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TECHNICAL AND TECHNOLOGICAL ASPECTS OF HEAT PROCESSING OF EGGPLANTS

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This article deals with the analysis of current technological issue of removing solanine from eggplants, which showed that using the process of deep fat frying is not perfect in terms of ensuring high quality indicators. There has been proposed an alternative solution aimed to provide the solanine removal process. Conducting research, the authors designed an experimental appliance which operated under conditions close to actual production environment. Experimental studies were carried out with a wide range of geometric, structural and mechanical characteristics of eggplant fruits. There are given the results of researching the dynamics in thermal processing of eggplants with different geometric types and sizes at different temperature regimes. The authors represent a mathematical relation that correctly describes the process of heating fruits with hot air. Also they give graph-analytical solutions that allow to calculate rational regimes of their thermal processing with hot air in ovens and to ensure the necessary degree of flesh cells plasmolysis for the possibility of subsequent solanine removal from them. There has been developed a theoretical model of the process which allows to describe the behaviour and characteristics inherent in conductive heating of fruits. Data were obtained for the design and development of modern heating equipment and supplies for restaurant establishments and small-scale processing enterprises.

Keywords: *solanine, process of frying eggplants, geometric parameters, medium temperature, heating rate, heating intensification.*

ТЕХНІКО-ТЕХНОЛОГІЧНІ АСПЕКТИ ТЕПЛОВОЇ ОБРОБКИ БАКЛАЖАНІВ

О.Г. Терешкін, Д.В. Горєлков, В.В. Дуб

Наведено результати дослідження динаміки термічної обробки баклажанів із різними геометричними типорозмірами за різних температурних режимів, а також математичну залежність, яка адекватно описує процес нагрівання плодів гарячим повітрям. Отримано графоаналітичні рішення цієї залежності, що дозволяє розрахувати раціональні режими їх теплової обробки гарячим повітрям у жарильних шафах та забезпечити необхідний ступінь плазмолізу клітин м'якоті для подальшого видалення з них соланіну під час підпресовування.

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Ключові слова: *соланін, смаження баклажанів, геометричні параметри, температура середовища, швидкість нагрівання, інтенсифікація процесу.*

ТЕХНИКО-ТЕХНОЛОГИЧЕСКИЕ АСПЕКТЫ ТЕПЛОВОЙ ОБРАБОТКИ БАКЛАЖАНОВ

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Приведены результаты исследования динамики термической обработки баклажанов с разными геометрическими типоразмерами при разных температурных режимах, а также математическая зависимость, которая адекватно описывает процесс нагрева плодов горячим воздухом. Получены графоаналитические решения этой зависимости, которые позволяют рассчитать рациональные режимы их тепловой обработки горячим воздухом в жарочных шкафах и обеспечить необходимую степень плазмолиза клеток мякоти для последующего удаления из них соланина при подпрессовывании.

Ключевые слова: *соланин, жарка баклажанов, геометрические параметры, температура среды, скорость нагрева, интенсификация нагрева.*

Statement of the problem. Eggplants are very popular in the range of canned and culinary products made from vegetables. They have an original appearance, high palatability and combine dietary, therapeutic, and prophylactic properties. However, the technologies of their processing are far from perfect, because most technological operations do not have the equipment decision, it determines their labour intensity and duration, and does not ensure a proper quality control of products, which are often made by hand.

The presence of a significant amount of fibre and pectic substances in the fruits indicates that eggplants have valuable therapeutic and prophylactic properties: they normalize intestinal motility, help the elimination of waste products and heavy metal compounds from the body, reduce blood cholesterol in the treatment of atherosclerosis [1-5].

Particular attention is drawn to the presence in eggplants of the gluco-alkaloid solanine M, which consists of solanine, galactose, and rhamnose residues. Solanine is a substance that has moderate toxicity and when used can cause typical signs of poisoning (asphyxia, nausea, vomiting, indigestion, and headache) [5]. In addition, solanine has a negative impact on the taste of eggplants, giving them a bitter taste (at concentrations above 0.018% on a dry matter). The content of solanine in eggplant fruits varies significantly, first of all it depends on the degree of ripeness: in the stage of technical ripeness – 0.004…0.009%, in overripe fruits – 0.028…0.049%, in biologically ripe – 0.087% on a dry matter. Besides, the concentration of solanine is significantly affected by agronomic growing conditions [5]. This leads to the fact that in most cases, eggplants have an excess (or close to that) concentration of solanine, which in the time of moister removal during their processing increases significantly, far exceeding the permissible limits. Therefore, a special attention should be paid to the issue of regulating the concentration of solanine in eggplants, in their culinary use.

Review of the latest research and publications. Some technologies use an osmotic active substance – sodium chloride (table salt) – to remove solanine [5-6]. Prepared fruits are heavily sprinkled with salt, mixed and kept until the removal of a certain amount of juice with solanine (the amount of salt and the duration of exposure is determined intuitively, and the effectiveness of this process depends on the experience and qualifications of the cook).

The use of the process of removing bitterness from eggplants, in our opinion, is the result of its simplicity, accessibility and the possibility of its implementation without any equipment decision. However, to control its regimes, for example, to achieve optimal values of solanine concentration in fruits is quite a difficult task. In addition, there are no positive phenomena, which we can observe during blanching. For example, inactivation of enzymes doesn't take place here, and it leads to darkening of the fruit flesh with other negative phenomena.

The process of frying eggplants in vegetable oil partially fulfils the task of the blanching process. The purpose of heat processing of eggplants during their frying in refined vegetable oil at a temperature of 130…140 ^{0}C for 5–20 min is bringing eggplants to culinary readiness, removing a significant amount of moisture, absorbing a certain amount of oil, lowering calorie content of the product, and providing specific organoleptic properties (colour, taste, smell).

The parameters of the frying process are controlled by such indicators as the visible percentage of frying losses (relative change in fruits weight due to moisture loss and simultaneous oil absorption), which is 32–35%, as well as the appearance of eggplant.

It is known that during frying eggplant in oil, a relative change in their volume (so-called shrinkage) depends on the initial moisture content in the fruit, oil temperature and process duration. So, for example, when initial moisture content in eggplants and oil temperature is higher, if other conditions are equal, the rate of change in relative fruits volumes will be maximum. All of the above-mentioned occurs due to the high rate of moisture loss by eggplants, which affects their shrinkage. In this regard the rate of volumes change will be maximum in the initial frying period (5–10 min), when the process of intensive moisture removal is observed. With the removing of moisture, there is a moment of decreasing the rate of volumes change (10–40 min), and in the final stage of the process (after 40 min); when the moisture content reaches certain values close to the complete moisture removal, change in the volume of eggplants does not occur [7; 8].

The process of heat treatment of eggplants has the disadvantage: the difficulty of ensuring the quality of oil storage, which leads to either a decrease in the quality of canned products, or significant losses of oil during its replacement. Moreover, after frying, eggplants are kept for some time to drain excess oil and cool them, which causes the increase in the duration of the process and adversely affects the microbiological contamination of raw materials. It can be stated that thermal appliances are not perfect in terms of ensuring high quality of fried raw materials, they are significantly complex, highly productive, bulky and have a high cost.

The objective of the research is to identify the dynamics of changes in structural and mechanical properties of eggplants in the process of their heat treatment with the flow of hot air, to obtain graph-analytical dependences that will allow us to calculate rational heat treatment regimes.

Presentation of the research material. For the research we have used fruits with certain geometric parameters, weight, volume, density, and porosity.

In this research we have used an experimental appliance, which consists of a cabinet oven ШЖЕСМ-2К (electrical cabinet sectional modulated oven), potentiometer KSP-4, thermoelectric transducer with open chromel-drop thermocouples inserted into steel needles and fixed so that their solder joint would be on the tops of the needles and could come into contact with product when they are inserted. The thermoelectric transducer was connected to the potentiometer by elongated wires through the measuring point selection switch PTI-M, mounted on its housing. The error in measuring temperatures was not more than 1°C (didn’t exceed 5%).

To conduct one series of experiments on heat processing of eggplants (at a certain temperature in the frying chamber) we used 10 fruits with the same geometric parameters, one of which was used to control the dynamics of its heating, and the other were applied to study weight, volume, density, and porosity of the fruits at different stages of heat processing (numbered sampling units with known parameters were taken to determine weight, volume, density and porosity every 120 s of heat treatment).

Study of the process of heat treatment of eggplants was carried out until the moment of equalization and stabilization of the temperature at all points of its measurement (up to a temperature of 96–98 ^{o}C). For each series of experiments, we used fruits with a diameter of 50–70 mm.

The dynamics of changes in weight, volume, density and porosity of eggplants at different stages of their heat processing at medium temperatures was recorded by determining their relative indicators:

$$\Delta m = \frac{m_i - m_f}{m_f}, \tag{1}$$

$$\Delta V = \frac{V_i - V_f}{V_f}, \tag{2}$$

$$\Delta m = \frac{p_i - pf_f}{p_f}, \tag{3}$$

$$\Delta P = \frac{P_i - P_f}{P_f}, \tag{4}$$

where Δm, ΔV, $\Delta \rho f$, ΔP correspond to relative changes in mass, volume, density and porosity of the samples at different stages of their heat processing;

m_i, V_i, ρ_i, P_i are respectively the initial values of mass, volume, density and porosity of the samples before heat processing, kg, m^3, kg/m^3, %;

m_f, V_f, ρf_f, P_f are respectively the initial data of the mass, volume, density and porosity of the samples at certain stages of their heat processing, kg, m^3, kg/m^3, %.

Fruits of certain geometric parameters, mass, volume, density and porosity, and solanine concentration were subjected to heat treatment at 150–300 ^{o}C until the temperature in the centre reaches 55–65^{0} C. This range of fruit heating temperatures, as it has been shown by previous experiments, provides plasmolysis of fruit flesh cells, meanwhile maintaining sufficient mechanical strength of their structure. During the process of heating (at the initial stage) the difference in temperature values under the layers in certain areas of fruit cross-section will obviously be quite significant.

The conducted research allowed us to determine the heating dynamics of eggplants under different regimes of their heat processing. The results are presented in Fig. 1–4. To test the adequacy of the obtained theoretical dependence, which describes the dynamics of heating the inner layers of eggplants at different media temperatures, we calculated the values of Θ using experimental values t_{med}, t_0, t, τ, r_{max}, $\frac{r}{r_{max}}$.

$$\Theta = 1{,}072e^{5{,}784\ F0} + 0{,}085e^{30{,}47\ F0} - 0{,}15^{74{,}82F0}. \tag{5}$$

The proposed dependence (formula 5) adequately describes the heating of eggplants during their heat processing when we change the coefficient of thermal conductivity (α). As a result of calculations, we have obtained the dependence of α on Θ, which characterizes the coefficient of thermal conductivity in the process of eggplants heating (Fig. 5). Analysis of the obtained dependence graph shows that in the initial period of heating of eggplants (Θ=0.87…1, t=20…43 ^{o}C) the values of the coefficient do not change and are 1.5 10^{-7} m/s; then the value of the coefficient α increase to Θ=0.64, which corresponds to the temperature in the fruit 85 ^{o}C (α=1.7·10^{-7}m/s), and at the last stage of heating the coefficient decreases to α=1.35·10^{-7}m/s at a temperature Θ=0,57, which corresponds to a temperature of 98 ^{o}C. The obtained dependence of the dynamics in the values of thermal conductivity coefficient on the eggplants heating temperature reflects the changes in their structure during heating.

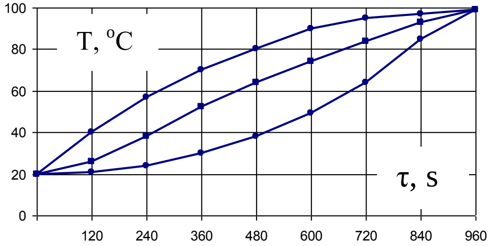

Fig. 1. Dynamics of heating of eggplants d_{max}=60 mm at a medium temperature of 150 ^{o}C: 1 – under the skin (R=1); 2 – in the intermediate layer (R=0.5); 3 – in the centre of the fruit (R=0)

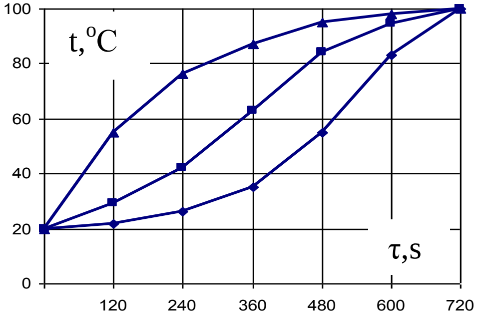

Fig. 2. Dynamics of eggplants heating d_{max}=60 mm at a medium temperature of 200 ^{o}C: 1 – under the skin (R=1); 2 – in the intermediate layer (R=0.5); 3 – in the centre of the fruit (R=0)

At the initial stage of heating, due to the high density of the flesh (the presence of numerous air layers), its thermal conductivity is low due to the fact that plasmolysis of the cell structure did not take place.

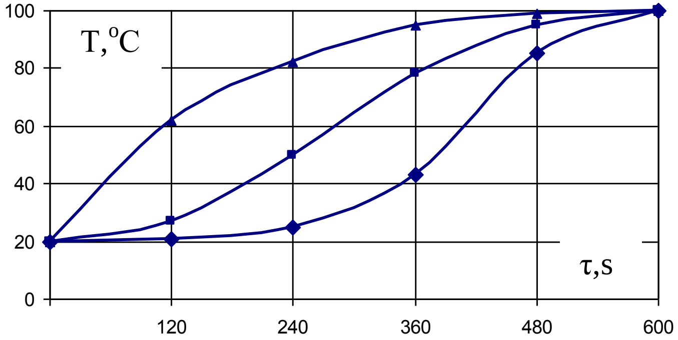

Fig. 3. Heating dynamics of eggplant d_{max}=60 mm at a medium temperature of 250 °C: 1 – under the skin (*R*=1); 2 – in the intermediate layer (*R*=0.5); 3 – in the centre of the fruit (*R*=0)

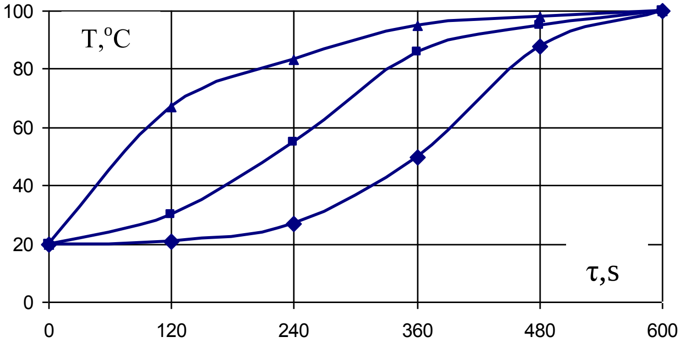

Fig. 4. Heating dynamics of eggplant d_{max}=60 mm at a medium temperature of 300 °C: 1 – under the skin (*R*=1); 2 – in the intermediate layer (*R*=0.5); 3 – in the centre of the fruit (*R*=0)

Then during heating of fruits to 43…85 °C the phenomena of plasmolysis takes place there, cell juice flows into intercellular spaces (pores filled with air); during heating it forms steam-air mixes which thermal conductivity is higher, than air; it leads to increase in coefficient of thermal conductivity. At the final stage of the process the reduce in thermal conductivity occurs due to the intensification of the process of moisture transfer (movement of fluid from the centre of the fruit to the skin) directed opposite to heat transfer, as well as reducing the driving force – difference in temperatures. To make the calculating formula usable we will present it in the form of dependence graph of Θ on F_0 (Fig. 6).

$$\Theta = \frac{t_{med} - t}{t_{med} - t_o}$$

The obtained dependence allows to determine the heating time of eggplants of any initial diameter or radius (r_{max}), at different initial temperatures (t_0), media temperatures (t_m), to the required temperature (t) in the intermediate layer (R=0.5). Meanwhile it is necessary to use the selected values r_{max}, t_m, t_0, t for calculation $\Theta = \frac{t_{med} - t}{t_{med} - t_o}$, t_{med} according to the graph (Fig. 6) to determine the corresponding to Θ values of F_0, and then calculate the heat processing time by the formula: $\tau = \frac{F_0 \cdot r_{\max}}{\alpha}$.

The values of the thermal conductivity coefficient α are determined according to the graph (Fig. 5), using the calculating values Θ. Analysis of the obtained patterns allows us to draw the following conclusions. With the increase in air temperature, the heating rate of the fruit increases proportionally. For example, the equalization of temperatures in the entire volume of the fruit (when the temperature reaches 97…98 °C) depends on the medium temperature (150, 200, 250, 300 °C), corresponding to 960, 720, 580 and 480 s. So, with a relative increase in temperature by 33.25 and 20%, the duration of heating consequently increases by 33.25 and 20%.

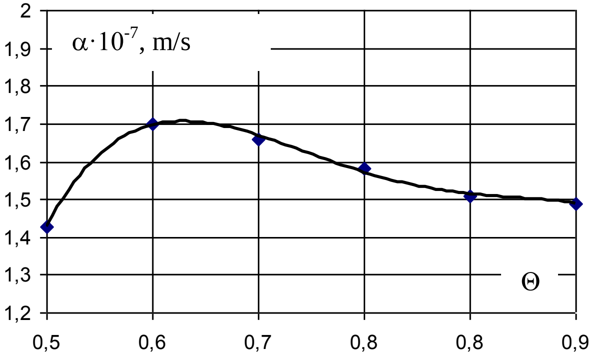

Fig. 5. Dependence of the coefficient of eggplants thermal conductivity on the relative temperature during their heat processing

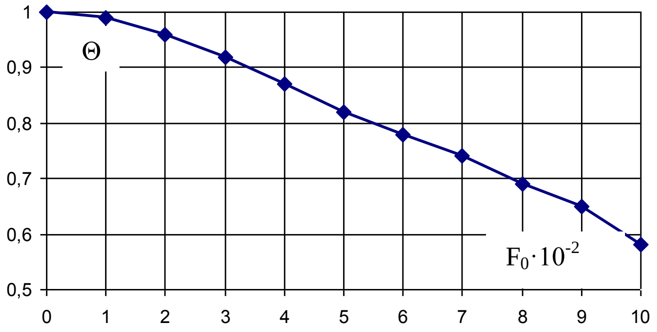

Fig. 6. Dependence of Fourier's criterion on relative temperature during heat processing of eggplants

The characteristics of curves describing the dynamics of heating in different layers of fruits indicates that their rate is different at different time intervals. So, the heating rate of the upper layer (under the eggplant skin) is maximum in the first stage of heat treatment (due to the proximity of the heated layer to the heat source), and in the process of heating to 80 °C a decrease starts there, and when the temperature reaches 97…98 °C heating stops (this is due to the driving force of the process, that is the temperature difference, the intensification of moisture transfer process and evaporation, which leads to a decrease in thermal conductivity coefficient).

Conclusion. The conducted research allowed us to get data about the dependence of changes in mass, volume, density and porosity of eggplants during their heat processing. A theoretical model of the process has been developed, it allows to describe the characteristics of the conductive heating of fruits and to obtain its graph-analytical solution. The findings allow us to determine the temperatures at all points of flesh in eggplants of different sizes, at different medium temperatures. The results of research can be used in the design of heating appliances, which will ensure a high quality of products, intensify the production processes of small enterprises and restaurant establishments.

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РОЗРОБКА АСОРТИМЕНТУ М’ЯСНИХ КУЛІНАРНИХ ВИРОБІВ НА ОСНОВІ РОСЛИННОЇ СИРОВИНИ ІЗ ЗАСТОСУВАННЯМ ЕЛЕКТРОКОНТАКТНОГО НАГРІВАННЯ

В.М. Михайлов, І.В. Бабкіна, А.О. Шевченко, С.В. Прасол

Проаналізовано використання рослинної сировини в харчуванні людини, зокрема для приготування м’ясних кулінарних виробів. Обґрунтовано доцільність застосування електроконтактного нагрівання для комбінованої теплової обробки. Запропоновано асортимент м’ясних кулінарних виробів із додаванням рослинної сировини, виготовлених із застосуванням

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