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Effect of Variety on Rehydration Characteristics of Dried Apples

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Abstract: The effect of dried apple varieties on their rehydration characteristics was investigated. Four varieties of apples, Champion, Cortland, Grey Reinette and Ligol, were taken into consideration. Rehydration properties and color of apples were investigated. In order to examine the influence of apple variety on its rehydration properties, the process of rehydration was modeled. The model parameters obtained for investigated apple varieties were compared. Apple cubes were dried in a tunnel dryer (air temperature 60 °C and air velocity 2 m/s) and next rehydrated in distilled water at temperature: 20, 45 and 70 °C. Mass, dry matter mass, volume and color attributes of apples (raw, dried and rehydrated) were measured. The process of rehydration was modeled using empirical (Peleg and Weibull models) and theoretical (the Fick's second law) models. Results of the analysis showed that the apple variety affects values of mass and volume increase, dry matter decrease and color of the rehydrated apple. Discussed parameters were also affected by rehydration temperature. Fick's second law model can be considered as the most appropriate. Apple variety and rehydration temperature influenced the values of the model's constants. Obtained values enabled attempts of the explanation of the rehydration course. It can be stated that apple var. Champion showed a greater rate of water absorption during the entire process of rehydration than other investigated varieties.

Keywords: apple; variety; material properties; rehydration; color

1. Introduction

Rehydration belongs to one of the most significant quality properties of dehydrated foods. The quick and complete process of rehydration can lead to a reduction of labor costs and floor-space requirements and, very importantly, to improving the efficiency of production [1]. Moreover, some of the dried food products are consumed after their rehydrating (in milk or fruit juices). Therefore, a better understanding of the discussed process can cause the quality improvement of both dried and rehydrated products [2,3]. Rehydration is a complex process intended to restore the properties of the raw food product by contacting the dried product with liquid [4]. It can be assumed that during the described process, the following processes take place simultaneously: absorption of liquid by the dehydrated product, swelling of the rehydrated material and leaching of the solutes (vitamins, minerals, sugars, acids) from the product to the rehydrating medium. The kinetics of the mass transfer mechanisms depends on the rehydrating liquid [5,6].

Pre-drying treatments, drying and rehydration cause the changes in structure and composition of product tissue, which result in worsening of reconstitution characteristics. Rehydration can be, therefore, treated as a measure of the degree of alternations taking place during processing [7,8]. The effect of different parameters of pre-drying treatments, subsequent drying and rehydration on rehydration characteristics of food products has been widely investigated in the literature. Some examples are given below.

Taiwo et al. [9] studied the influence of pre-drying treatments (high-intensity electric field pulses and osmotic dehydration in sucrose solution) on characteristics of the rehydrated apples. Severini et al.'s [10] work was to study the effects of different combined systems of blanching and dehydration on the behavior during rehydration of cubed potatoes. Blanching was alternatively performed in hot distilled water, hot sugary-saline solution, by microwaves in distilled water or by microwaves in saline solution. Doymaz and Sahin [11] investigated the effect of pretreatment (with a solution of citric acid, blanching by immersing in hot water) on rehydration characteristics of broccoli slices, whereas Kocabay and Ismail [12] applied two different pretreatments for okra (immersing in a salt solution or hot water).

Kumar et al. [13] studied the effect of convection, freeze and freeze-convection drying on carrot and pumpkin rehydration, whereas Giri and Prasad [14] investigated the influence of convection and microwave-vacuum dehydration on rehydration of button mushrooms. Yi et al. [15] studied how rehydration of pitaya was affected by convection, convection-explosion and puffing drying. The effect of drying air temperature on rehydration characteristics was investigated, among others, by Wang and Chao [16] for apple, Vega-Gálvez et al. [17] for red bell pepper and Rafiq et al. [18] for parboiled rice. Giri and Prasad [14] studied how rehydration of microwave-vacuum dried button mushrooms was affected by the different pressures. Rhim et al. [19] evaluated the effect of freezing temperature on rehydration characteristics of freeze-dried rice porridge.

Some studies investigated the effect of water temperature on the rehydration behavior of such food products as apples [9], mangos [4], carrots [20], parboiled rice [18]. The influence of the rehydrating medium on rehydration characteristics has also been evaluated in the literature. Oliviera and Ilincanu [21] rehydrated dried apple in milk and water, whereas Prothon et al. [22] immersed apple in water and yogurt. Giraldo et al. [6] rehydrated candied mango fruit in the sucrose solutions of different concentrations.

The ability of the food products to absorb liquid also depends on the chemical composition of the material [23]. It can be presumed, therefore, that the product varieties influence the course of the rehydration but very little has been published on the considered subject. Markowski et al. [24] investigated the effect of six varieties of carrots (Kazan, Maxima, Nandor, Nektarina, Simba and Tito) on the water absorption of dried ones. It was noticed that the process of rehydration was significantly influenced by variety. Kaptso et al. [25] studied the rehydration kinetics of the cowpea (varieties CW and CG) and bambara seeds (varieties BB and WB). The differences observed in the course of the rehydration process underline the differences between the varieties and species. Ciurzyńska et al.'s [26] work was to study the influence of variety on rehydration properties of vacuum-dried strawberries. The analysis showed that fruit variety Bounty obtained higher-final water content after one-hour immersion in water in comparison to variety Pandora.

Apples are one of the basic horticultural products. Apple plantations are present all over the world, and Poland is a significant global producer of these fruits. Apples play a significant role in the human diet. They are low caloric fruits containing typically about 86% of water, 12–14% of carbohydrate, 0.3% of protein, 0.2% of lipids, 2% of dietary fiber (including pectins) and many important minerals (calcium, magnesium, potassium). Apples may help in reducing the effect of asthma and cholesterol levels and maintaining the weight [27–29].

Some information about the influence of apple varieties on their morphological and physical characteristics and drying kinetics can be found in the literature. Willix et al. [30] obtained different formulas for calculating the thermal conductivity of the following three varieties of apple: Cox's Orange, Fiesta and Royal Gala. Chakespari et al. [31] stated that the mean values of properties such as length, width, thickness, geometric mean diameter, volume, surface area, mass and projected area for the *Shafi Abadi* variety were significantly greater than of the *Golab Kohanz* variety. Santos et al. [32] investigated the infrared drying of apple slices of Fuji and Gala varieties. They found that the mathematical model of drying common to both varieties cannot be representative. Torabi et al. [33] developed formulas for the prediction of the volume of three apple varieties (Red Delicious, Golden Delicious, Granny Smith) based on the mass of fruit and also stated that one formula for investigated varieties could not be representative. Cruz et al. [34] studied the convective drying of apples from two varieties Golden Delicious and Granny Smith, and found that values of mass transfer properties such as moisture diffusion coefficient and moisture transfer coefficient were different for both varieties. Pissard et al. [35] determined the phenolic compounds and dry matter content in peel and flesh of twenty apple varieties. Both properties showed great variability among the varieties.

There is, however, little or no information about the effect of variety on the rehydration behavior of dried apples in the literature. Therefore, attempts were made to investigate the influence of apple variety on rehydration characteristics. The present study was conducted with the following objectives:

1. To determine the effect of variety and rehydration temperature on the rehydration characteristics of dried apples;
2. To fit the experimental rehydration data obtained to the Peleg model, Weibull model and Fick's second law model in order to: (i) estimate their suitability to describe the rehydration behavior of dried apples, (ii) obtain the values of models constants which have physical meaning and therefore can enable the explanation of the phenomena occurring during rehydration of different varieties of dried apples.

2. Materials and Methods

Four different varieties of apples, viz. Champion, Cortland, Grey Reinette and Ligol were procured from a local market in Warsaw, Poland. Homogenous fruits were chosen for each variety according to such maturity indicators as fruit appearance and size [28]. Champion belongs to a dessert variety but can also be used for cooking and processing. Its flesh is greenish-white with a cream undertone, medium loose, juicy, sweet, aromatic and tasty [36]. Cortland is a dessert variety. It has white, crispy, fine-grained, juicy, sweet, with medium contents of acids flesh. Cortland is aromatic and very tasty [36]. Grey Reinette has crispy, very juicy and green-yellow flesh. Its taste is acid; therefore, the variety is mostly used for cooking and processing [36]. Ligol belongs to a dessert variety. It has cream-colored, very juicy and tasty flesh [36]. Before the drying experiments, the apples were washed, hand peeled, and the outer cortex was cut into 10 ± 1 mm cubes. Drying was carried out on the same day in the tunnel dryer at the drying air temperature 60 °C and air velocity 2 m/s. The final moisture content of dried samples was ca. 9% w.b. (0.098 d.b.). Drying equipment and a method of conducting the experiments can be found in the paper by Kaleta and Górnicki [37]. The dried apples of the same variety obtained from the three independent experiments were mixed and then stored for further investigations in a sealed container for approx. seven days at 20 °C.

Dried apples were rehydrated in distilled water at temperature T_r = 20, 45 and 70 °C. The temperature conditions were warranted with a water bath. The rehydration time amounted to 6 h at the water temperature 20 °C, 5 h at 45 °C and 4 h at 70 °C. Experiments were done in three repetitions. The water was not stirred, and its temperature was constant during the process of rehydration. The mass of each dried sample at the beginning of rehydration was 10 g. Mass of dried apple cubes to distilled water mass ratio amounted to 1:20. The WPE 300 scales (RADWAG, Radom, Poland) were used for the measurement of the sample mass (with 0.001 g accuracy). The change of dry matter of solid during rehydration was measured in accordance with AOAC standards [38]. The volume changes of dried apple cubes during rehydration were measured by the buoyancy method using petroleum benzine [39] with a relative error lower than 5%.

The color attributes of raw, dried and rehydrated apples were evaluated using a scanner (Canon CanoScan 5600F). Obtained color images were loaded into the sRGB color space. The mean brightness of pixels in each RGB channel of the image was used to express color parameters. The fresh, dried and rehydrated (color inside the cubes were additionally measured for the rehydrated apples (cubes were cut)) apple cubes were randomly positioned on the scanner platen. A total number of 20 images for each apple batch (different varieties and rehydration temperatures) were acquired. The ImageJ ver.47i software was used.

Two empirical models were adopted for describing the course of dried apple cubes rehydration, namely the Peleg model [40] and the Weibull model [41]. Such models were chosen because their constants have physical meaning.

Peleg model [40] is given by Equation (1):

$$M = M_0 + \frac{t}{k_1 + k_2 t} \tag{1}$$

where M is the moisture content (dry basis), M_0 is the initial moisture content (dry basis), t is the time (h), k_1 is the Peleg rate constant (h/d.b.), and k_2 is the Peleg capacity constant (1/d.b.). When the rehydration process lasted long enough ($t \rightarrow \infty$) the equilibrium moisture content can be determined as follows:

$$M_e = M_0 + \frac{1}{k_2} \tag{2}$$

Constant k_1 informs about the rate of water absorption during the early stage of the rehydration; on the other hand, constant k_2 is related to the maximum capacity of water absorption [42,43]. The Peleg model has been used to describe the rehydration process of such dried products as carrots [44], mango [45] and potatoes [46].

The Weibull model is presented by the following equation:

$$\frac{M - M_0}{M_e - M_0} = 1 - \exp\left[-\left(\frac{t}{\beta}\right)^{\alpha}\right] \tag{3}$$

where M_e is the moisture content at saturation (equilibrium moisture content, dry basis), α is the dimensionless shape parameter, and β is the scale parameter (h).

Constant α represents product behavior during rehydration. The initial rate of the rehydration decreases with an increase in the α value. Constant β is related to the kinetics of the process and presents an inverse relation with the rehydration rate [43,47]. The Weibull model has been found to give satisfactory results in the descriptions of rehydration of such dried materials as ready-to-eat breakfast cereal [48], pumpkin [49] and *Rosa rubiginosa* fruits [43].

One theoretical model was also applied for describing the kinetics of rehydration. Different transport mechanisms take place during the discussed process, namely molecular diffusion, convection, hydraulic flow and capillary flow [50]. Theoretical models describing water absorption in foods are mostly based on the water diffusion through a porous medium; therefore, Fick's second law is frequently applied for mathematical modeling of rehydration. When following simplifying assumptions are considered: (1) the initial moisture content M_0 in the material is uniform, (2) the water diffusion coefficient is constant, (3) moisture gradient at the center of material equals zero, (4) shrinkage is negligible, (5) the sample surface reaches equilibrium moisture content M_e instantaneously after immersion in rehydrating medium, (6) the process can be treated as isothermal, the Fick's second law describing the rehydration of cubes receives the following form [51,52]:

$$\frac{M - M_0}{M_0 - M_e} = \frac{512}{\pi^6}\left\{\sum_{i=1}^{\infty} \frac{1}{(2i-1)^2} \exp\left[-(2i-1)^2 \pi^2 \frac{Dt}{L^2}\right]\right\}^3 \tag{4}$$

where D is the water diffusion coefficient (m^2/h), and L is the cube thickness (m).

Ten terms of the series were taken for the calculations. Theoretical models based on Fick's second law of diffusion with given above simplifying assumptions have been successfully applied to different products such as carrots [53], dactyls [54] and soybeans [55].

The Levenberg–Marquardt nonlinear estimation method was applied to determine the model's constants while the significance of the influence of apple variety and the temperature of rehydrating water on the course of rehydration was determined with the use of the ANOVA technique applying the Levene test of homogeneity of variances. Homogenous groups were tested using Tukey's test HSD

(α = 0.05). Calculations were conducted using the Statistica 12.5 application. The above-discussed Peleg model, Weibull model and Fick's second law model were chosen for describing the kinetics of dried apple cubes rehydration because their model constants have physical meaning, and obtained values of constants can be useful while discussing and explaining the course of different varieties of dried apple rehydration. Moreover, a comparison of the results obtained for three discussed models can give the answer, which of then can be treated as the most appropriate for describing the rehydration characteristics of dried apples.

The following statistical methods were used for finding the model suitability for the prediction of rehydration kinetics of dried apples:

- Standard error of estimation SEE

$$\text{SSE} = \frac{\sum_{i=1}^{N}\left(M_{exp,i} - M_{pre,i}\right)^2}{N} \tag{5}$$

where $M_{exp,i}$ is the i-th experimentally observed moisture content (dry basis), $M_{pre,i}$ is the i-th predicted moisture content (dry basis), and N is the number of observations.

Lower SEE values indicate better fitness of the established model. Witrowa-Rajchert and Lewicki [56] and Rafiq et al. [18] used this statistical criterion for selecting the most suitable model to predict the rehydration kinetics.

- Coefficient of determination R^2

$$R^2 = \frac{\sum_{i=1}^{N}\left(M_i - M_{pre,i}\right) \cdot \sum_{i=1}^{N}\left(M_i - M_{exp,i}\right)}{\sqrt{\sum_{i=1}^{N}\left(M_i - M_{pre,i}\right)^2 \cdot \sum_{i=1}^{N}\left(M_i - M_{exp,i}\right)^2}} \tag{6}$$

The closer R^2 to 1, the greater is the relationship between experimental and predicted values. The coefficient has been applied by, e.g., Doymaz and Sahin [11] and Markowski et al. [46].

- Root mean square error RMSE

$$\text{RMSE} = \left[\frac{1}{N}\sum_{i=1}^{N}\left(M_{pre,i} - M_{exp,i}\right)^2\right]^{\frac{1}{2}} \tag{7}$$

The lower the RMSE values, the better is the goodness of the fit. Such a criterion has been used by, e.g., Kaleta et al. [57] and Ricce et al. [44].

3. Results and Discussion

The results of the experiments are shown in Figure 1. The figure presents functions (Peleg model) approximating results of three repetitions of mass gain (Figure 1a), dry matter loss (Figure 1b) and volume increase (Figure 1c) measurements in the course of the rehydrating process.

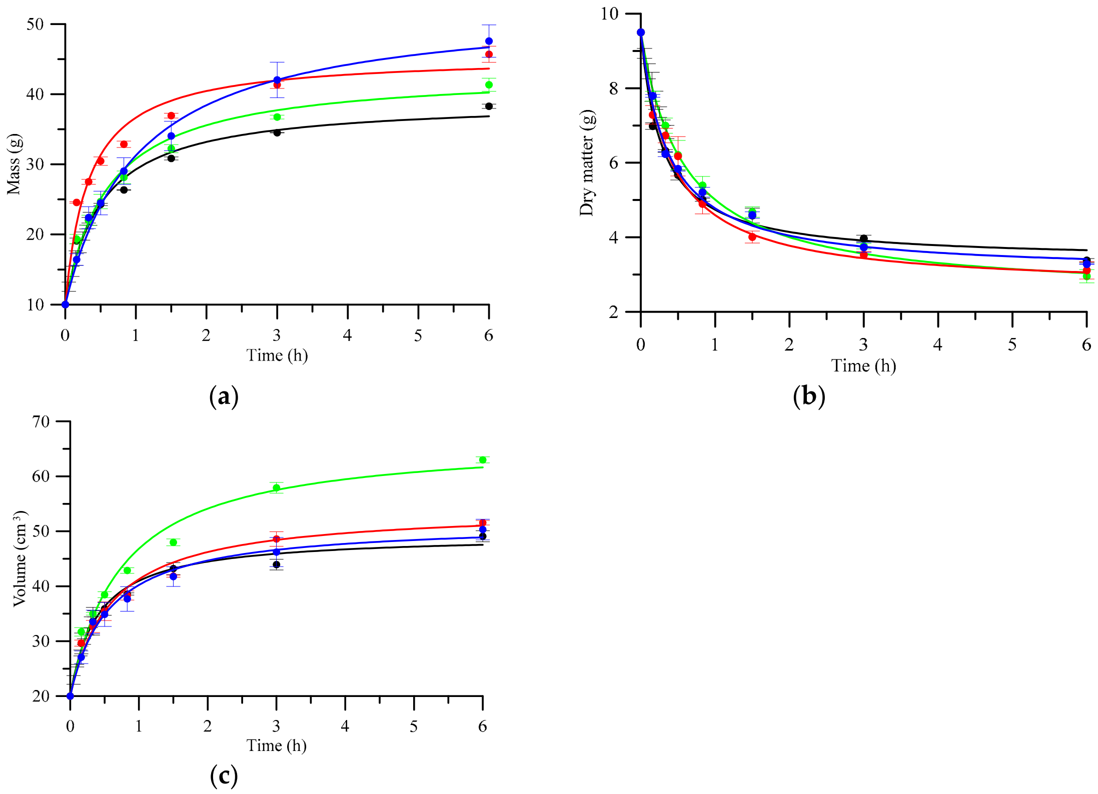

Figure 1. Mass vs. time (**a**), dry matter vs. time (**b**) and volume vs. time (c) for the rehydration (at 20 °C) of dried apples of different varieties: (——)—Champion, (——)—Cortland, (——)—Gray Reinette, (- - -)—Ligol.

The Peleg model took the following form:

- for mass:

$$m = m_0 + \frac{t}{k_1 + k_2 t} \tag{8}$$

where m is the mass (g), m_0 is the initial mass (g) and equilibrium mass:

$$m_e = m_0 + \frac{1}{k_2} \tag{9}$$

- for dry matter:

$$m_{d.m.} = m_{d.m.0} - \frac{t}{k_1 + k_2 t} \tag{10}$$

where $m_{d.m.}$ is the dry matter (g), $m_{d.m.0}$ is the initial dry matter (g) and equilibrium dry matter:

$$m_{d.m.e} = m_{d.m.0} - \frac{1}{k_2} \tag{11}$$

- for volume:

$$V = V_0 + \frac{t}{k_1 + k_2 t} \tag{12}$$

where V is the volume (cm^3), V_0 is the initial volume (cm^3) and equilibrium volume:

$$V_e = V_0 + \frac{1}{k_2} \tag{13}$$

According to the calculations, the Peleg model well described the mass gain, the dry matter loss, and the volume increase of dried apples during their rehydration, since the value of the coefficient of determination R^2 was within 0.9595 to 0.9883 for mass, 0.9150 to 0.9959 for dry matter and 0.9137 to 0.9896 for volume.

Statistical analysis of the influence of apple variety on the mass gain, the dry matter loss and the volume increase of dried apples during their rehydration at 20 °C (division into homogenous groups) are shown in Table 1. In this table, numbers mean average values from three repetitions of measurements of the current mass, dry matter and volume of the rehydrated dried material (with the standard deviation), whereas homogenous groups for each time of rehydration were determined with the same letters.

It can be noticed (Figure 1a) that for all investigated apple varieties, water uptake increased with increasing rehydration time. The rate of the process was faster in the initial period and decreased up to the saturation level. Such a course of rehydration at the beginning could be explained by rapid filling up of capillaries and cavities near the surface with the water. The cell walls absorb water, soften, and then according to the natural cellular structure elasticity, the cells return to their original shape by drawing water into the inner cavities. In the further stage of the process, water absorption slows down because the rehydrated sample gets close to the state of equilibrium [58–60]. A similar character of mass changes during rehydration has been reported by, among others, Marabi et al. [61] for carrot, Markowski et al. [46] for potato and Maldonado et al. [4] for mango.

According to Table 1, the apple variety influenced the rehydration of the dried product. It can be observed that at the beginning of the process (0–1.5 h), the course of the dried Champion rehydration differed statistically significantly from the kinetics of dried Cortland, Gray Reinette and Ligol (the difference between the mass gain for these three varieties was at the same time statistically insignificant). The final mass was the greatest for the Cortland variety and the smallest for Ligol one, and the differences for all investigated apple varieties were statistically significant.

The results of the application of the Peleg model (Equations (8) and (9)) for approximating the mass gain during the rehydration of investigated varieties of dried apples are presented in Table 2. It could be noticed that apple variety had a statistically significant influence on the value of the equilibrium mass of the rehydrated sample. The highest value, 52.93 g, demonstrated Cortland variety rehydrated at 20 °C, the lowest 39.13 g Ligol one at 20 °C. The value of m_e for the same apple variety depended in a statistically significant way on the temperature of rehydrating water. For the Ligol variety, the discussed value increased with increasing temperature, but for the Champion and Grey Reinette, m_e value for 70 °C was lower than for 45 °C. This may be explained in such a way that higher temperature causes damage of cellular tissue and a decrease of permeability within the apple structure, and perhaps a loss of solids during rehydration. Similar trends for rehydration at higher temperatures have been noticed, among others, Femenia et al. [62] for broccoli stems, Garcia-Pascual et al. [41] for Boletus edulis mushroom and Maldonado et al. [4] for mangoes. The apple variety demonstrated a statistically significant influence on the value of constant k_1. The highest value at 20 °C showed Cortland variety, the lowest one Champion variety. For Champion, Grey Reinette and Ligol varieties, the k_1 value decreased with increasing temperature. The results suggest that the rate of water absorption during the early stage of the rehydration at 20 °C was the highest for Champion and the lowest for Cortland (Figure 1a) and, moreover, the discussed rate became higher at a higher temperature of rehydration. The achieved results confirm the statement that constant k_2 was related to the maximum capacity of water absorption [42,43]. The highest k_2 value was obtained for Ligol at 20 °C and the lowest for Cortland at 20 °C and the difference was statistically significant.

Table 1. Average values of mass (g), dry matter (g) and volume (cm^3) of the rehydrated dried apples (with standard deviation) in the rehydration process at 20 °C.

Quantity	Variety of Apple	Time (h)							
		0	**0.16**	**0.33**	**0.5**	**0.83**	**1.5**	**3**	**6**
mass (g)	Champion	10	24.56 ± 0.11 c	27.51 ± 0.35 b	30.46 ± 0.60 b	32.86 ± 0.46 b	36.94 ± 0.34 b	41.34 ± 0.51 b	45.69 ± 1.15 bc
	Cortland	10	16.42 ± 0.83 a	22.40 ± 1.57 a	24.48 ± 1.69 a	29.03 ± 1.91 a	34.04 ± 2.11 ab	42.03 ± 2.53 b	47.57 ± 2.31 c
	Gray Reinette	10	19.34 ± 0.66 b	22.02 ± 0.72 a	24.69 ± 1.03 a	28.14 ± 0.90 a	32.24 ± 0.58 a	36.74 ± 0.28 a	41.34 ± 0.93 ab
	Ligol	10	19.07 ± 0.41 b	22.03 ± 0.41 a	24.28 ± 0.15 a	26.34 ± 0.04 a	30.84 ± 0.21 a	34.50 ± 0.04 a	38.28 ± 0.30 a
dry matter (g)	Champion	9.5	7.29 ± 0.25 b	6.73 ± 0.20 ab	6.18 ± 0.53 a	4.90 ± 0.27 a	4.01 ± 0.16 a	3.53 ± 0.09 a	3.11 ± 0.23 a
	Cortland	9.5	7.80 ± 0.04 c	6.23 ± 0.07 a	5.84 ± 0.06 a	5.21 ± 0.13 a	4.60 ± 0.09 b	3.73 ± 0.13 ab	3.28 ± 0.01 a
	Gray Reinette	9.5	7.79 ± 0.13 c	7.00 ± 0.20 b	6.21 ± 0.39 a	5.39 ± 0.24 a	4.68 ± 0.14 b	3.76 ± 0.07 ab	2.95 ± 0.18 a
	Ligol	9.5	6.98 ± 0.09 a	6.32 ± 0.04 a	5.67 ± 0.13 a	5.01 ± 0.04 a	4.58 ± 0.20 b	3.97 ± 0.09 b	3.38 ± 0.05 a
volume (cm^3)	Champion	20	29.66 ± 0.55 ab	32.67 ± 1.11 a	35.45 ± 1.68 a	38.32 ± 0.83 ab	41.84 ± 0.19 a	48.60 ± 1.33 a	51.55 ± 0.40 a
	Cortland	20	27.08 ± 1.14 a	33.51 ± 2.14 a	34.88 ± 2.19 a	37.70 ± 2.25 a	41.75 ± 1.78 a	46.22 ± 2.65 a	50.32 ± 1.88 a
	Gray Reinette	20	31.71 ± 0.78 b	34.99 ± 0.24 a	38.45 ± 0.54 a	42.87 ± 0.51 b	47.98 ± 0.63 b	57.91 ± 0.98 b	62.99 ± 0.55 b
	Ligol	20	29.60 ± 1.89 ab	33.62 ± 2.53 a	35.90 ± 1.18 a	38.59 ± 0.21 ab	43.21 ± 1.09 ab	43.94 ± 0.98 a	49.09 ± 0.99 a

Values for the same quantity, followed by different letters in the same column, are significantly different at the 5% level (Tukey's test HSD).

Table 2. Results of the application of the Peleg model (Equations (8) and (9)) for approximating the mass gain during the rehydration of different varieties of dried apples.

Variety of Apple	T_r (°C)	m_e (g)	k_1 (h/g)	k_2 (1/g)	R^2
Champion	20	45.51 cd	0.0094 ab	0.0282 bc	0.9748
	45	47.18 d	0.0081 a	0.0269 b	0.9608
	70	44.48 bcd	0.0049 a	0.0290 bc	0.9656
Cortland	20	52.93 e	0.0238 e	0.0233 a	0.9595
Gray Reinette	20	43.27 abcd	0.0181 d	0.0301 c	0.9847
	45	45.36 cd	0.0151 bcd	0.0283 bc	0.9627
	70	42.82 abc	0.0106 ab	0.0305 cd	0.9747
Ligol	20	39.13 a	0.0176 cd	0.0343 e	0.9840
	45	40.11 ab	0.0154 bcd	0.0332 de	0.9883
	70	42.38 abcd	0.0103 abc	0.0309 cd	0.9796

The same letters in the same column indicate homogenous groups ($\alpha < 0.05$, Tukey's test HSD).

It can be observed (Figure 1b) that for all investigated apple varieties, solute loss increased with increasing rehydration time. The rate was faster at the beginning of the process and decreased up to the saturation level. The explanation of such a course of rehydration could be the following. At the beginning of the process, there was a high rate of mass transfer because of the high difference between the solid concentration in rehydrated dried apple and rehydrating water. In the further stage, the rate of mass transfer slowed down because both concentrations approached the state of equilibrium [60]. Similar rehydration kinetics had been observed by, among others, Górnicki [63] for parsley and apple var. Idared, Maté et al. [64] for potatoes and Stępień [65] for carrots.

According to Figure 1b and Table 1, it can be assumed that the apple variety had a statistically insignificant influence on the loss of dry matter. The same statement regards the equilibrium dry matter and Peleg capacity constant k_2 (Table 3). The highest value $m_{d.m.e}$ = 3.387 g and k_2 = 0.1636 1/g reached Champion variety rehydrated at 70 °C, the lowest one $m_{d.m.e}$ = 2.329 g and k_2 = 0.1395 1/g Gray Reinette rehydrated at 45 °C, but the differences were statistically insignificant. As far as Peleg rate constant k_1 was concerned, the statistically significant influence of dried apple variety could be observed. For rehydration conducted at 20 °C, Gray Reinette showed the highest value of k_1 = 0.0814 h/g, whereas Ligol variety demonstrated the lowest value of k_1 = 0.0468 h/g. The obtained results suggest that the rate of dry matter loss during the early stage of the rehydration at 20 °C was the highest for Ligol and the lowest for Gray Reinette variety (Figure 1b). The value of k_1 for the same apple variety depended in a statistically significant way on the temperature of rehydrating water, and at 20 °C was higher than at 70 °C.

Table 3. Results of application of the Peleg model (Equations (10) and (11)) for approximating the dry matter loss during the rehydration of different varieties of dried apples.

Variety of Apple	T_r (°C)	$m_{d.m.e}$ (g)	k_1 (h/g)	k_2 (1/g)	R^2
Champion	20	2.63 a	0.0584 cd	0.1455 a	0.9657
	45	2.91 a	0.0380 abc	0.1517 a	0.9470
	70	3.39 a	0.0143 a	0.1636 a	0.9378
Cortland	20	3.04 a	0.0568 cd	0.1549 a	0.9959
Gray Reinette	20	2.42 a	0.0814 d	0.1412 a	0.9787
	45	2.33 a	0.0468 bc	0.1395 a	0.9247
	70	3.14 a	0.0234 ab	0.1572 a	0.9150
Ligol	20	3.38 a	0.0468 bc	0.1633 a	0.9845
	45	2.78 a	0.0577 cd	0.1489 a	0.9777
	70	3.14 a	0.0243 ab	0.1571 a	0.9884

The same letters in the same column indicate homogenous groups ($\alpha < 0.05$, Tukey's test HSD).

For all investigated apple varieties, the volume increased with increasing time of rehydration (Figure 1c). The fastest increase of volume took place in the initial period of rehydration; in the further stage of the process, water absorption slowed down because rehydrated samples approached the state of equilibrium. Fast water absorption at the beginning of the process was probably related to filling with water capillaries at the surface of a sample [66]. A similar rehydration behavior has been noticed by, among others, Bilbao-Săinz et al. [66] for apple var. Granny Smith, Maskan [67] for wheat and Witrowa-Rajchert [68] for apple var. Idared, carrots, parsley, potatoes and pumpkins. It can be stated that in the initial period of rehydration (0–0.5 h), the apple variety had a statistically insignificant influence on the increase of volume (Table 1). In the further stage (3–6 h), however, Gray Reinette showed the highest values of volume which differ statistically significant from volume values for Champion, Cortland and Ligol variety. Differences of volume values for these three apple varieties were statistically insignificant.

The results of the application of the Peleg model (Equations (12) and (13)) for approximating the volume increase during the rehydration of investigated varieties of dried apples are shown in Table 4. It can be admitted that apple variety had a statistically significant influence on the value of the equilibrium volume of the rehydrated sample. As far as rehydration at 20 °C is concerned, the highest value, 66.8 cm^3, was obtained for Gray Reinette, the lowest one 49.4 cm^3 for Ligol. For Champion and Gray Reinette varieties, the V_e value decreased with increasing rehydration temperature. The dependence of the V_e on the temperature was statistically significant. The apple variety showed a statistically significant influence on the value of constant k_1. The highest value at 20 °C demonstrated Cortland variety, the lowest one Ligol variety. Received results suggest that the rate of volume increase during the early period of the rehydration at 20 °C was the highest for Ligol and the lowest for Cortland. For Champion and Gray Reinette varieties, the k_1 value decreased with increasing temperature, whereas for the Ligol variety, k_1 at 45 °C was higher than at 20 °C and 70 °C. The dependence of the Peleg rate constant k_1 on the temperature was statistically significant. The Peleg capacity constant k_2 depends in a statistically significant way on apple variety and for Champion and Ligol on rehydration temperature. The highest value at 20 °C was obtained for Ligol, the lowest for Gray Reinette what was in agreement with the results achieved for the equilibrium volume of the rehydrated sample.

Table 4. Results of the application of the Peleg model (Equations (12) and (13)) for approximating the volume increase during the rehydration of different varieties of dried apples.

Variety of Apple	T_r (°C)	V_e (cm^3)	k_1 (h/cm^3)	k_2 (1/cm)	R^2
Champion	20	54.20 b	0.0177 cd	0.0293 b	0.9732
	45	51.44 ab	0.0125 abcd	0.0318 bcd	0.9651
	70	48.68 a	0.0106 abc	0.0349 d	0.9507
Cortland	20	51.76 ab	0.0178 d	0.0316 bc	0.9137
Gray Reinette	20	66.84 d	0.0159 bcd	0.0214 a	0.9775
	45	67.75 d	0.0109 abc	0.0214 a	0.9763
	70	61.11 c	0.0068 a	0.0243 a	0.9774
Ligol	20	49.44 a	0.0136 abcd	0.0340 cd	0.9555
	45	52.51 ab	0.0157 bcd	0.0309 bc	0.9896
	70	51.62 ab	0.0085 ab	0.0316 bcd	0.9566

The same letters in the same column indicate homogenous groups ($\alpha < 0.05$, Tukey's test HSD).

As it was told before, during the rehydration simultaneously took place absorption of liquid by the dried product, swelling of the rehydrated material and leaching of the solutes from the product to the rehydrating medium. Therefore, the value of the moisture content of the rehydrated product can be treated as a parameter that informs about the summary result of rehydration. An evaluation of the Peleg model (Equation (1)), Weibull model (Equation (3)) and Fick's second law model (Equation (4)) was applied in this work to describe the rehydration characteristics of investigated varieties of apples.

The calculations were carried out in the following way. The curve fitting computations with the drying time were carried on considered models. Then the regressions were undertaken to account for the effect of rehydrating water temperature T_r on the model's constants/parameters. The effects of T_r on the model's constants/parameters were also included in the models. The linear type of equations was examined. The constants/parameters combinations that gave the highest R^2 values were considered in the final model. Obtained equations were next used for determining the moisture content of investigated varieties of apples at any time during rehydration. The established models were validated by comparison of computed and measured moisture content in any particular rehydration run.

Table 5 presents the coefficients of constant equations for the Peleg model (Equations (1) and (2)) and the results of statistical analyses on the rehydration modeling of different varieties of dried apples. The following linear type constant equations were examined:

$$k_1 = A_1 + A_2 T_r \tag{14}$$

$$k_2 = B_1 + B_2 T_r \tag{15}$$

Table 5. Coefficients of the constant equations for the Peleg model (Equations (1) and (2)) and results of statistical analyses on the rehydration modeling of different varieties of dried apples.

Variety of Apple	T_r (°C)	M_e (d.b.)	Coefficients of Constant Equations				Constant	SSE	R^2	RMSE
			A_1	A_2	B_1	B_2				
Champion	20	16.78 bcd	0.1098	−0.0011	0.0490	0.0005	k_1 = 0.0875 ac k_2 = 0.0598 ab	6.8415	0.9795	0.6539
	45	16.35 cd					k_1 = 0.0656 ab k_2 = 0.0614 abd	10.0500	0.9556	0.8473
	70	11.48 a					k_1 = 0.0272 b k_2 = 0.0875 c	3.4864	0.9727	0.539
Cortland	20	19.63 d					k_1 = 0.1428 de k_2 = 0.0511 a	15.8500	0.9794	0.6144
Gray Reinette	20	20.21 d	0.1660	−0.0016	0.0448	0.0004	k_1 = 0.1630 ef k_2 = 0.0496 a	7.9579	0.9784	0.6842
	45	18.48 cd					k_1 = 0.0896 ac k_2 = 0.0543 ab	6.0174	0.9795	0.5949
	70	12.5 ab					k_1 = 0.0506 ab k_2 = 0.0803 c	4.5392	0.9768	0.5694
Ligol	20	12.56 ab	0.1658	−0.0014	0.0804	−0.0002	k_1 = 0.1288 cde k_2 = 0.0799 cd	2.2635	0.9835	0.4173
	45	14.28 abc					k_1 = 0.1125 cd k_2 = 0.0703 bcd	5.8827	0.9527	0.8085
	70	14.27 abc					k_1 = 0.0663 ab k_2 = 0.0703 bcd	1.9776	0.9864	0.4688

The same letters in the same column indicate homogenous groups ($\alpha < 0.05$, Tukey's test HSD).

The R^2 values were greater than 0.9527, the RMSE ones were lower than 0.8473, and the SSE values were lower than 15.8500, so it can be admitted that the Peleg model described the rehydration kinetics in a quite acceptable manner. Determined values for k_1 ranged from 0.0272 to 0.1630 h/d.b., while estimated values for k_2 varied between 0.0496 and 0.0875 1/d.b. Obtained values for k_1 were within the values reported in the literature for various foods, which vary within the range of 0.0073–0.2317 h/d.b. for temperatures between 15 and 100 °C [41,47,69]. The determined values for k_2 were slightly lower than the reported in the literature for food (in the temperature range 15–100 °C): 0.074–1.57 1/d.b. [5,45,70,71].

It turned out that the Peleg rate constant depended in a statistically significant manner on the apple variety. The apple var. Champion showed the lowest values of k_1 at the examined rehydration temperatures 20–70 °C. This suggests that the rate of water absorption in the early phase of the rehydration process was the fastest for the Champion variety. The highest value of k_1 at 20 °C was obtained for Gray Reinette, whereas Ligol showed the highest k_1 at 45 °C and 70 °C. The Peleg rate constant tended to decrease along with the rehydration temperature for investigated varieties, and statistically significant differences were found between data. This suggests a higher rate of water absorption at a higher rehydration temperature. Therefore, it could be stated that water transfer, related to the inverse of the constant k_1, was promoted by the temperature increase. Similar behavior, as far as the dependence on the temperature was concerned, has been found, among others, for chickpeas [72], mangos [45] and *Rosa rubiginosa* fruits [43].

It resulted from the conducted investigations that the Peleg capacity constant was influenced in a statistically significant manner by the apple variety. The highest value of k_2 at 20 and 45 °C was demonstrated by apple var. Ligol, the lowest apple var. Grey Reinette, whereas at 70 °C Champion variety, showed the highest k_2 value and Ligol the lowest one. The Peleg capacity constant for apple var. Grey Reinette increased with increasing temperature, and the differences were statistically significant. The same tendency was observed for Champion, but the differences for the values of k_2 at 20 and 45 °C were statistically insignificant. Apple var. Ligol demonstrated the highest Peleg capacity constant at 20 °C, whereas the k_2 values at 45 and 70 °C were the same and lower than the value at 20 °C. The differences between the discussed constant at 20 °C and 45 °C was statistically significant. The Peleg capacity constant was related to equilibrium moisture content M_e by Equation (2). According to this equation, a growing value of M_e means a decreasing value of k_2. Equilibrium moisture content was a characteristic parameter of each product. The maximum capacity of water absorption of biological material depends on the type of product, structure of its tissue and chemical composition of the cells and could be modified by thermal treatments. The value of M_e (so consequently k_2) could change if the structure or other properties were modified by temperature during rehydration [47,58]. The effect of rehydration temperature on M_e depended on the product. The results found in the literature indicate that equilibrium moisture content increased with increasing temperature [5,73], decreased with increasing rehydration temperature [42,72] or, in some cases, was independent of temperature [74,75].

Table 6 shows the coefficients of constant equations for the Weibull model (Equation (3)) and the results of statistical analyses on the rehydration modeling of different varieties of dried apples. The following linear-type constant equations were applied:

$$M_e = M_{e1} + M_{e2}T_r \tag{16}$$

$$\alpha = A_1 + A_2T_r \tag{17}$$

$$\beta = B_{1r} + B_2T_r \tag{18}$$

As can be seen from the statistical analysis results, the R^2 values varied between 0.9580 and 0.9978, the RMSE ones fell within the range of 0.1602 to 0.8087, and the SSE values were between 0.3081 and 14.2117. It could be therefore accepted that the Weibull model showed a slightly better fit upon the experimental resulted than the Peleg model. The estimated values for α varied between 0.53 and 0.96, whereas calculated values for β range from 0.73 to 7.06 h. The following variation ranged for the values of discussed constants could be found in the literature: α = 0.530–0.701 and β = 0.25–1.867 h for mango at rehydration temperatures 20–80 °C [45], α = 0.60–0.90 and β = 0.0414–0.1414 h for *Morchella esculenta* mushrooms in the temperature range 15–70 °C [58], α = 0.409–1.069 and β = 0.0645–1.123 h for pumpkin at 30–60 °C [49], α = 0.614–0.893 and β = 0.807–2.75 h for parboiled rice at 30–50 °C [18], α = 0.428–0.598 and β = 0.0817–0.4767 h for potato at 95 °C [46], α = 0.402–0.951 and β = 0.55–0.58 h for tomato for rehydration temperatures between 25 and 80 °C [47]. It can be accepted, therefore, that obtained values of α were within the values reported in the literature, whereas part of the estimated β values was higher than shown in the literature.

Table 6. Coefficients of the constant equations for the Weibull model (Equation (3)) and results of statistical analyses on the rehydration modeling of different varieties of dried apples.

Variety of Apple	T_r (°C)	Constant	SSE	R^2	RMSE	Coefficients of Constant Equations						SSE	R^2	RMSE
						M_{e1}	M_{e2}	A_1	A_2	B_1	B_2			
Champion	20	M_e = 15.4613 abc α = 0.7446 ab; β = 2.1483 ab	6.1004	0.9817	0.6377	15.85	−0.0026	0.9007	−0.0064	2.3220	−0.0062	20.9321	0.9700	0.70612
	45	M_e = 17.5000 abc α = 0.6670 ab; β = 2.4650 ab	6.5875	0.9709	0.6860									
	70	M_e = 12.0491 ab α = 0.5332 a; β = 0.7294 a	2.5934	0.9797	0.4856									
Cortland	20	M_e = 17.9032 bc α = 0.7885 ab; β = 3.8746 ab	14.2117	0.9815	0.5888	-	-	-	-	-	-	-	-	-
Gray Reinette	20	M_e = 20.6185 c α = 0.7582 ab; β = 5.8016 b	6.6173	0.9820	0.6431	17.44	−0.0029	0.9516	−0.0053	3.8660	−0.0027	48.8417	0.9451	0.9786
	45	M_e = 16.4272 abc α = 0.7811 b; β = 2.1755 ab	5.5915	0.9809	0.5912									
	70	M_e = 13.3600 a α = 0.6619 ab; β = 1.4970 a	3.6248	0.9814	0.5280									
Ligol	20	M_e = 17.2583 abc α = 0.5996 a; β = 7.0607 b	0.3081	0.9978	0.1602	8.687	0.1849	0.7847	−0.0035	1.5260	0.0680	8.7741	0.9789	0.5321
	45	M_e = 11.2023 a α = 0.9638 b; β = 1.5037 ab	5.2318	0.9580	0.8087									
	70	M_e = 14.6891 ab α = 0.6585 ab; β = 1.9488 ab	0.7570	0.9948	0.3076									

The same letters in the same column indicate homogenous groups (α < 0.05, Tukey's test HSD).

It resulted from the investigations that the dimensionless shape parameter α depended on the apple variety but in a statistically insignificant manner. The apple var. Cortland showed the highest value of α at rehydration temperature 20 °C and then next in the sequence were Grey Reinette, Champion and Ligol. The sequence from the highest value of α to the lowest at 45 °C was the following: Ligol, Grey Reinette and Champion. The apple var. Ligol and Grey Reinette demonstrated at 70 °C the same value of the dimensionless shape parameter, which was higher than α for Champion. As it was written, parameter α can be related to the rate of water absorption at the beginning of the rehydration. The lower the value of α, the faster was the rate of absorption. The obtained results were in good accordance with results obtained for Peleg rate constant k_1, namely the process rate in the early phase of the rehydration was the fastest for Champion variety and the lowest for Ligol and Grey Reinette one at 45 and 70 °C. The dimensionless shape parameter tended to decrease with the rehydration temperature for apple var. Champion, whereas for Grey Reinette and Ligol, parameter α increased from 20 to 45 °C, and then decreased along with temperature, but the differences were statistically insignificant. A similar trend as for Champion was observed by Goula and Adamopoulos [47] for tomato, whereas Garcia-Pascual et al. [58] noticed for *Morchella esculenta* similar tendency as for Gray Reinette and Ligol. However, the dimensionless shape parameter had also been found to be independent of temperature [41,69].

It can be stated that the apple variety affects the value of the scale parameter β. Ligol showed the highest value of β at the rehydration temperatures 20 and 70 °C, whereas Champion the lowest value. The sequence at 45 °C was reversed, but at this temperature, the differences were statistically insignificant. According to Goula and Adamopoulos [47], parameter β represents the time needed to accomplish approx. 63% of rehydration. The high value of the scale parameter suggests a difficulty of the material to absorb water during the rehydration, resulting in a low process rate [43]. Therefore, it can be assumed that the rate of absorption during the entire process of rehydration at 20 and 70 °C was the highest for Champion and the lowest for Ligol. The values of parameter β decreased with increasing temperature for Grey Reinette (statistically significant differences), whereas Champion demonstrated the highest value of β at 45 °C and the lowest one at 70 °C. Ligol showed the highest β value at 20 °C and the lowest one at 45 °C, but the differences were statistically insignificant. The following behavior as far as the dependence of β on the temperature was concerned could be found in the literature: β value for pumpkin decreased when rehydration temperature increased [49], in case of *Morchella esculenta,* discussed value decreased along with temperature except at 70 °C, where β value increased [58], whereas for tomato scale parameter increased with increasing temperature [47]. Such a different effect of rehydration temperature on the value of the β parameter could be attributed to the different changes in the structure of material during the process of rehydration. Explanation of this phenomenon needs a deep understanding of the correlation between structure and mass transfer process during the rehydration.

The values of equilibrium moisture content M_e, identified from the Weibull model, depended on apple variety, although the differences were statistically insignificant. The highest value of M_e at rehydration temperature 20 °C showed apple var. Gray Reinette, whereas at 45 °C Champion and at 70 °C Ligol. The lowest M_e value at temperature 20 °C demonstrates Champion, whereas at 45 °C Ligol and at 70 °C Champion. The values of equilibrium moisture content identified from the Weibull model and Peleg one were comparable. As far as the dependence on the temperature is concerned, the M_e values for Gray Reinette decreased with increasing temperature, whereas apple var Champion shows the highest value of M_e at 45 °C and the lowest at 70 °C. On the other hand, Ligol demonstrated the highest moisture equilibrium content at 20 °C and the lowest at 45 °C. The Weibull model, however, did not present statistically significant differences among temperatures for the M_e values.

Table 7 presents the results of statistical analyses on the rehydration modeling of different varieties of dried apples using Fick's second law model (Equation (4)). The R^2 were equal or greater than 0.9214 except for apple var. Champion at 70 °C (0.8965), the RMSEs were equal or lower than 0.0865, and the SSEs were equal or lower than 0.0642 except for Champion at 70 °C (0.0972). It can be, therefore, observed that Fick's second law model describes the experimental data adequately. Comparing the results obtained for the three discussed models, the diffusion model could be considered as the most appropriate. The values determined for D/L^2 range from 0.00772 to 0.06987 1/h and were found to be lower than the values reported in the literature for mushrooms: 1.764–10.84 1/h [41,58]. It should be underlined, however, that the values of the water diffusion coefficient reported in the literature for food materials were within the general range of $3.6{\cdot}10^{-10}$ m^2/h to $3.6{\cdot}10^{-3}$ m^2/h [76–79]. It turned out from the investigations that the values of D/L^2 depend on the apple variety, but the differences were statistically insignificant. The apple var. Champion demonstrated the highest values of D/L^2 at the examined rehydration temperatures 20–70 °C. The lowest value of the discussed parameter at 20 °C was obtained for Grey Reinette, whereas Ligol showed the lowest D/L^2 at 45 and 70 °C. The received results were in agreement with calculations obtained for the Peleg rate constant k_1 and confirm the statement that k_1 was related to the rate of mass transfer, and its reciprocal could be compared with a water diffusion coefficient. The values of D/L^2 increase with rehydration temperature, but the differences were statistically insignificant. The same dependence on temperature had been observed among others for amaranth grain [80], date palm fruits [54] and mango [4]. Cunningham et al. [81] observed, however, a positive effect of temperature on water absorption of potatoes until 60 °C, and then a negative effect was obtained. A similar tendency had been found by Garcia-Pascual et al. [58] for *Morchella esculenta* because the values of D/L^2 increased with temperature except at 70 °C, where this value decreased.

Table 7. Results of statistical analyses on the rehydration modeling of different varieties of dried apples using Fisk's second law model (Equation (4)).

Variety of Apple	T_r (°C)	D/L^2 (1/h)	SSE	R^2	RMSE
Champion	20	0.01578 ab	0.0546	0.9542	0.0567
	45	0.01926 ab	0.0470	0.9429	0.0560
	70	0.06987 b	0.0972	0.8965	0.0865
Cortland	20	0.00894 a	0.0642	0.9680	0.0386
Gray Reinette	20	0.00772 a	0.0242	0.9732	0.0367
	45	0.01480 ab	0.0451	0.9474	0.0500
	70	0.03124 ab	0.0576	0.9543	0.0620
Ligol	20	0.01399 ab	0.0263	0.9700	0.0434
	45	0.01446 ab	0.0483	0.9214	0.0695
	70	0.02436 ab	0.0284	0.9604	0.0533

The same letters in the same column indicate homogenous groups (α < 0.05, Tukey's test HSD).

Table 8 presents the results of statistical analyses on the color changes of different varieties of raw, dried and dried apples during rehydration at different temperatures. The Gray Reinette variety (raw apple cubes) showed the lowest values of color attributes R and G (193.3 and 180.7, respectively), which differed statistically significant from discussed attributes for Champion, Cortland and Ligol. The differences between these three apple varieties were statistically insignificant.

Table 8. Results of statistical analyses on the RGB color attributes of different varieties of raw, dried and dried apples during rehydration at different temperatures.

Variety of Apple	Material			RGB Channel		
				R	G	B
Champion	Raw			203.2 ± 4.6 h	199.6 ± 4.6l m	173.7 ± 6.7 ij
	Dried			235.4 ± 5.4 k	225.7 ± 6.1 n	178.4 ± 7.4 jk
	Rehydrated	T_r (°C)		Place		
		20	side	200.9 ± 5.5 fgh	196.0 ± 5.6 klm	165.6 ± 8.3 ghij
			center	200.3 ± 8.0 fgh	196.3 ± 8.4 klm	166.4 ± 9.1 ghij
		45	side	203.5 ± 4.9 h	196.7 ± 4.7 klm	167.8 ± 7.5 ghij
			center	204.6 ± 7.1 h	197.8 ± 7.3 klm	167.7 ± 8.4 ghij
		70	side	197.4 ± 6.0 defgh	189.7 ± 6.2 ghijklm	167.1 ± 5.2 ghij
			center	198.7 ± 4.2 defgh	191.6 ± 3.8 hijklm	166.0 ± 3.4 ghij
Cortland	Raw			204.2 ± 5.7 h	202.7 ± 5.2 m	193.9 ± 5.3 k
	Dried			230.2 ± 7.9 ik	201.1 ± 16.9 lm	163.2 ± 18.6 efghij
	Rehydrated	T_r (°C)		Place		
		20	side	184.4 ± 7.6 a	152.6 ± 14.9 a	121.5 ± 20.2 a
			center	187.7 ± 8.2 ab	160.7 ± 11.2 ab	133.4 ± 12.0 abc
Gray Reinette	Raw			193.3 ± 9.0 abcdefg	180.7 ± 10.2 efghi	145.6 ± 10.6 bcde
	Dried			226.7 ± 9.3 ik	199.3 ± 10.2 lm	146.0 ± 9.1 bcdef
	Rehydrated	T_r (°C)		Place		
		20	side	185.4 ± 8.5 a	161.3 ± 15.1 abc	121.2 ± 16.5 a
			center	190.5 ± 4.3 abcde	177.7 ± 6.7 efgh	151.0 ± 6.6 cdefg
		45	side	197.2 ± 5.7 bcdefgh	181.3 ± 9.6 efghij	146.0 ± 14.7 bcdef
			center	201.8 ± 4.3 gh	187.0 ± 6.8 fghijkl	158.1 ± 8.0 defghi
		70	side	190.2 ± 8.8 abcde	175.2 ± 10.2 cdef	143.1 ± 11.4 bcd
			center	197.3 ± 6.3 cdefgh	187.1 ± 6.1 fghijkl	157.2 ± 7.6 defghi
Ligol	Raw			202.9 ± 7.5 h	195.4 ± 7.9 jklm	171.2 ± 8.9 hij
	Dried			221.5 ± 8.2 i	192.5 ± 9.6 ijklm	150.1 ± 10.1 cdefg
	Rehydrated	T_r (°C)		Place		
		20	side	189.3 ± 5.4 abcd	160.7 ± 9.6 ab	125.1 ± 10.8 a
			center	189.3 ± 7.0 abcd	170.0 ± 11.8 bcde	145.4 ± 12.2 bcd
		45	side	190.4 ± 6.1 abcde	162.8 ± 10.6 abcd	129.3 ± 13.5 ab
			center	197.7 ± 5.7 defgh	178.3 ± 7.0 efghi	152.9 ± 6.1 defg
		70	side	196.4 ± 5.1 bcdefgh	175.6 ± 8.1 defg	145.5 ± 11.0 bcde
			center	199.1 ± 6.3 efgh	184.8 ± 7.4 fghijk	163.6 ± 8.3 fghij

The same letters in the same column indicate homogenous groups ($\alpha < 0.05$, Tukey's test HSD).

The Cortland variety showed the highest values of color attribute B (193.9), whereas Gray Reinette demonstrated the lowest one (145.6). The differences between apple varieties were statistically significant. Dry apple cubes of Gray Reinette and Ligol showed the lowest values of color attributes R, G and B (R: 226.7 and 221.5, G: 199.3 and 192.5, B: 146.0 and 150.1, respectively), whereas Champion demonstrated the highest ones, namely R = 235.4, G = 225.7 and B = 178.4. The differences between apple varieties were statistically significant. The color of the rehydrated cubes of apples was measured in two places: at the surface of the side and in the center of the cube (cubes were cut). There was no effect of the place of the color test on the R channel values of the rehydrated apples, whereas values for channels G and B were greater at the center of the rehydrated apple cubes. The differences for Gray Reinette (T_r = 20 °C—channel G) and Ligol (T_r = 20 °C—channel B, T_r 45 °C and 70 °C—channels G and B) were statistically significant. The resulted of the statistical analysis showed the influence of rehydration temperature on RGB channels. The values of each RGB channel increased with an increase of T_r for rehydrated apple var. Ligol. The differences were statistically significant.

It turned out from the investigations that the values of RGB depend on the apple variety, and the differences were statistically significant. The apple var. Champion demonstrated the highest values of all RGB channels at the examined rehydration temperatures 20–70 °C. For apple var. Champion rehydrated at T_r = 20 °C the values of R, G and B channels were higher than for other considered varieties.

Drying results in adverse changes that occur due to complex biochemical reactions and water loss and are dependent on the drying regime. Especially apples are exposed to undesirable quality changes due to the high content of water and sugars, particularly glucose and fructose, as well as the presence of pectins and malic acid [82]. The apple color change (especially the rapid increment in the initial stage of the drying process [83]) could be associated with the rapid synthesis of phenolic compounds and the non-enzymatic browning reactions [84]. Nadian et al. [83] stated as the color changes of pretreatment apples were visually different from the color changes of untreated slices at different drying times, and this difference could be related to the further progressing of chemical, biochemical and physical changes in untreated apple by stimulating most of the enzymatic and non-enzymatic reactions. Additionally, color change in the apple could have resulted from the decomposition of original pigments, the formation of brown pigments by enzymatic and non-enzymatic browning reactions and the formation of other undesirable pigments, wherein for pigments responsible for the original apple color is believed chlorophyll (green color), carotenoids, flavonoids (yellow color) and anthocyanins (red color) [85]. The Millard reaction during which interaction between reducing sugars and amino acids occurs is easily stimulated in wet products during thermal processing [86] and also be resulted from the product's structural shrinkage that subsequently increases the opacity of dehydrated samples [87,88]. The conducted research shows the influence of apple variety on both the color of the dried fruit and the color of the rehydrated dried material. Therefore, in order to obtain dried apples and rehydrated apple with desired (sensory attractive) color qualities, it should keep in mind the apple variety.

4. Conclusions

The following conclusions can be drawn from the conducted investigations.

1. Apple variety and temperature of rehydrating water had a statistically significant influence on the value of the equilibrium mass of the rehydrated sample. The highest value demonstrated Cortland variety rehydrated at 20 °C, the lowest Ligol one at 20 °C. The rate of water absorption during the early stage of rehydration at 20 °C was the highest for Champion and the lowest for Cortland, and the discussed rate becomes higher at a higher rehydration temperature;
2. The apple variety had a statistically insignificant influence on the loss of dry matter. The rate of dry matter loss during the early stage of the rehydration for some apple variety depended in a statistically significant way on the rehydration temperature, and at 20 °C was higher than at 70 °C;
3. Apple variety and temperature of rehydrating water had a statistically significant influence on the value of the equilibrium volume of the rehydrated sample. The highest value demonstrated Gray Reinette at 45 °C, the lowest Champion at 70 °C;
4. Comparing the results obtained for three considered models, namely Peleg model, Weibull model and Fick's second law model, the diffusion model can be considered as the most appropriate for describing the rehydration behavior of dried apples;
5. The values of the water diffusion coefficient to the second power of the cube thickness ratio (D/L^2) depend on the apple variety, but the differences were statistically insignificant. Apple var. Champion demonstrated the highest values of D/L^2 at the rehydration temperatures of 20–70 °C. The lowest value of the discussed parameter at 20 °C was obtained for Gray Reinette, whereas Ligol showed the lowest D/L^2 at 45 and 70 °C. The values of D/L^2 increased with rehydration temperature, but the differences were statistically insignificant;
6. Taking into account all the obtained results, it can be stated that apple var. Champion showed a greater rate of water absorption during the entire process of rehydration than other investigated varieties; therefore, it could easily apply for special purpose food products;

7. The apple variety had a statistically significant influence on the color attribute B of raw apple. The highest value demonstrated Cortland, the lowest Gray Reinette one. The apple variety had a statistically significant influence on the color attribute of dried apple. The highest value demonstrated Champion, the lowest Gray Reinette and Ligol. Apple variety and temperature of rehydrating water had a statistically significant influence on the color attribute of the rehydrated apples.

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