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Pol. J. Food Nutr. Sci.
2007, Vol. 57, No. 1, pp. 69–76

SORPTION PROPERTIES OF OSMOTICALLY-DEHYDRATED AND FREEZE-DRIED STRAWBERRIES

Monika Janowicz, Andrzej Lenart, Wioleta Idzikowska

Department of Food Engineering and Production Management, Warsaw University of Agriculture, Warsaw

Key words: strawberries, osmotic dehydration, freeze drying, sorption properties

The study was aimed at determining isotherms and kinetics of water vapour adsorption by osmotically-dehydrated and freeze-dried strawberries. An attempt was also undertaken for mathematical description of both isotherms as well as kinetics of water vapour adsorption. The application of a saccharose solution for 3 h at a temperature of 30°C was found to change the internal structure of raw material and to enable achieving a different result during adsorption of water vapour as compared to the non-hydrated strawberries and dehydrated under different parameters. The Lewicki's equation enables describing, with a high coefficient of correlation, the shape and elucidating the course of the isotherm of water vapour adsorption by freeze-dried strawberries after initial osmotic dehydration with the use of variable parameters of that process.

INTRODUCTION

Strawberries are a highly attractive fruit to a consumer, yet after the season they are available only in the processed form as an additive to food products or as a frozen product. In those forms, they are devoid of attractive functional traits, which results from structure breakdown and a high drip after thawing. Thus, it seems advisable to search for new applications of frozen products [Ogonek & Lenart, 2001].

A special method for the preservation of structure and maintaining strawberries in the form the consumer is used to is freeze-drying which consists in the removal of water from frozen products by means of ice lyophilization, *i.e.* its direct transition into the state of water vapour omitting the liquid state. During water removal, the product is in the frozen state, as a result of which its structure and freshness are preserved to the maximal extent [Gawlik, 2001].

The most intensive loss of nutrients and deterioration of sensory traits of dried material occur during drying up [Kozak & Lis, 1999]. Hence, the application of pre-treatment aimed at improving the quality of the finished product is of great significance. Recently, a great interest is being observed in the application of various methods for initial processing prior to the exact drying. The basic treatments performed before drying include blanching, freezing and freeze-drying. All those processes induce physicochemical changes in the dried material produced and affect its sensory traits [Zadernowski & Oszmański, 1994].

Current trends recommend the application of freeze drying as an initial processing aimed, most of all, at improving the quality of the food dried and not at removing considerable quantities of water [Janowicz & Lenart, 2001; Marabi *et al*., 2006]. Therefore it is postulated as an initial processing prior to such processes as: drying, freezing or drying of initially frozen materials. It results in obtaining products with specified, desired nutritional and sensory properties. The application of osmotic dehydration of frozen products to be subjected to freeze drying enables improving a number of properties of food products [Lenart & Lewicki, 1996].

Dehydration of fruits in the frozen state exerts a significant impact on the character of the process and its end product, mainly as a result of changes in the material's structure. Viberg [1998] demonstrated that the more damaged the cellular structure of the plant material during initial processing (*e.g.* freezing, blanching), the more intensive the penetration of the osmoactive agent. The freezing of strawberries modifies surface properties of those fruits. It is observed to exert a high effect on water content reduction in strawberries, in the case of which losses of water after 24-h osmotic dehydration were 2-fold higher than in the fresh fruits [Kowalska & Lenart, 2001]. According to Ogonek & Lenart [2001], the loss of mass during dehydration of frozen strawberries reached 29% on average, whereas in the case of fresh fruits – as little as 9%. The mass loss is correlated with the loss of water content, which is over 3 times higher in the case of the frozen samples.

A search is still underway for the initial treatment that would be capable of preserving appropriate colour during the drying process of fruits and vegetables [Mandala *et al*., 2005]. The colour of osmotically-dehydrated strawberries is comparable with that of fresh fruits [Donsi *et al.*, 2000]. Simultaneously it was observed that, irrespective of the applied parameters of osmotic dehydration, brightness degree of the red colour of freeze-dried strawberries decreased and the fruits were still characterised by a high intensity of the colour [Janowicz *et al*., 2003].

Author's address for correspondence: Monika Janowicz, Department of Food Engineering and Production Management, Warsaw University of Agriculture, ul. Nowoursynowska 159c, 02-776 Warsaw, Poland; tel.: (48 22) 593 75 70; e-mail: monika_janowicz@sggw.pl

The research was aimed at determining isotherms and kinetics of water vapour adsorption by osmotically-dehydrated and next freeze-dried strawberries. An attempt was also undertaken for mathematical description of both the isotherms and adsorption kinetics of water vapour.

MATERIAL AND METHODS

The experimental material were strawberries of Senga-Sengana variety (BINDER). The strawberries were simultaneously thawed and dehydrated osmotically in solutions of glucose, saccharose and starch syrup. Next, the material was subjected to freezing and freeze-drying.

Osmotic dehydration was run in solutions with concentrations corresponding to the activity of water of a_w = 0.9: saccharose – 61.5%, starch syrup – 67.5%, and glucose – 49.5%. The ratio of the mass of raw material to the mass of osmotic substance accounted for 1:4. Parameters of the osmotic dehydration (Table 1) were adjusted based on investigations carried out within research activities of the Department of Food Engineering and Production Management, Warsaw University of Agriculture [Ogonek & Lenart, 2001; Janowicz *et al*., 2003].

Initially-prepared strawberries were fixed directly on pull out shelves of a lyophilizing cabinet. The shelves with fruits were fixed with a stand into a Profi Master fridge (National Lab GmbH) at a temperature of -70±1°C for 2 h. Strawberries that were not subjected to pre-treatment, were frozen up from a temperature of -18°C for 1 h under the same conditions. So prepared material was transferred into a laboratory lyophilizer Alpha 1–4 and subjected to the drying process. Constant parameters of air-drying were established for all samples (Table 1): pressure 63±0.1 Pa, shelf temperature 30±1°C, and safety pressure 103±0.1 Pa. The total time of drying of one batch of strawberries reached 24 h. Drying materials were closed in tight vessels and stored at a temperature of 20–25°C in a shaded room. All determinations and weighing of strawberries for determinations of isotherms were carried out within 2 weeks from obtaining the dried material.

TABLE 1. Parameters of osmotic dehydration (initial treatment) of strawberries.

Sample	Solution	Temperature (°C)	Time (h)
1	Saccharose	30	3
2	Saccharose	70	3
3	Saccharose	30	20
4	Saccharose	30	0.25
5	Starch syrup	30	3
6	Glucose	30	3
7	Non-dehydrated	-	0

Isotherms of water adsorption were determined with the static desiccator method based on three experiments carried out in parallel. Ten desiccators containing saturated salt solutions were prepared that provided specified conditions of air humidity (water activity) in the range from 0 to 0.903. A weighted sample was a whole strawberry weighing *ca*. 0.8 g. The measurement was carried out at a temperature of 25±1°C, under atmospheric pressure. After 90 days, the vessels with strawberries were weighed.

For seven properly prepared strawberry dried materials (Table 1), kinetics of water vapour adsorptions were determined with a dynamic method using a Mettler AE 240 scale. The stand was adapted for continuous measurement of sample mass, under conditions of constant temperature and relative humidity of the air. Results were registered with the use of "Pomiar" software. In the first hour of the process, results were recorded every 5 min, in the two subsequent hours – every 15 min, and till the end of measurements – every 30 min [Domian & Lenart, 1999]. Sorption properties were examined at water activity of a_w=0.648 and a temperature of 25±1°C using $NaNO_2$ solution as a hygrostatic agent. After 20 h of measurements, the dried materials were determined for the activity of water (a_w) with the use of a Hygroskop DT hygrometer, with measurement accuracy of a_w = 0.001.

In the paper, an attempt was also made to describe the course of isothermes of water vapour adsorption in strawberries that were initially osmotically-dehydrated and then freeze dried, considering parameters of osmotic dehydration, by means of the following equations:

Iglesias & Chiriffe [Boquet *et al*., 1978]

$$u=\frac{e^{2\cdot(A\cdot a_w+B)}-a_{0.5}}{2\cdot e^{(A\cdot a_w+B)}} \quad (1)$$

Lewicki & Raoult [Lewicki, 2000]

$$u=A\cdot\left(\frac{1}{a_w}-1\right)^{B-1} \quad (2)$$

Oswin [1946]

$$u=\frac{A+B\cdot t}{e^{\frac{1}{C}\ln\left(\frac{1}{a_w}-1\right)}} \quad (3)$$

Henderson [1952]

$$u=\left(\frac{\ln(1-a_w)}{-A\cdot(t+C)}\right)^{\frac{1}{B}} \quad (4)$$

GAB [Bizot, 1983]

$$u=\frac{A\cdot B\cdot C\cdot a_w}{(1-C\cdot a_w)\cdot[1+(B-1)\cdot C\cdot a_w]} \quad (5)$$

Lewicki [1998]

$$u=\frac{A}{(1-a_w)^B}-\frac{A}{1+a_w^{\,C}} \quad (6)$$

Peleg [1993]

$$u=A\cdot a_w^{\,B}+C\cdot a_w^{\,D} \quad (7)$$

The effect of osmotic dehydration and its parameters on the course of isotherms and kinetics of water vapour adsorption in freeze-dried strawberries was analysed statistically with the use of analysis of variance based on a summary table ANOVA in Statistica 5.0. software. For a comparative analysis of the results obtained and their correlations, use was made of the NIR test [StatSoft Polska, 1997].

RESULTS AND DISCUSSION

The experiments conducted enabled determining the effect of osmotic dehydration and its parameters on the course of isotherms and kinetics of water vapour adsorption for freeze-dried strawberries. Analyses were carried out for the impact of temperature, time and the type of osmotic solution on the course of water vapoour adsorption isotherms and kinetics of that process.

Description of the course of isotherm curves and kinetics of water vapour adsorption in freeze-dried strawberries

Analyses of the impact of osmotic dehydration in a solution of saccharose at three temperatures of the process demonstrated a statistically significant effect of osmotic dehydration on the course of isotherms of water adsorption in the water activity range of 0 to 0.328. In turn, a change of dehydration temperature from 30 to 70°C had no significant effect on the course of isotherms of water vapour adsorption in the same range of water activity. In the case of water activity ranging from 0.328 to 0.903 it was demonstrated that the course of isotherm was significantly affected by the application of dehydration in a saccharose solution at a temperature of 30°C as a pre-treatment before freeze-drying. Also temperature change from 30 to 70°C in the analysed range of water activity was shown to significantly affect the course of the adsorption process (Figure 1a). Simultaneously, a statistically significant effect of both osmotic dehydration and temperature of that process on the course of isotherm of water vapour adsorption was shown in the entire range of water activity, *i.e.* from 0 to 0.903 (Figure 1a).

While investigating the course of kinetics of water vapour adsorption in the environment with a constant value of water activity reaching 0.648 (Figure 1b) it was observed that, irrespective of process parameters, osmotic dehydration resulted in a decrease in water content of the freeze-dried strawberries after a given time of adsorption. The course of kinetics for strawberries dehydrated at a temperature of 30 and 70°C was similar, still more mild only at the beginning of the process as compared with the material not subjected to initial dehydration. After five hours of the adsorption process also the course of kinetics of water vapour adsorption for the strawberries not dehydrated osmotically was becoming smoother and tended for a constant water content of the material at a level of 0.25 gH_2O/g d.m. The statistical analysis demonstrated a significant effect of temperature of that process on the course of kinetic curves in the environment with water activity of 0.648.

In analysing the impact of the time of osmotic dehydration on the course of isotherms of water vapour adsorption, 3-h and 20-h dehydration of strawberries before freeze-drying was found to affect the course of the curves (Figure 2a). Strawberries not subjected to initial dehydration and those

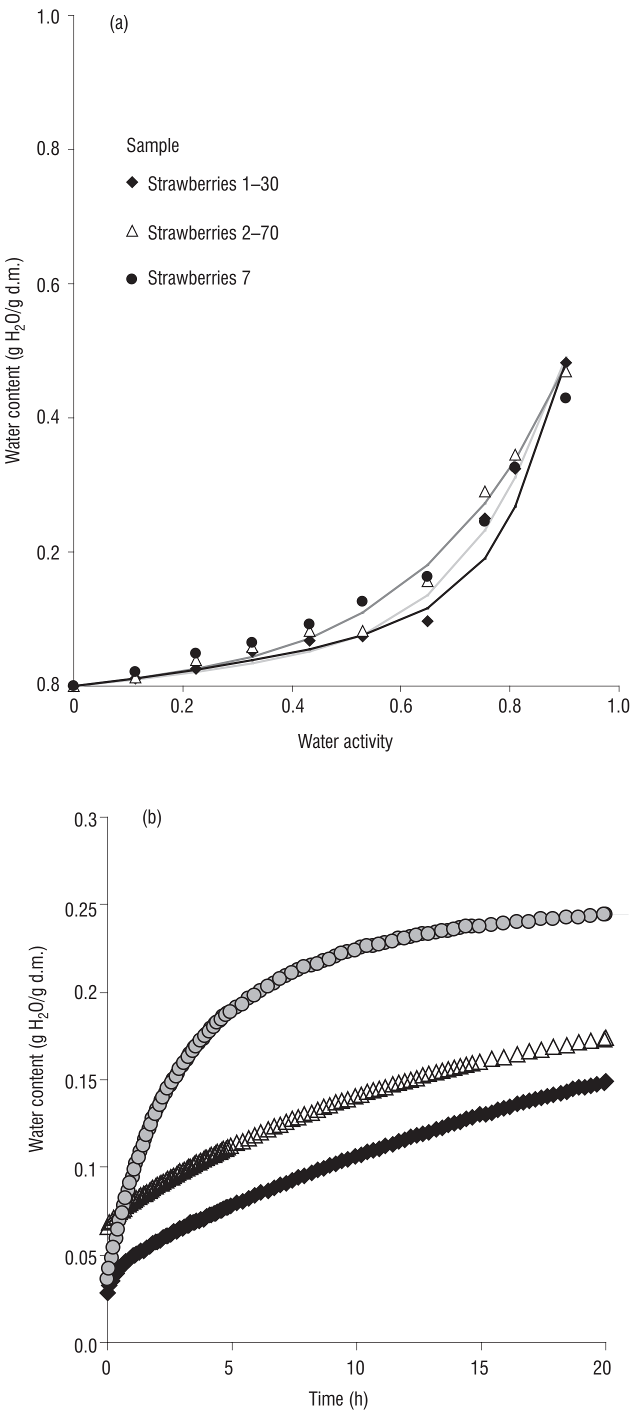

FIGURE 1. The influence of osmotic dehydration temperature on the isotherms (a) and on the kinetics (b) of water vapour adsorption for freeze-dried strawberries.

subjected to that process for 15 min were characterised by a similar course of isotherm in the entire range of water activities examined. The statistical analysis of the course of water vapour adsorption isotherms in the entire range of water activities did not demonstrate any significant differences. A different character of the course of isotherms was observed, in turn, for the strawberries dehydrated prior to freeze drying for 3 h and 20 h. The statistical analysis of the course of those two isotherms did not demonstrate any significant differences. As a result of analysig the effect of the time of osmotic dehydration of freeze-dried strawberries it was found that in the case of osmotic dehydration of the strawberries for 3 h that treatment enables obtaining a different effect during adsorption of water vapour in the material. The application of longer times of osmotic dehydration, *i.e.* 3 h and 20 h, caused that in the water activity range of 0 to 0.648 the osmotically-dehydrated strawberries were characterised by lower water contents. Simultaneously it was observed that the longer the time of dehydration, the lower the content of water. At water activity ranging from 0.648 to 0.903, for so prepared strawberries the water contents obtained were higher or similar to those obtained for strawberries dehydrated before freeze drying for 15 min and those not subjected to the dehydration process. Simultaneously, the highest water contents obtained at a_w ranging from 0.648 to 0.903 were reported for strawberries dehydrated for 20 h, yet the differences were not so high as compared with the material dehydrated initially for 3 to demonstrate statistically significant differences in the course of isotherms of water vapor adsorption.

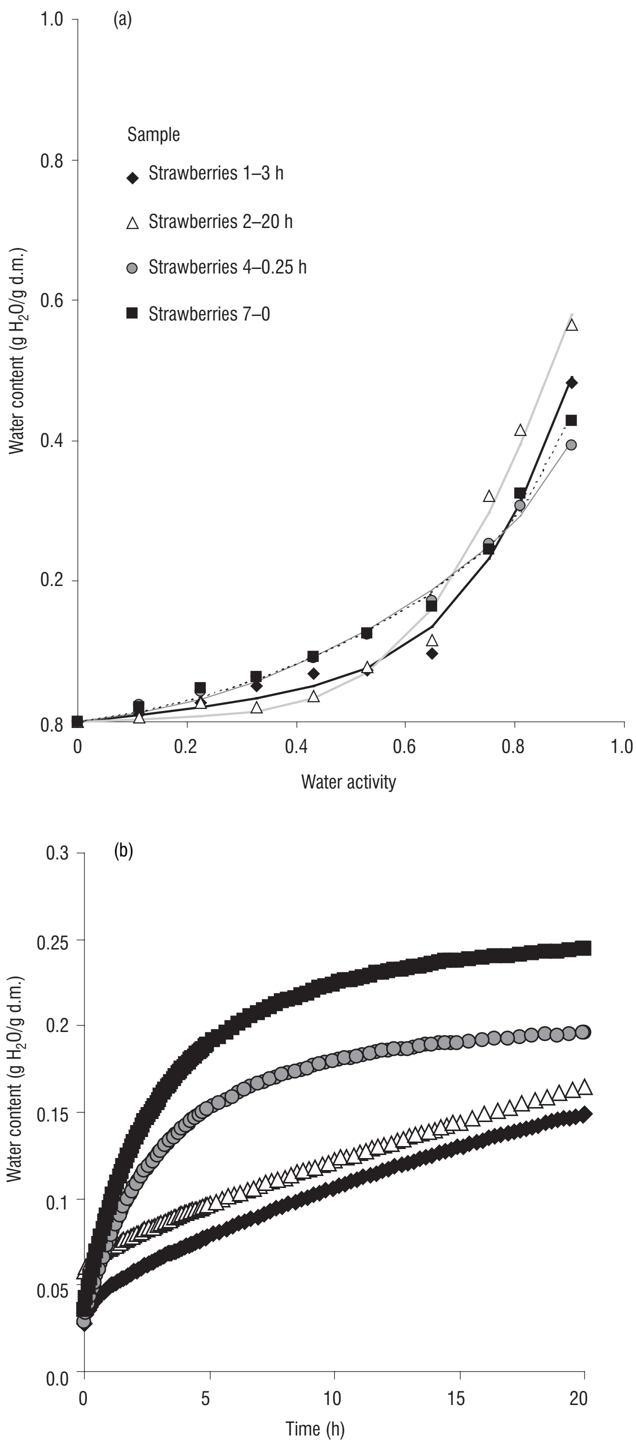

FIGURE 2. The influence of osmotic dehydration time on the isotherms (a) and on the kinetics (b) of water vapour adsorption for freeze dried strawberries.

Analyses of the kinetics of water vapour adsorption in the aspect of the initial time of osmotic dehydration of freeze-dried strawberries demonstrated that the course of the curves was significantly affected by both osmotic dehydration and its time (Figure 2b). The character of the course of water vapour adsorption curves for strawberries did not subjected to dehydration and those subjected to initial osmotic dehydration for 15 min was the same, as was the course of kinetics for strawberries dehydrated for 3 and 20 h. Elongated osmotic dehydration results in the curves of water vapour adsorption in freeze-dried strawberries becoming rectilinear. Consequently, in the entire course of the curve lower values of water content are obtained, as compared to the non-dehydrated strawberries and those dehydrated osmotically for 15 min.

Analyses of the effect of the type of osmotic solution on the course of isotherms of water vapour adsorption based on the statistical analysis of the courses for non-dehydrated strawberries and those dehydrated in glucose, saccharose and starch syrup indicated that only the use of saccharose as an osmotic agent for the pre-treatment of strawberries before freeze dring had a significant effect on the course of isotherms (Figure 3a). In addition, based on a statistical comparison of data obtained only for dehydrated strawberries it was found that the application of saccharose affected to a significant extent the course of isotherms of water vapour adsorption by strawberries freeze dried after the initial osmotic treatment.

The course of isotherms of water vapour adsorption in the range from 0 to 0.423 indicates that strawberries not dehydrated before freeze drying and those subjected to the process of osmotic dehydration in a solution of glucose and starch syrup are characterised by similar water contents. In the discussed range of water activity, its highest contents were reported for strawberries freeze dried after the initial osmotic dehydration in a solution of glucose, whereas the lowest ones – for those dehydrated in a solution of saccharose (Figure 3a). A change in water activity range from 0.75 to 0.903 results in the lowest water contents observed for the strawberries initially dehydrated in a solution of glucose and the highest ones for the non-dehydrated strawberries and those dehydrated in a solution of saccharose.

The statistical analysis carried out for particular, above-described, ranges of water activity enabled confirming that only saccharose solution had a significant effect on the course of kinetics of water vapour adsorption in the freeze-dried strawberries that were first subjected to osmotic dehydration in various solitions.

Analyses of the kinetics of water vapour adsorption in freeze-dried strawberries in terms of the impact of the type of osmotic solution on their course demonstrated that the substance used for the pre-treatment of strawberries had a significant effect on the increase in water content of the material while analysing the kinetics of water vapour adsoprtion

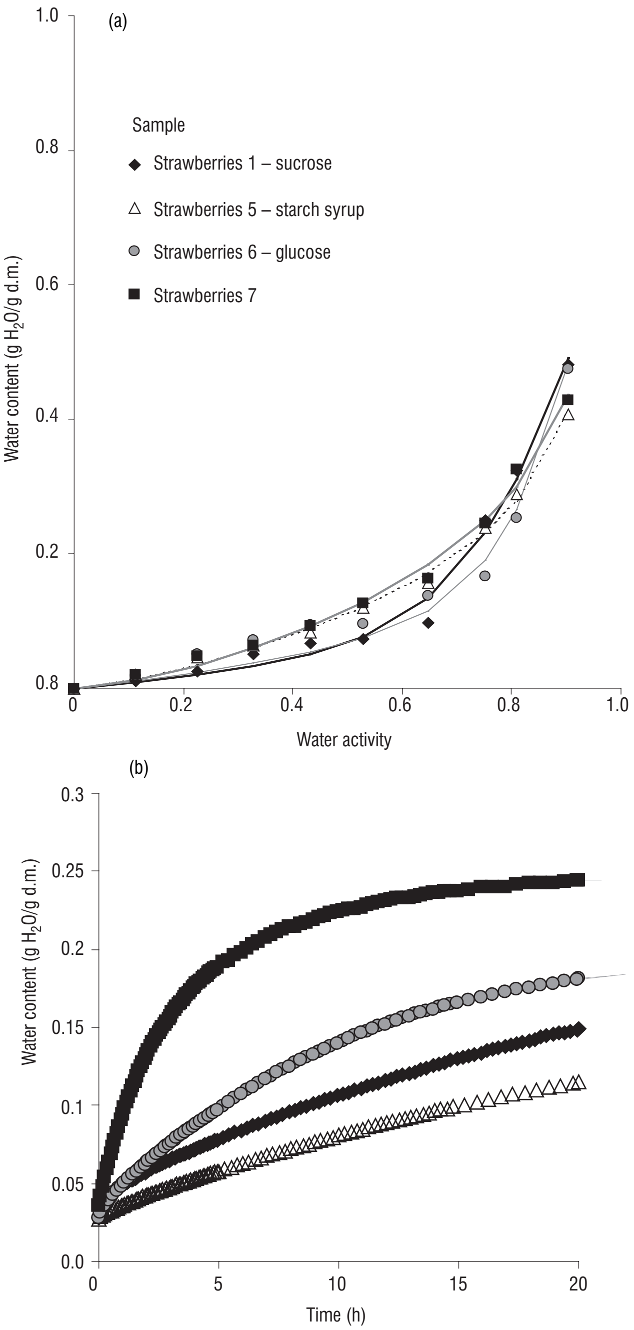

FIGURE 3. The influence of the kind of osmotic solution on the isotherms (a) and on the kinetics (b) of water vapour adsorption for freeze--dried strawberries.

in the environment with a_w=0.648 (Figure 3b). The character of the course of water vapour adsorption kinetics for the dehydrated strawberries, irrespective of the osmotic solution, is alike. It was observed that the higher the molecular weight of the substance applied for the initial dehydration of strawberries, the lower the water contents of the material during water vapour adsorption. A change of the osmotic substance from glucose to saccharose was found to evoke a decrease in the volume of water adsorbed by the freeze-dried strawberries as well as to change the water content of the material in the entire course of water vapour kinetics from 4% to 32%. In the case of starch syrup applied as the osmotic solution, water content of the material was observed to increase from 1% to 76 % (Figure 3b).

Mathematical description of the course of isotherm curves of water vapour adsorption in freeze-dried strawberries

In the study use was made of 7 equations most commonly applied to describe phenomena occurring during water vapour adsorption process in food products. Table 2 presents coefficients of adaptation RMS, which for most of the samples examined are lower than 25%, once the values of correlation coefficients reach at least 0.99. Based on the analysis of coefficients of particular equations an interpretation of physical changes linked with transformations during water vapour adsorption for strawberries subjected or not subjected to osmotic dehydration, the Lewicki's equation [Lewicki, 2000] (Table 2) was selected due to RMS values (≤25%) computed for all types of the strawberries analysed. Good adaptation coefficients RMS were also found in the case of GAB, yet during description by means of that equation no restrictions resulting from theories of values of B and C coefficients were applied. Introduction of simultaneous restrictions for the range of the occurrence of B coefficient from 0.24 to 1 and that of C coefficient from 5.67 to $+\propto$ [Lewicki, 97] made the description of isotherms of water vaopur adsorption in osmotically-dehydrated and freeze-dried strawberries impossible. Still, not implementing those conditions does not allow the theoretical interpretation of the course of isotherms. In such a case, the GAB equation can be treated as any mathematical equation enabling the description of the course of isotherm of water vapour adsorption by osmotically-dehydrated and freeze-dried strawberries.

Analysis of the effect of dehydration and its parameters on the course of isotherms of water vapour adsorption based on coefficients calculated for the Lewicki's equation [Lewicki & Raoult, 2000] demonstrated that the values of coefficient B were considerably lower than those of coefficient C, which is likely to

TABLE 2. The adaptation coefficients RMS of equations describing the isotherm of water vapour adsorption for strawberries.

Sample	Iglesias & Chiriffe	Lewicki & Raoult	Oswin	Henderson	GAB	Lewicki	Peleg [1993]
1	187.41	58.13	31.16	30.22	25.23	21.37	53.95
2	226.08	49.70	49.70	15.81	15.54	19.22	41.11
3	1356.36	382.52	382.52	179.54	204.13	59.07	45.79
4	171.33	26.95	26.95	6.98	10.29	18.38	30.29
5	171.57	22.59	22.59	9.86	6.42	12.92	35.66
6	92.53	17.24	17.24	36.76	27.25	30.56	56.82
7	163.91	24.00	24.00	10.53	9.42	16.21	36.26

indicate a greater effect of low water activities on the course of isotherms of the materials examined and, consequently, results in the flattening of the isotherm (Table 3). Of significance is also the value of B coefficient, *i.e.* the lower the value of the coefficient, the more visible the inflexion of the isotherm.

Table 3 specifies coefficients for the Lewicki's equation (6), taking into account the effect of parameters of osmotic dehydration, as well as coefficients of adaptation of the equation to experimental points. In analyzing the influence of osmotic dehydration and its temperature on the course of isotherms (Figure 1a) as well as values of B and C coefficients of the Lewicki's equation (Table 3), it was demonstrated that the application of osmotic dehydration reduced the values of B coefficient in the range from 53 to 71% for strawberries initially dehydrated before freeze drying in a solution of saccharose at temperatures of 70 and 30°C, respectively. Simultaneously, a change in that coefficients triggered a change in the value of C coefficient. Osmotic dehydration evoked *ca.* 2-fold increase of that coefficient for strawberries dehydrated osmotically at a temperature of 70°C and over 3--fold increase for these dehydrated at a temperature of 30°C.

TABLE 3. The influence of osmotic dehydration parameters on the values of Lewicki equation coefficients [1998].

Sample	A	B	C	r^2
Effect of dehydration temperature				
7	0.2479	0.3592	2.0772	0.986
1	0.8111	0.1011	6.5446	0.985
2	0.5471	0.1681	4.1878	0.988
Effect of dehydration time				
7	0.2479	0.3592	2.0772	0.986
4	0.3427	0.2338	2.2961	0.989
1	0.8111	0.1011	6.5446	0.985
3	1.3948	0.0189	5.1807	0.986
Effect of osmotic solution				
7	0.2479	0.3592	2.0772	0.986
6	0.8855	0.1063	9.997	0.968
1	0.8111	0.1011	6.5446	0.985
5	0.2064	0.4002	1.7870	0.995

In addition, a respective decrease and increase in the values of B and C coefficients elucidates the reduced water content of strawberries dehydrated osmotically at various temperatures, as compared to the non-dehydrated ones, at stable values of water activity of the environment. The described relationship between values of the B and C coefficients of the Lewicki's equation results in the flattening of the course of isotherms, which is linked with a reduced effect of low water activities on their course (Figure 1a).

In the description and interpretation of the values of coefficients no consideration was given to coefficient A since the capacity of a monolayer in the material cannot be concluded on its basis. The use of whole strawberries, especially those subjected to surface osmotic dehydration, for the determination of adsorption isotherms affects obtaining the values of the A coefficient to which no physical sense can be ascribed [Lewicki, 1998].

The analysis of the effect osmotic dehydration time on the course of isotherms of water vapour adsorption (Figure 2) as well as values of coefficients of the equation describing their course (Table 3) demonstrated the lowest value of B coefficient and the highest value of C coefficient for the strawberries subjected to initial osmotic dehydration in a solution of saccharose for 20 h. Such correlations between their values elucidate the course of water vapour adsorption isotherms. The low value of B coefficient explains a tangible inflexion of the isotherm and a significant effect of high water activities on its course, whereas the low value of C coefficient explains the flattening of the curve at low values of water activity.

Dehydration of strawberries prior to freeze-drying for a shorter period of time, *i.e.* 15 min, causes an increase in the value of B coefficient and a decrease in that of C coefficient (Table 3), as compared to the material dehydrated for 3 and 20 h. Changes in the coefficients of the Lewicki's equation in such a range elucidate convexion of a tendency outlined for the above-described time spans of osmotic dehydration applied before drying. At the same time it was observed that a short period of osmotic treatment does not result in any statistically significant change in the course of the isotherm (Figure 2a), as compared to the material that was not subjected to initial osmotic dehydration, which has been confirmed by the values of B and C coefficients (Table 3) for the Lewicki's equation used in their description.

Analyses of the effect of osmotic dehydration and the type of osmotic solution (Figure 3a) on the course of the isotherm of water vapour adsorption indicated that the dehydration in the solution of glucose and saccharose reduced the values of B coefficient and, simultaneously, increased these of C coefficient as compared to the freeze-dried strawberries not subjected to initial dehydration (Table 3). An opposite dependency was observed for the freeze-dried strawberries initially dehydrated in a solution of starch syrup (Figure 3a, Table 3).

Similar courses of isotherms, depicted in the figure for the strawberries without pre-treatment and those after initial treatment in a solution of starch syrup, are also reflected in the values of B and C coefficients (Table 3). The reduced value of C coefficient for the freeze-dried strawberries subjected to initial osmotic dehydration in a solution of starch syrup results from low water activities obtained for so prepared material under specified conditions of water activity in the entire range of isotherm course.

Mathematical description of the course of kinetics of water vapour adsorption in freeze-dried strawberries

In the study, an attempt was undertaken to describe the kinetics of water vapour adsorption by means of two types of kinetic equations [Marzec & Lewicki, 2004] presented below:

$$u = a + b\left(1 - \frac{1}{(1+bct)}\right) \tag{8}$$

where: if $t \rightarrow \propto$, equilibrium content of water u_r equals $(a+b)$

$$u = a + b(1 - \exp^{-ct}) + d(1 - \exp^{-et}) \tag{9}$$

where: if $t \rightarrow \propto$, equilibrium content of water u_r equals $(a+b+d)$.

Values of the final water content calculated from equation 2 are usually higher than those calculated from equation 1 (Table 4). The range of those changes fluctuates between 10% and 35.5% depending on the method of pre-treatment of strawberries before freeze-drying. Only the change in the temperature of a saccharose solution used for osmotic dehydration from 30 to 70°C caused that the value of the final water content calculated from equation 1 in the material examined was higher by *ca.* 0.5% than that computed from equation 2.

A comparison of the values of the final water content calculated based on the selected equations with data obtained experimentally demonstrate that water content calculated from the equation was always higher (Table 4). The value of water content calculated from equation 1 is higher than that obtained experimentally by *ca*. 11.5–58.5%, and the value calculated from equation 2 – by 1.9–62%, depending on the type of material. Those relationships can be explained by a lack of reaching the state of equilibrium by strawberries during kinetic analyses at a constant water activity of the environment, *i.e.* a_w=0.648. The values of the initial contents of water calculated based on the selected kinetic equations were different, depending on the pre-treatment applied. Usually, calculations based on equation 2 provided lower values of water contents and the range of those changes fluctuated between *ca*. 1 and 12.7%. Only the application of saccharose as an osmotic solution for 3 and 20 h caused that the initial values of water contents computed from equation 1 were higher by 25.3 and 6.5%, respectively.

A high content of saccharides in the samples examined as well as their amorphous form did not allow the material to reach the state of equilibrium after 20 h at water activity of the environment reaching 0.648, which caused that in most cases water content calculated from the kinetic equations was higher than that read from the isotherm. This may indicate that in the case of analyses of dehydrated and freeze-dried whole strawberries subjected to the process of water vapour adsorption the time of kinetics analysis should be elongated considerably to enable observation of subsequent changes proceeding in the process of adsorption and transfer of saccharides from amorphous into crystalline forms which, in turn, will affect a change in the course of water vapour kinetics in the material and, consequently, diminish the final water content of the material.

CONCLUSIONS

Analyses of the effect of temperature, time and type of an osmotic solution used for the pre-treatment of freeze-dried strawberries enabled concluding that strawberries should be dehydrated osmotically in a solution of saccharose for 3 h at a temperature of 30°C, as it may alter the inner structure of the material, which enables obtaining a different effect during water vapour adsorption. The application of dehydration times of 15 min and 20 h as well as solutions of glucose and starch syrup has no significant effect on the changes in water vapour adsorption in the water activity range examined.

In analysing the course of kinetics of water vapour adsorption in the environment with a constant water activity of 0.648 it was observed that, irrespective of process parameters, osmotic dehydration results in reduced water content of freeze-dried strawberries after a given time of adsorption. In addition, the high content of saccharides in the samples examined as well as their amorphous form did not allow the material to reach the state of equilibrium after 20 h.

The Lewicki's model proved to be a reliable tool for the description of water vapour adsorption in such a complex material as freeze-dried strawberries subjected to initial osmotic dehydration under various process parameters. Simultaneously, a high coefficient of correlation between experimental points and the Lewicki's equation as well as values of equation coefficients enables elucidating the course and shape of isotherm of water vapour adsorption and, consequently, is linked with physicochemical changes proceeding in the analysed material.

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TABLE 4. Water content of strawberries calculated and obtained experimentally during water vapour adsorption.

	Water content (g H_2O/g d.m.)	Sample 1	2	3	4	5	6	7
Equation 1	Initial t=0 → $u_0=(a)$	0.0388	0.0686	0.0644	0.0260	0.0295	0.0305	0.0326
	Final t= +∝ → $u_r=(a+b)$	0.3034	0.2627	0.3964	0.2219	0.2749	0.2867	0.2774
Equation 2	Initial t=0 → $u_0=(a)$	0.0290	0.0691	0.0602	0.0293	0.0297	0.0322	0.0363
	Final t= +∝ → $u_r=(a+b)$	0.2330	0.2184	0.4341	0.1996	0.1774	0.2068	0.2488
Experimental	Initial	0.0308	0.0671	0.0594	0.0313	0.0279	0.0294	0.0390
	Final (after 20 h)	0.1485	0.1734	0.1651	0.1957	0.1153	0.1805	0.2441
	Read from the isotherm after 20 h of adsorption in the environment with a_w=0.648	0.0970	0.1560	0.1158	0.1725	0.1580	0.1383	0.1632

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Received January 2006. Revision received May and accepted June 2006.

WŁAŚCIWOŚCI SORPCYJNE TRUSKAWEK ODWADNIANYCH OSMOTYCZNIE I SUSZONYCH SUBLIMACYJNIE

Monika Janowicz, Andrzej Lenart, Wioleta Idzikowska

Katedra Inżynierii Żywności I Organizacji Produkcji, Szkoła Główna Gospodarstwa Wiejskiego, Warszawa

Celem pracy było wyznaczenie izoterm i kinetyk adsorpcji pary wodnej przez odwodnione osmotycznie truskawki i następnie wysuszone sublimacyjnie. Ponadto podjęto próbę opisu matematycznego zarówno izoterm jak i kinetyk adsorpcji pary wodnej.

W efekcie badania wpływu temperatury, czasu oraz rodzaju substancji osmotycznej zastosowanej do obróbki wstępnej truskawek suszonych sublimacyjnie, stwierdzono że zasadnym jest użycie roztworu sacharozy przez 3 h w temperaturze 30°C, ponieważ zabieg ten zmienia już strukturę wewnętrzną materiału i pozwala uzyskać inny efekt podczas adsorpcji pary wodnej. Badając przebiegi kinetyk adsorpcji pary wodnej w środowisku o stałej aktywności wody wynoszącej 0,648 zaobserwowano, że odwadnianie osmotyczne bez względu na parametry powoduje obniżenie zawartości wody w truskawkach suszonych sublimacyjnie po danym czasie adsorpcji. Jednocześnie obecność dużej ilości cukrów w badanych próbkach oraz ich amorficzna forma nie pozwoliły po czasie 20 h osiągnąć w materiale stanu równowagi.

Równanie Lewickiego jest dobrym narzędziem do opisu adsorpcji pary wodnej tak złożonego materiału jakim są truskawki suszone sublimacyjnie wstępnie odwadniane osmotycznie z zastosowaniem różnych parametrów procesu. Duży współczynnik korelacji pomiędzy punktami doświadczalnymi a równaniem Lewickiego oraz wartościami współczynników równania pozwala wyjaśnić przebieg i kształt izotermy adsorpcji pary wodnej, a w efekcie opisać zjawiska fizyko-chemiczne zachodzące w badanym materiale.