Equilibrium moisture content of pumpkin seeds

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Abstract. The equilibrium moisture content of Pumpkin Seeds is studied and the sorption and desorption curves at temperature 20°C are obtained. The strain measurement method for taking down of sorption curves is used for the aim. Analytic dependences describing the sorption and desorption curves are derived. Values of equilibrium moisture contents for temperatures higher than 20°C (40°C, 60°C, 80°C) are obtained by using the method of Pass-Slepchenko. The results are presented in graphical and table form.

1. Introduction
Prolonged contact between a food product and the wet gas at constant external conditions leads to the establishment of thermal and diffusive equilibrium, which was maintained throughout the period of storage. The temperature of the product becomes equal to the ambient temperature, as well as the partial vapour pressure of the liquid is equal in the material and the environment. At this point the moisture of the material is constant and it is called equilibrium moisture content.

The equilibrium moisture content of a product $W_P$ can be measured for series of values of the relative humidity of the air at a constant temperature. The functional dependence of $W_P = f(\varphi)$ at $t=$ const has been plotted according the data obtained in the coordinate system $\varphi$, $W_P$, and it represents an isotherm of sorption or desorption, depending upon whether it is obtained, by moistening or drying a wet material to an equilibrium state [2, 3].

The equilibrium dependencies are a valuable source of information about the type and the format of the connection of the water with the material, for determining the acceptable level of saturation of the drying agent at the exit of the drying chamber etc.

1.1. Aim of the work
The aim of this study is to determine experimentally the equilibrium moisture content of pumpkin seeds and to obtain dependences describing the sorption-desorption isotherms at different temperatures. They will be used in determining the conditions for storage and sizing of drying plants.

2. Materials and methods
The object of this study was pumpkin seeds (Cucurbita maxima) of the “Sampson F1” variety were cultivated in a field situated close to Plovdiv (Bulgaria) – harvest 2017. Pumpkin seeds have been rich in protein, glyceride oil, phytosterols and vitamins. The seeds have been a source of carotenoids, tocopherols and trace elements (K, Mg, Mn, Zn, Se, Co, Cr and Mo). Seeds have been a major product for the oil-producing industry in the production of vegetable oil after cold pressing. The resulting oil has been a high content of unsaturated fatty acids. All these qualities have determined the application of pumpkin seeds to the food industry and medicine [5, 6].
The equilibrium moisture content of pumpkin seeds has been experimentally determined by the strain measurement method. This method is long and labour-consuming but it provides high accuracy measurements.

The method comprises the following: a certain amount of material has been placed in an exicator at a constant temperature (20°C) and relative humidity. The sample has been periodically weighed. Upon reaching a constant weight the equilibrium moisture content of the material has been determined. An analytical balance with accuracy of 0.0001 g has been used for determining the mass of the material. The equilibrium moisture content of the product has been determined by the weight method by drying the sample to constant mass in an atmospheric oven at 100 ± 2 °C.

The constant humidity of the air into each sealed vessel (exicator) has been maintained by means of saturated aqueous solutions of some salts, which have the ability to maintain a constant pressure of water vapour in the atmosphere above them. The relative humidity and the salts used in the experiment at a temperature of 20°C are shown in Table 1.

| Salts  | NaOH | LiCl | CH₃COOK | MgCl₂ | K₂CO₃ | NaBr | NaCl | Na₂SO₄ |
|--------|------|------|---------|-------|-------|------|------|--------|
| Φ, %   | 6.98 | 11.14| 23.1    | 32.1  | 43.9  | 58.7 | 75.4 | 86.9   |

Dependences of the $W_P = f(Φ)$ type (equation (1)) have been obtained from the experimental results, taken at 20°C. A standard statistical program Table Curve 2D v.5.01 has been used for determining the abovementioned dependences. Values of the equilibrium moisture content of pumpkin seeds for accurate values of relative humidity have been calculated from the resulting equations for sorption and desorption.

However, for dimensioning of the drying processes and systems, it is necessary to have a sorption (desorption respectively) isotherms for a sufficiently wide temperature range. For determination of the equilibrium moisture content at other temperatures (40, 60 and 80°C) the Pass and Slepchenko’s methods have been used [2]. These methods give good results for cereals and wood in the temperature range (-20°C ÷ 100°C). On the basis of the data received, analytical dependences have been deduced. The equilibrium moisture content of the product has been calculated using these equations for the same values of relative humidity.

3. Results and discussion

The results for the equilibrium moisture content of pumpkin seeds are presented in Table 2 and Table 3. The values at 20°C have been obtained experimentally, and those at 40, 60 and 80°C have been defined theoretically by the Pass and Slepchenko’s method.

Except in tabular form, analytical consideration of sorption and desorption isotherms is also interesting. Due to the large number of factors that affect the sorption process, the describing of the equilibrium isotherm with a single equation is not possible. Many empirical and semi-empirical equations valid in a certain range of relative humidity for specified products have been derived in practice. The equations of the BET (Brunauer, Emmett and Teller) or GAB (Guggenheim, Anderson and de Boer) type are the most commonly used [4]. These equations have a common disadvantage that except their theoretical basis, they contain constants which must be experimentally determined [1, 4].

The resulting analytical relationships describing the sorption-desorption curves have the following form:

$$W_P = a + bΦ + c_Φ^2 + d_Φ^3 + f_Φ^n$$

where: Φ - relative humidity of the air, %; $W_P$ - equilibrium moisture of pumpkin seeds, %; $a$, $b$, $c$, $d$ and $f$ are coefficients whose values are given in Table 4 and Table 5.

Correlation coefficients - $r^2$ and the average statistical error are presented in the same tables. The resulting equations are valid in the range $0 < Φ < 0.9$. 

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Table 2. Equilibrium moisture content of pumpkin seeds $W_p$, %, determined by sorption at different temperatures.

| $\phi$, % | Temperature, °C |
|----------|----------------|
|          | 20     | 40     | 60     | 80     |
| 10       | 2.76   | 2.10   | 1.73   | 1.53   |
| 20       | 4.46   | 3.82   | 3.19   | 2.87   |
| 30       | 5.51   | 4.90   | 4.19   | 3.78   |
| 40       | 6.25   | 5.66   | 4.98   | 4.51   |
| 50       | 7.00   | 6.41   | 5.83   | 5.30   |
| 60       | 8.08   | 7.47   | 6.97   | 6.40   |
| 70       | 9.82   | 9.17   | 8.65   | 8.07   |
| 80       | 12.54  | 11.82  | 11.13  | 10.56  |
| 90       | 16.57  | 15.75  | 14.66  | 14.12  |

Table 3. Equilibrium moisture content of pumpkin seeds $W_p$, %, determined by desorption at different temperatures.

| $\phi$, % | Temperature, °C |
|----------|----------------|
|          | 20     | 40     | 60     | 80     |
| 10       | 3.73   | 2.74   | 2.37   | 2.11   |
| 20       | 5.67   | 4.91   | 4.36   | 3.78   |
| 30       | 6.80   | 6.17   | 5.57   | 4.85   |
| 40       | 7.52   | 6.95   | 6.37   | 5.63   |
| 50       | 8.24   | 7.66   | 7.12   | 6.44   |
| 60       | 9.35   | 8.71   | 8.18   | 7.58   |
| 70       | 11.25  | 10.52  | 9.90   | 9.37   |
| 80       | 14.34  | 13.50  | 12.66  | 12.13  |
| 90       | 19.02  | 18.07  | 16.81  | 16.17  |

Table 4. Coefficients for the equation of sorption.

| Coefficients | Temperature, °C |
|--------------|----------------|
|              | 20     | 40     | 60     | 80     |
| $a$          | 0.090934154 | -0.59139928 | -0.42551847 | -0.50496383 |
| $b$          | 0.32581379 | 0.32799478 | 0.25914591 | 0.2460491 |
| $c$          | -0.0064648998 | -0.0064289349 | -0.0047628187 | -0.0046895179 |
| $d$          | 5.421925x10^{-5} | 5.3361224x10^{-5} | 4.1620998x10^{-5} | 4.1785683x10^{-5} |
| $f$          | -0.090763689 | 0.59396246 | 0.43397981 | 0.51179484 |
| $r^2$        | 0.9921   | 0.9993  | 0.9978  | 0.9964  |
| Fitt Std Err | 0.46595  | 0.15747 | 0.27083 | 0.33416 |
Table 5. Coefficients for the equation of desorption.

| Coefficients | Temperature, °C |
|--------------|-----------------|
|              | 20              | 40              | 60              | 80              |
| a            | 0.5819142       | -0.73260932     | -0.74871477     | -0.47772246     |
| b            | 0.38858797      | 0.42719159      | 0.38115402      | 0.31523576      |
| c            | -0.0080424875   | -0.0086413011   | -0.007489932    | -0.0061530981   |
| d            | 6.6682343x10⁻⁵  | 6.9072976x10⁻⁵  | 6.0195917x10⁻⁵  | 5.228519x10⁻⁵   |
| f            | -0.58189573     | 0.73631271      | 0.75153411      | 0.48464056      |
| r²           | 0.9941          | 0.9993          | 0.9986          | 0.9962          |
| Fitt Std Err | 0.44784         | 0.181184        | 0.26511         | 0.40997         |

The data from Tables 2 and 3 are presented graphically in Figures 1 and 2. As can be seen the increase in temperature leads to a shift of the equilibrium isotherms to the left in the entire temperature range. There is also a pronounced sorption hysteresis.

The isotherms have clearly depicted S-shaped character, which indicates the existence of three types of connection of moisture to the material - monomolecular adsorption, polymolecular adsorption and capillary condensation. The analysis of the character of the sorption and desorption curves shows that the adsorption bound moisture in the material is a minor portion (up to \( W_p = 2\% \) at 20°C) and decreases with increasing the temperature, which is testified by convex section of the curve in the direction of the X-axis [1]. This convex section decreases at high temperatures, which means that the major part of the moisture is related to the capillary and polymolecular adsorption.

![Figure 1. Sorption isotherms of pumpkin seeds at different temperatures.](image-url)
4. Conclusion

1. Experiments for determination of the equilibrium moisture content of pumpkin seeds at a temperature of 20°C have been conducted. The values of the equilibrium moisture content at higher temperatures - 40, 60 and 80°C have been recalculated by Pass and Slepechenko’s methods. The results are presented in tabular form - Table 2 and Table 3.

2. An analytical relationship (equation 1) for calculating the equilibrium humidity of pumpkin seeds for a range of relative humidity $0 < \varphi < 0.9$ and range of temperatures $t = 20 \div 80^\circ C$ has been obtained.

3. Sorption and desorption isotherms of pumpkin seeds at various temperatures have been presented in graphic form.

4. The results may be useful in determining the storage conditions and design of drying equipment and installations for the production of pumpkin seeds.

References

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