on the obtained and analyzed data, the processes of heat and mass transfer occurring within rice grains have been calculated. The influence of

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the parameters of heat and mass transfer processes on the drying process has been analyzed, and temperature regimes for conducting the drying process have been recommended.

Keywords: Internal structure of rice grain, capillaries, capillary radius, heat and mass transfer processes, humidity, humidity gradient, viscosity, surface tension force.

Introduction

Rice grain possesses a number of unique characteristics, such as a specific anatomical structure, susceptibility of rice kernels to cracking, and other related properties, and it can be described as a colloid capillary-porous body. Chinese and South Korean researchers have conducted numerous studies not on rice grain drying itself, but on processes occurring in milled rice, such as moisture absorption and changes during cooking. Researchers from Nanjing Agricultural University, including Yao Deng, Yongchao Yu, Yuxiang Hu, Li Ma, Yan Lin, Yue Wu, Zhen Wang, Ziteng Wang, Jiaqi Bai, Yanfeng Ding, and Lin Chen, investigated the distribution of capillaries and voids responsible for transporting water and nutrients during rice grain development [1]. By microscopic analysis, they determined that the rice grain structure consists of the following components: husk, embryo, longitudinal channel within the grain, transverse capillaries or pores, endosperm layers, and hull layers. In addition, researchers from Shahid Beheshti University, including Rhehele Panahabadi, Asadollah Ahmadhiah, along with scientists from the Swedish Wood Science Centre such as Loren S. McKee, Per K. Ingvarsson, and Nasser Farrokhi, studied the structure of rice grains and the spatial distribution of nutrients within the grain [2]. Furthermore, in classical studies conducted by Juliano (1984) and Luikov (1966), rice grains are treated as capillary-porous materials, and their heat and mass

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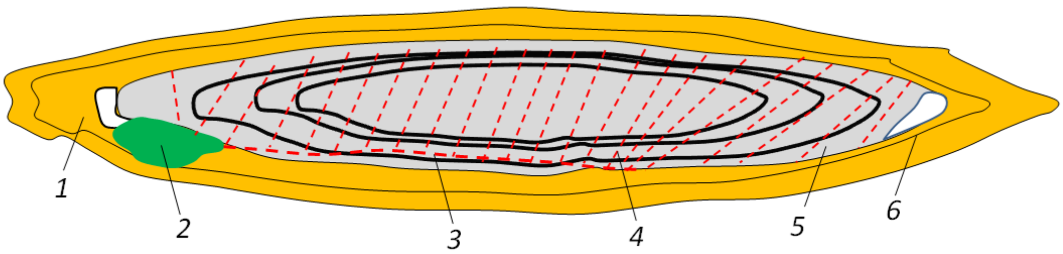
transfer processes are described using diffusion laws and the coupled heat–moisture transfer model proposed by Luikov [3,4,5].

Discussion and Method

Based on the information presented above, the rice grain takes the structure shown in Figure 1. Thus, inside the rice husk there are the embryo and the endosperm. In the ventral part of the rice grain (or endosperm), a longitudinal main channel is located, which is connected to the embryo. From the dorsal side of the endosperm to this channel, capillaries or voids pass through the nutrient substances of the endosperm. When rice is placed in water, water or moisture spreads from the main channel toward the nutrient substances or toward the dorsal side. The size of the capillaries or voids gradually decreases toward the dorsal side, and therefore the swelling or moistening of the dorsal part occurs very slowly. To accelerate this process, water is heated and boiled [6,7,8].



1 – Structural diagram of capillaries and layers in a rice grain
1 – husk, 2 – embryo, 3 – longitudinal channel, 4 – transverse capillary voids, 5 – endosperm layers, 6 – husk layers

In our research, the objective is to reduce energy consumption and significantly shorten the drying time when bringing rice grains to the required moisture content for long-term storage. During the rice drying process, heat and mass transfer processes occur within the grain, and this process can be described by the

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following differential equation of mass transfer, which determines the rate of moisture evaporation from the grain surface:

$$\frac{dm_u}{dt} = \beta \cdot S \cdot (P_{ds} - P_h), \qquad (1)$$

Here, $\frac{dm_u}{dt}$ - rate of moisture change in the grain (evaporation rate), kg/s;

β- mass transfer coefficient, characterizing the intensity of vapor transfer from the grain surface to the surrounding environment, kg/(m²·Pa·s); this coefficient takes into account the additional resistance of the husked rice grain;

S – evaporation surface area, m²;

P_{ds} - partial pressure of water vapor at the grain surface, Pa;

P_h - partial pressure of the drying agent (or air), Pa;

To simplify and solve the equation, the available parameters should be expressed by representing the partial pressure of moisture P_{ds} in terms of the current moisture mass m_u or the moisture content W (in percentage). In practice, within the working range, the variation of vapor pressure is usually assumed to follow a linear or exponential relationship [9].

The simplification is carried out using absolute moisture content. The absolute moisture is taken into account as follows $= \frac{m_u}{m_{qsh}}$, m_{qsh}– mass of absolutely dry matter. In this case, the equation takes the following form:

$$m_{qsh} \cdot \frac{dW}{dt} = \beta \cdot S \cdot (P_{ds}(W) - P_h). \qquad (2)$$

If the difference in partial pressures is proportional to the current and storage moisture content W_{saq} (or $P_{ds} - P_h \approx k(W - W_{saq})$), the equation takes the following form:

$$\frac{dW}{dt} = -K(W - W_{saq}), \qquad (3)$$

Here $K = \frac{\beta \cdot S \cdot k}{m_{qsh}}$ is the generalized drying coefficient.

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By separating the variables and considering the moisture content at time t=0 as W0, and integrating up to time t, we obtain the following:

$$\ln\left(\frac{W-W_{saq}}{W_0-W_{saq}}\right) = -K \cdot t \qquad (4)$$

The solution in exponential form takes the following form:

$$W(t) = W_{saq} + \left(W_0 - W_{saq}\right) \cdot e^{-K \cdot t}. \quad (5)$$

From the obtained results, it follows that the moisture content of the rice grain approaches the storage moisture content W_{saq} with a rate determined by the coefficient K, which is directly related or directly proportional to the mass transfer coefficient β and the grain surface area S.

For husked rice, the drying time is determined by using the solutions obtained from solving the previous equations.

$$t = \frac{1}{K} \cdot \ln\left(\frac{W_0-W_{saq}}{W-W_{saq}}\right). \qquad (6)$$

The average surface area of a rice grain is $S = 25 - 32 \cdot 10^{-5}\ \mathrm{mm}^2$, and considering that the average weight of a dry grain is 0.02–0.03 g and the value of K, the drying time is found to be 60 seconds per kilogram of grain.

The above calculations were carried out without taking into account the internal structure of the rice grain.

Considering that mass transfer depends on many factors, the above results may raise some doubts. Therefore, taking into account the structure proposed by Chinese specialists, the calculations are performed again. In the drying of husked rice, the mass transfer process through the capillaries in the husk and endosperm is considered the limiting stage. In this case, the equation is supplemented by Poiseuille's law or capillary potential. When solving the equation with respect to capillaries, we move from the difference in vapor pressures to the capillary pressure gradient[10,11].

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The moisture passing through the capillary is described by the following equation:

$$\frac{dm_u}{dt} = \sum \left(\frac{\pi \cdot r^4 \cdot \rho_l}{8 \cdot \eta \cdot L}\right) \Delta P_{kap}, \qquad (7)$$

Here r is the radius of the capillaries, µm;

η is the viscosity of water (it decreases significantly when heated, thereby accelerating the drying process);

L is the capillary length, mm;

ΔP_{kap} is the capillary pressure, determined by Laplace's equation, $\Delta P_{kap} = \frac{2 \cdot \sigma \cdot \cos\theta}{r}$;

If the capillary parameters are substituted into the coefficient β, we obtain a differential equation for determining the moisture (or vapor) velocity in the capillaries,

$$\frac{dW}{dt} = -\frac{A \cdot \sigma \cdot \cos\theta}{\eta \cdot L}\left(W - W_{saq}\right), \qquad (8)$$

where A is the structural distribution coefficient of voids or capillaries in the grain.

Taking into account the parameters of the capillaries, the drying time can be determined as follows:

$$t = \left(\frac{\eta \cdot L}{A \cdot \sigma \cdot \cos\theta \cdot r}\right) \cdot \ln\left(\frac{W_0 - W_{saq}}{W - W_{saq}}\right). \qquad (9)$$

Analyzing this expression, the following conclusions can be drawn: the rice husk has very fine porosity; if these pores become filled, blocked, or the structure is dense, the drying rate decreases and the drying time increases; an increase in water temperature reduces its viscosity and increases the moisture velocity in the capillaries; and the greater the thickness of the husk, the lower the drying rate and the longer the drying time [12,13].

Temperature affects the mass transfer process in the endosperm capillaries in two ways: a significant decrease in water viscosity facilitates vapor movement within

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the capillaries, and changes in surface tension increase the driving force of the process.

The viscosity of water in capillaries decreases rapidly with increasing temperature, which is considered a key factor in drying. For its calculation, approximation or empirical fitting methods are commonly used.

$$\eta(T) = \eta_0 \cdot e^{\frac{E_a}{R \cdot T}}. \qquad (10)$$

According to the given or approximated formula, the viscosity of water varies with temperature in the following form: at 20°C $\eta \approx 1{,}002$ MPa · s; at 45°C $\eta \approx 0{,}596$ MPa · s; at 60°C $\eta \approx 0{,}467$ MPa · s. With every 20–25°C change in temperature, the flow rate of moisture inside the capillaries doubles.

Surface tension increases the capillary pressure and helps to force moisture out of the capillaries. With increasing temperature, σ decreases linearly. The approximated formula for surface tension is as follows:

$$\sigma(T) = 0{,}0728 \cdot \big((1 - 0{,}002) \cdot (T - 20)\big), \text{Н} \cdot \text{м}. \qquad (11)$$

Due to changes in the physical properties of water, the rate of moisture removal from rice capillaries increases up to 1.7 times. However, when the drying temperature is increased to 50–55°C, a sharp decrease in viscosity leads to rapid moisture release, resulting in internal capillary rupture and the formation of microcracks in the endosperm. This condition causes the rice to break into smaller fragments during subsequent processing and leads to a deterioration in product quality.

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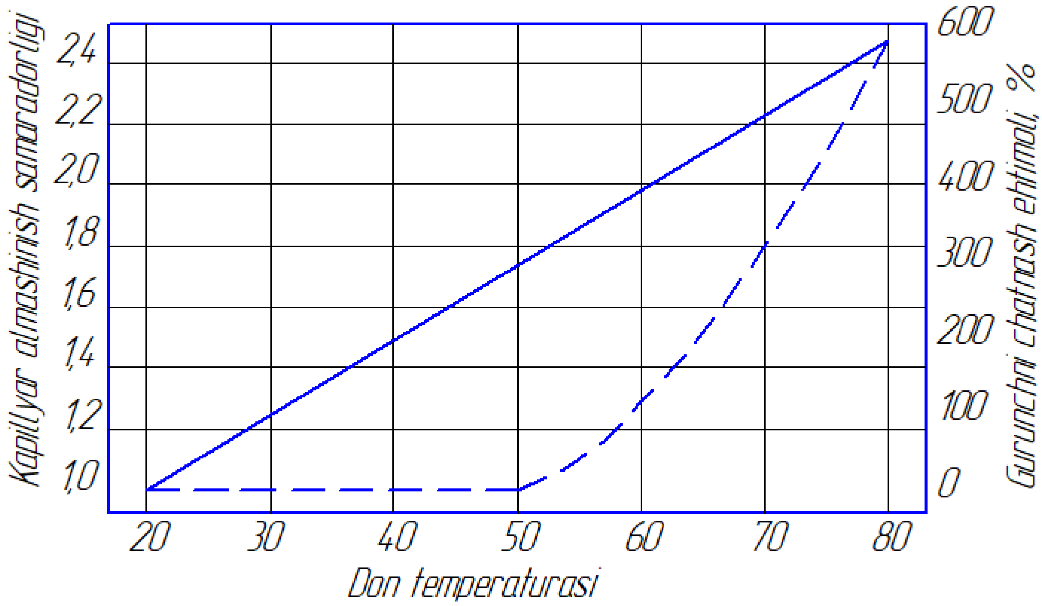

Figure 2. Effect of temperature on the drying of rice grain through capillaries

Conclusion and Recommendations

The presented graph or relationship shows the following: in the temperature range of 20 to 40°C, the increase in moisture removal rate is considered an acceleration zone, mainly due to the reduction in viscosity. The range of 40–50°C is regarded as the optimal zone for preserving the integrity of rice grains. Above 50°C, due to a sharp decrease in viscosity and an increase in thermal stress, the probability of microcrack formation in rice grains increases. In addition, the moisture gradient in the capillaries increases, causing the outer layer to dry rapidly and leading to compression of the still-moist inner part.

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https://eurekaoa.com/index.php/9

References

1. Deng Y., Yu Y., Hu Y., Ma L., Lin Y., Wu Y., Wang Z., Wang Z., Bai J., Ding Y., Chen L. Auxin-mediated regulation of dorsal vascular cell development may be responsible for sucrose phloem unloading in large panicle rice // Frontiers in Plant Science. – 2020. – Vol. 11. – Art. 695.
2. Panahabadi, R., Ahmadikhah, A., McKee, L. S., Ingvarsson, P. K., & Farrokhi, N. (2021). Genome-wide association mapping of mixed linkage (1,3;1,4)-β-glucan and starch contents in rice whole grain. Frontiers in Plant Science, 12, 665745. https://doi.org/10.3389/fpls.2021.665745.
3. Juliano, B.O. Rice Chemistry and Technology.
4. Luikov, A.V. Heat and Mass Transfer in Capillary-Porous Bodies.
5. Brooker, F.W. et al. Drying and Storage of Grains.
6. Abdumannopov, N., Otahanov, B., & Ergashev, S. (2025). Drying rice grain with microwave in false boiling layer. Engineering, 17(8), 403–412. https://doi.org/10.4236/eng.2025.178024
7. Abdulkhayev, X. A., Otakhanov, B. S., Sodiqov, M. A., & Abdumannopov, N. A. (2025). Motion equation of rice grain in false boiling process. Scientific Journal of Construction and Education, 4(2), 429. https://jurnal.qurilishtalim.uz
8. Otaxanov, B. S., Abdulkhayev, X. G., Sodiqov, M. A., & Abdumannopov, N. A. (2026). Heating intensity of rice in a fountain-type boiling layer. Scientific Journal of Mechanics and Technology, 7(1), 178. https://mextex.uz
9. Otakhanov, B.S., Sodiqov, M.A.O. and Abdulkhakimov, A.N. (2023) Analysis of Methods Used to Determine the Need for Spare Parts of Industrial Enterprises. Scientific Impulse, 1, 1789-1794.
10. Tolanovich, E.S., Otakhanov, B.S., Rustamov, Q.A., Abdulkhakimov, A.N. and Saidmuradov, M.A. (2024) Aerodynamic Characteristics of Rice Grain. Construction and Education, 3, 142-146.

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Eureka Journal of Geoscience, Materials & Resource Engineering (EJGMRE)

ISSN 2760-4985 (Online) **Volume 02, Issue 05, May 2026**

https://eurekaoa.com/index.php/9

11. Hadi, M. and Ghasemi, M. (2022) Modelling and Experimental Analysis of Rice Drying in a New Fluidized-Microwave Dryer. Journal of Food Measurement and Characterization, 16, 1264-1275.
12. Zhu, Y., Zhou, L., Zhang, M. and Wang, Y. (2022) Multi-Objective Optimization of Hybrid Microwave-Fluidized Bed Drying of Paddy Using Response Surface Methodology. Journal of Stored Products Research, 97, Article 102001.
13. Yu, Y., Zhang, M. and Mujumdar, A.S. (2022) Effects of Stepwise Microwave Heating and Expanded Bed Height Control on Combined Fluidized Bed/Microwave Drying for Instant Brown Rice. Food and Bioprocess Technology, 15, 2263-2276.