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T a h r i r   h a y' a t i   a ' z o l a r i:

KINETICS OF DRYING PROCESS OF TOMATO FRUIT

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Abstract:

Objective. The scientific research shows studies on the analysis of the kinetic laws of the drying process of tomato fruit were carried out. Non-traditional methods of heat treatment are proposed, based on low-temperature drying regimes aimed at preserving the biologically active substances contained in the tomato fruit. The molecular movement of liquid droplets in the product and the laws of movement of moisture towards the surface in the appropriate wavelength range of infrared light were studied on the basis of experiments.

Methods. On the basis of full-factorial experiments, the threshold values of the parameters affecting the drying process of tomato fruit were determined. In the initial stage of the period of heating and constant drying speed of the product, pulse treatment in the wavelength range of 0.7÷1.1 μm of infrared light, and in the period of decreasing moisture content of the product, use of continuous drying method in the wavelength range of infrared light of 2.4÷2.8 μm based on A drying device designed for processing tomato fruit based on pulse mode and continuous drying at low temperature has been developed.

Results. By using the non-traditional drying method, the results representing the drying curves of tomato fruit with a thickness of 8, 10, 15 mm and the drying process speed curves were obtained. The results show that 34-35% of the moisture content of the 8 mm thick tomato, 25-26% of the 10 mm thick tomato fruit, and 14-15% of the 15 mm thick tomato fruit content were experimentally confirmed.

Keywords: drying, equilibrium humidity, desorption, heat capacity density, wavelength, equilibrium humidity.

Introduction. In the world, a number of scientific research works are being carried out on the creation of techniques and technologies for drying agricultural products, production of canned ready-made products [2,3,6,16]. Development of drying devices and regimes that allow preserving BAS (biologically active substances) in the product by using modern methods of energy impact in the drying system, researching the kinetic laws of the drying process for the entire volume of the product, as well as developing scientific research aimed at accelerating metabolic processes are current issues. Based on these tasks, the issue of experimental research of the kinetic laws of the drying process of tomatoes grown in the open fields and greenhouses of our Republic is expressed in this article.

Methods. On the basis of theoretical and experimental studies, the analysis of the kinetic laws of the tomato fruit drying process was carried out [8,9,12]. A drying device designed for low-temperature drying of tomato varieties grown in the open air was developed, and based on the relevant equations, the change in the amount of moisture released from the tomato fruit per unit of time was determined [10]. The drying process of tomato fruit varieties "Alamingo", "Sultan", "Moderna" and "Tashkent" was carried out, and the change of moisture in the samples with the size δ=8 mm, δ=10 mm and δ=15 mm was experimentally studied (1,2,3 Tables). In the theory of drying, the moisture content of the product is usually calculated in relation to the mass of the completely dry product , which remains intact during the drying process, which in turn provides great convenience for calculations . Accordingly, the total mass of the tomato fruit is: [1,7,11,17].

$G = G_{wet} + G_{adm}$ (1)

where: G_{wet}- the amount of water in the raw material, kg,

The moisture content of the tomato fruit in relation to the total mass:

$$W = \frac{G_{wet}}{G} \cdot 100 \quad (2)$$

The amount of absolute dry matter in tomato fruit is determined by the following equation:

$G_{adm} = G_b/(1 + w_b^d)$ (3)

where: G_b is the initial mass of the product, kg; W_b^d - initial moisture content of the product, %.

From this equation, the moisture content of the product, kg.moisture/kg.dry. substance:

$$(W^d = G_b - G_{adm})/G_{adm} \quad (4)$$

Results. In the study of drying kinetics, the drying process of tomato fruit with initial moisture content of 94÷95%, dry matter content of 5.0÷5.3 % and mass (m=1384gr, Table 1; m=1367gr, Table 2; m=1052gr, Table 3) was carried out. ÷was increased, and a change in product moisture level was detected every 30 minutes (Fig. 1).

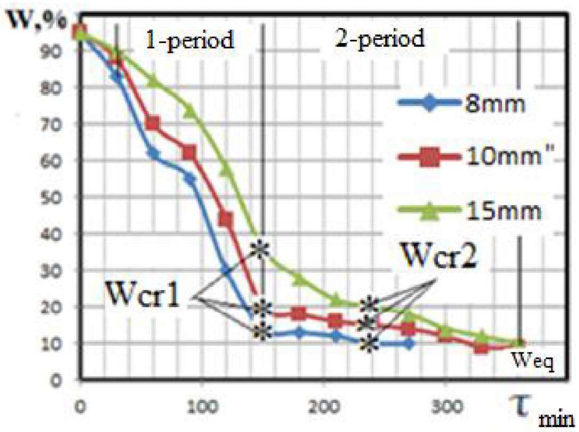

Figure 1. Drying curve

The results of the drying process of tomatoes of three different thicknesses show that during 15-20 minutes, i.e., during the heating of the product, a partial change in the moisture content of the product was observed, the moisture content of the 8 mm thick tomato fruit increased from 95 percent to 86 percent, and the moisture content of the 10 mm thick sample increased to 88 percent. the moisture content of the sample with a thickness of 15 mm decreased to 91%. In the period of constant drying rate (period I), the acceleration of the rate of decrease of moisture content according to the straight line law was observed, and the period of decrease of moisture according to this law ω_{cr1}^{c}continued until the first critical moisture point of the drying rate [20].

Table 1

Dry tooth time hour	Size (mm)	Dry dental process product in change in lot mass shi, (grams)	Dry matter in the product, %/ gr	Break up the amount of moisture that leaks outri,%	Moisture change of shi, %	Dry tooth is fastgi % / min	Product moisture storage of (kg.moisture / kg.dry matter)
0	8	1384	5.0 ÷5.3/ 69.2 ÷73.3	5	95		0.97
30	8	407	5.0÷5.3 / 69.2÷73.3	17	83	32.5	0.8 5
60	8	182	5.0÷5.3 / 69.2÷73.3	38	62	3.75	0. 65
90	8	153	5.0÷5.3 / 69.2÷73.3	45	55	0.32	0.56 _
120	8	98	5.0÷5.3 / 69.2÷73.3	70	30	0.45	0. 30
1 5 0	8	80	5.0÷5.3 / 69.2÷73.3	86	14	0.12	0. 141
180	8	79	5.0÷5.3 / 69.2÷73.3	87	13	0.0055	0.130
210	8	78	5.0÷5.3 / 69.2÷73.3	88	12	0.0047	0.120
240	8	77	5.0÷5.3 / 69.2÷73.3	90	10	0.0041	0.10
270	8	76	5.0÷5.3 / 69.2÷73.3	92	8	0.0037	0.081

Table 2

Dry tooth time hour	Size (mm)	Dry dental process product in change in lot mass shi, (grams)	Dry matter in the product, %/ gr	Break up the amount of moisture that leaks outri,%	Moisture change of shi, %	Dry tooth is fastgi % / min	Product moisture storage of (kg.moisture / kg.dry matter)
0	10	1367	5.0÷5.3 / 69.2÷73.3		95		0.95
30	10	576	5.0÷5.3 / 69.2÷73.3	12	88	26.3	0.92
60	10	230	5.0÷5.3 / 69.2÷73.3	30	70	5.76	0.76
90	10	182	5.0÷5.3 / 69.2÷73.3	38	62	0.53	0.65
120	10	123	5.0÷5.3 / 69.2÷73.3	52	44	0.49	0.44
1 5 0	10	86	5.0÷5.3 / 69.2÷73.3	80	20	0.24	0.201
180	10	84	5.0÷5.3 / 69.2÷73.3	82	18	0.111	0.181
210	10	82	5.0÷5.3 / 69.2÷73.3	84	16	0.0095	0.161
240	10	81	5.0÷5.3 / 69.2÷73.3	85	15	0.0041	0.147
270	10	80	5.0÷5.3 / 69.2÷73.3	86	14	0.0037	0.141
300	10	79	5.0÷5.3 / 69.2÷73.3	88	12	0.0033	0.120
330	10	78	5.0÷5.3 / 69.2÷73.3	92	9	0.0030	0.090

Table 3

Dry tooth time hour	Size (mm)	Dry dental procedure nida mahsu change in lot mass, (grams)	Dry matter in the product, %/ gr	Break up the amount of moisture that leaks outri,%	Moisture change of shi, %	Dry tooth is fastgi % / min	Product moisture storage of (kg.moisture / kg.dry matter)
0	15	1052	5.0÷5.3 / 69.2÷73.3		95		0.98
30	15	692	5.0÷5.3 / 69.2÷73.3	10	90	12	0.92
60	15	384	5.0÷5.3 / 69.2÷73.3	18	82	5.13	0.82

90	15	266	5.0÷5.3 / 69.2÷73.3	26	74	1.31	0.152
120	15	164	5.0÷5.3 / 69.2÷73.3	42	58	0.85	0.64
1 5 0	15	108	5.0÷5.3 / 69.2÷73.3	64	36	0.373	0.360
180	15	96	5.0÷5.3 / 69.2÷73.3	72	28	0.0666	0.281
210	15	88	5.0÷5.3 / 69.2÷73.3	78	22	0.0380	0.220
240	15	86	5.0÷5.3 / 69.2÷73.3	80	20	0.00833	0.201
270	15	84	5.0÷5.3 / 69.2÷73.3	82	18	0.0074	0.180
300	15	82	5.0÷5.3 / 69.2÷73.3	86	14	0.0066	0.148
330	15	80	5.0÷5.3 / 69.2÷73.3	88	12	0.0060	0.120
360	15	78	5.0÷5.3 / 69.2÷73.3	90	10	0.0055	0.100

The curves obtained during the period of decreasing speed of drying (period II) take two different forms in a certain character and explain the second critical speed ω_{cr2}^{c}. At the end of the second period, the product moisture asymptotically approaches the equilibrium moisture limit. Therefore, the equilibrium moisture limit in the drying cycle explains that the evaporation of moisture from the product composition is completely stopped.

During the drying process, the threshold values of the equilibrium humidity were analyzed, and $10 \leq \varphi \leq 90\%$ the desorption process was studied at the relative humidity of air and the corresponding temperature 25^{0}C $\leq t$ 62^{0}C. The obtained results show that the desorption isotherm of tomato fruit has a certain characteristic point at the above-mentioned limits of temperature and relative humidity of the air, among which the following quantities were determined according to the moisture content of the product in three sections of the drying kinetics [8,9,10,14]:

- monomolecular adsorption within the range of 0 ÷ 17% of relative air humidity;
- polymolecular adsorption from 15% to 30% relative air humidity;
- change of humidity in microcapillaries at the limit of 30% relative air humidity and above.

of the equilibrium function, $y = f\left(W_{eq,}, t, \varphi\right)$ the equilibrium moisture of the tomato fruit has the following form,

$$W_{eq} = K_1(\mathrm{t}) + K_2(\mathrm{t}) \;\; [lg(\frac{1}{1-\varphi}) \;]^{1/2} \quad (5)$$

Based on the results of the drying process speed curve (Fig. 2), the values of the drying process coefficients K_1 and K_2 were determined for the 2 sections of the desorption process, $K_1 = 7{,}9 + 0.43t$; $K_2 = 1.8 \cdot t^{0.169}$. The obtained results confirm that $8 \div 12$ % it is desirable to dry tomato fruit around [8,13].

The analysis of the curve of the drying process speed shows that during constant drying speed (I) w_{cr1}, 34-35% of the content of the tomato fruit with a thickness of 8 mm, 25-26% of the content of the tomato fruit with a thickness of 10 mm, and from the content of the tomato fruit with a thickness of 15 mm 14-15% moisture is released. In the period of decreasing drying rate (II), $w_{cr2}$the equilibrium moisture content of the tomato fruit with a thickness of 8 mm is 9%, the equilibrium moisture content of the sample with a thickness of 10 mm is 11%, and the equilibrium moisture content of the sample with a thickness of 15 mm is 12-13%. In this II period, the evaporation of moisture from the composition of the product slows down, the temperature of the product partially rises, and the $w_{\text{м}}$evaporation of moisture becomes zero when the moisture content of the product reaches the equilibrium state [19].

Density of heat capacity for the drying process of tomato fruit – g; the limits of influence of wavelength – λ and air speed were determined, and the duration of the drying process was calculated for the non-stationary regime V_{air}. When processing the results, a multifactorial experimental plan was drawn up and appropriate calculations were made using the derivative square method [4,5,10]. Based on the full factorial experiment, equations representing the value of constant drying rate N for the first period of the kinetics of the drying process, the value of the drying coefficient K for the second period of drying, and the critical moisture change were obtained W_{cr} [15]:

$$N = 0.38 \exp (0.18g + 0.163\, v_{air} + 0.072\, t_{air} + 0.18λ)$$

$$K = 0.137 \cdot 10^{-2} \cdot \exp(0.601 \cdot g + \frac{2.3V_{air}}{18.65+7.36 \cdot V_{air}} + 0.074\, t_x + 0.178\lambda$$

$$W_{cr} = 468.77 \cdot \exp (-0.0179 \cdot v_{air} + 0.0079\, t_{air} + 0.029λ)$$

N, K and W_{cr} correlation coefficients represent the adequacy of the tomato fruit drying process.

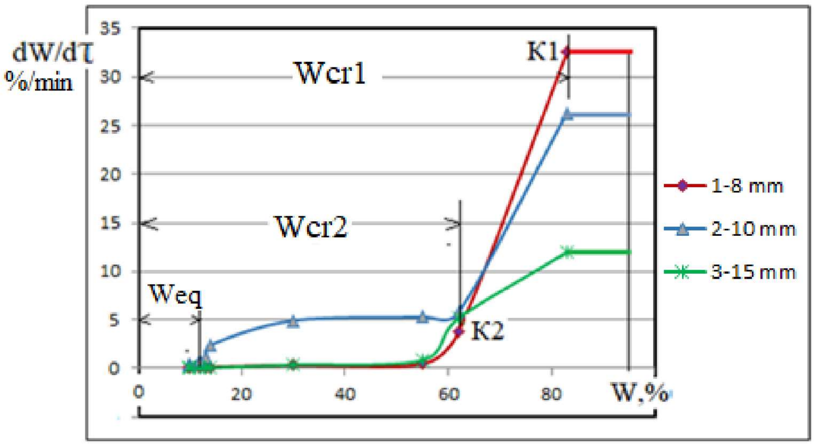

Figure 2. Drying process speed curve

Figure 2. Drying process speed curve

Parameters influencing the drying process (g, v, t, λ) within the following limits ($0 \le g \le 0,95\ kW/m^2$; $1.5 \le v_{air} \le 2,2\ m/s$; $58℃ \le t_{air} \le 62℃$; $0.7 \le \lambda \le 2,8\ mkm$) the deviation error of the performed calculations is 5%. The process slows down as a result of the initial direction of the drying process, i.e. through heat-moisture-conduction, liquid droplets in the product are directed toward the center. In the second period, the temperature gradient in the product decreases, and the movement of liquid drops begins to move in the opposite direction, that is, from the center to the evaporation zone (surface). As the temperature increases per unit of time, the release of moisture in the product accelerates. As a result, in the first period of the drying process, the drying speed increases by 3.5$\div$ 4 times, and the value of the drying coefficient $2,0 \div 2,5$ increases by times.

During the period of constant drying rate of the drying process, the critical moisture content of the product $1,5 \div 1,8$ was observed to decrease by 1.5 times, the rate of drying process was observed to increase by 1.5 times, and during the period of decreasing drying rate, it was observed to increase by 1.2 times.

A drying device was developed for processing tomato fruit based on pulse mode and drying at low temperature in the wavelength range of 0.7÷1.1 and 2.4÷2.8 μm of infrared light. In the drying device, it was possible to control and adjust the change of parameters such as product humidity, temperature, relative humidity of the air in the drying chamber by units of time, and to implement the technological process based on the automatic control system [9,11,18].

Discussions. The theoretical and practical experiments conducted on the drying process show that the efficiency level of the production of dried fruits and vegetables is evaluated by the energy efficiency of the device, the quality index of the finished product, and the shelf life. The most important factor affecting these indicators is the process of heat treatment of this product, and it is appropriate to develop an optimal design of the drying device on this basis . Traditional drying methods for the production of dried agricultural products are no longer suitable for low-productivity industries due to their high energy costs. Because a number of drying equipment is designed to work on the basis of liquid and gaseous fuels. Due to the rapid increase in the world price of such energy resources, the cost of the produced products is sharply high and does not cover the expenses. From this point of view, the application of optimal options of heat exposure based on the non-traditional heat treatment method and accelerating the movement of moisture in the product to the surface - in a step-by-step, pulse mode, creates the basis for obtaining targeted results [12].

Conclusion . The conclusion is that in the initial stage of the drying process (50-60 minutes of the period of heating and drying speed of the product) in order to accelerate the molecular movement of liquid droplets in the product, to generate the required heat for the release of moisture, the wave of infrared $\lambda = 07 \div 1.1\ mkm$ light based on the implementation of processing based on the pulse mode in the length range. Then, in the period of decreasing drying speed (II), as well as the continuous $\lambda = 2{,}4 \div 2.8\ mkm$ drying process in the wavelength range of infrared light up to the equilibrium moisture limit of tomato fruit, created the basis for obtaining a positive result. The advantage of continuous drying in the infrared wavelength range is that liquid droplets located in the center of the product have maximum absorption at this wavelength, which accelerates the movement of moisture to the surface .$\lambda = 2{,}4 \div 2.8\ mkm$.

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