Equilibrium isotherms of red beetroots

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Abstract. The equilibrium moisture content of red beetroot has been studied and the corresponding sorption-desorption curves have been obtained at temperature 20°C. The strain measurement method has been used to establish the sorption curves. Analytical dependence describing the sorption and desorption curves have also been derived. Values of equilibrium moisture contents for temperatures higher than 20°C have been obtained by the Pass and Slepchenko's method. The results are presented in graphical and table form.

1 Introduction

Fresh beetroot (Beta vulgaris ssp. vulgaris var. vulgaris), is a root vegetable consumed worldwide due to the high content of biologically active compounds [1-8]. Beetroot is used in many ways: raw, thermally processed - boiled, canned or minimally processed, depending on the region [9]. Its juice [8, 10] and extracts are used in traditional medicine, food colouring and as additives in cosmetics. The high antioxidant and anti-inflammatory properties of red beet make it possible to use it in the treatment of many diseases. In recent years, the influence of betalains extracted from red beets for the prevention of cancer diseases has been actively researched [11-13]. Due to its high humidity, beetroot is perishable. For long-term storage, in order to guarantee the product's properties, it is dried and stored in atmospheric conditions [14-16]. The product is dried to an equilibrium moisture content, which depends on its composition, structure, pretreatment, etc., as well as on the conditions of its storage in the environment - temperature, pressure, relative humidity, etc. [17, 18].

The equilibrium moisture content is determined experimentally and equilibrium isotherms are constructed. They represent dependences of the equilibrium moisture content of the material on the relative humidity of the environment at a constant temperature [19, 20].

Knowledge of moisture equilibrium characteristics is the starting point in food engineering and industrial control in the development of food products and processes. Our literature search found no information for red beetroot sorption and desorption isotherms.

The aim of this study is to determine experimentally the equilibrium isotherms of red beetroot and to obtain dependences describing the isotherms at different temperatures. They will be used in determining the conditions for storage and sizing of drying plants.

2 Materials and methods

The study was conducted experimentally with red beetroot (Beta vulgaris ssp. vulgaris var. vulgaris) of the "Matador" variety.

The equilibrium moisture content of red beetroot has been experimentally determined by the strain measurement method. This method has been long and labour-consuming but it provides high accuracy measurements. A small amount of crushed material with a mass of 3 - 5 g is poured into pre-prepared weighing glasses. The glasses with the tested material are placed on a stand in special vessels (desiccators), at the bottom of which there are saturated solutions of appropriately selected salts. The desiccators maintain a constant relative humidity and temperature. The mass of the sample is monitored and weighed periodically. The equilibrium humidity of the product is determined by recording a constant mass at two consecutive weightings. The mass of the product was measured with a digital scale with an accuracy of 0.0001 g. The moisture content of the product at an equilibrium state is determined by the weighting method. For this purpose, the sample is dried in an atmospheric cupboard at a temperature of 100 + 2°C, until a constant mass is reached. A constant temperature of 20°C and a constant relative humidity were maintained in all samples of the experiment. To achieve a constant relative humidity in each desiccator were used saturated aqueous solutions of salts, having the ability to maintain a constant pressure of water vapor over themselves (Table 1).

Table 1. Aqueous solutions of salts used in the experiment and the relative humidity they maintain at a temperature of 20°C

Salts	φ, %	Salts	φ, %
NaOH	6.98	K_2CO_3	43.9
LiCl	11.14	NaBr	58.7
CH_3COOK	23.1	NaCl	75.4
$MgCl_2$	32.1	Na_2SO_4	86.9

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3 Results and discussion

The results for different temperatures are presented in Table 2 and Table 3. Those for 20°C are determined experimentally, but those for 40, 60 and 80°C have been obtained theoretically by the Pass and Slepchenko's method.

Table 2. Equilibrium moisture content of red beetroot W_P, % determined by sorption at different temperatures

φ, %	Temperature, °C			
	20	**40**	**60**	**80**
10	3.70	2.63	1.58	0.92
20	5.75	4.65	3.70	2.77
30	7.19	6.31	5.60	4.73
40	8.70	7.85	7.11	6.38
50	10.80	9.62	8.56	7.81
60	14.16	12.31	10.79	9.66
70	19.73	17.11	15.09	13.26
80	29.04	25.92	23.19	20.68
90	44.41	41.54	37.18	34.85

For easier use in practice sorption and desorption isotherms are also presented in graphical form. There are many proposed equations describing the isotherms in the literature [18, 20]. Perhaps the most commonly used are the equations of the BET (Brunauer, Emmett and Teller) or GAB (Guggenheim, Anderson and de Boer) [18, 20]. Their characteristic feature is that they contain constants that have been empirically established [21].

Table 3. Equilibrium moisture content of red beetroot W_P, % determined by desorption at different temperatures

φ, %	Temperature, °C			
	20	**40**	**60**	**80**
10	4.91	3.74	2.30	2.24
20	7.42	6.05	4.87	3.98
30	9.00	7.98	7.25	6.08
40	10.44	9.70	9.00	8.15
50	12.55	11.41	10.27	9.71
60	16.91	14.33	12.38	11.23
70	26.54	21.66	18.39	15.52
80	46.69	39.53	33.67	28.52
90	77.65	70.53	62.02	57.59

The equations describing the sorption-desorption curves have the following form:

$$W_\mathrm{p} = a + b\varphi + c\varphi^2 + d\varphi^3 + e\varphi^4 + f\varphi^5 \quad (1)$$

where:
φ - relative humidity of the air, %;
W_P - equilibrium moisture of red beetroot, %;
a, b, c, d, e and *f* are coefficients, given in Table 4 and Table 5.

Correlation coefficients - r^2 and the average statistical error are presented in the same tables. The validity of the equations is in the range $0 < \varphi < 0.9$. As can be seen from Fig. 1 and 2 for the considered temperature interval, the increase in temperature leads to a shift of the isotherms to the left. A pronounced sorption hysteresis is observed.

Table 4. Coefficients for the equation of sorption

Coefficients	Temperature, °C			
	20	**40**	**60**	**80**
a	0.0002097	-0.000741	-0.0004895	-0.0003216
b	50.0412	30.6807	9.0876	1.0336
$c.10^3$	-0.1603	-0.05495	0.09208	0.1018
$d.10^3$	0.3301	0.1135	-0.2772	-0.2105
$e.10^3$	-0.3423	-0.1787	0.2651	0.09343
$f.10^3$	0.1916	0.1571	-0.029487	0.07384
r^2	0.999	0.999	0.999	0.999
Fitt Std Err	0.00343	0.0031027	0.009601	0.002121

From the shape of the isotherms, it can be judged that the moisture in the material is connected in three ways: monomolecular adsorption, polymolecular adsorption and capillary condensation. The convex section of the curve in the direction of the X-axis shows that the adsorption bound moisture in the material is not more than 2 % at 20°C and it decreases with increasing the temperature [20]. Therefore, the capillary and polymolecular adsorption are the main mechanism of moisture retention.

Table 5. Coefficients for the equation of desorption

Coefficients	Temperature, °C			
	20	20	20	20
a	0.0876	0.0829	0.04995	0.0358
b	51.485	35.8782	11.338012	26.1235
$c.10^3$	-0.0552	-0.01677	0.1274	-0.0916
$d.10^3$	0.131	-0.0357	0.3464	0.4815
$e.10^3$	0.2641	-0.087109	0.18539	-1.006
f	-2.9487	0.228	0.1347	0.7073
r^2	0.999	0.999	0.999	0.999
Fitt Std Err	0.508	0.481	0.2889	0.205

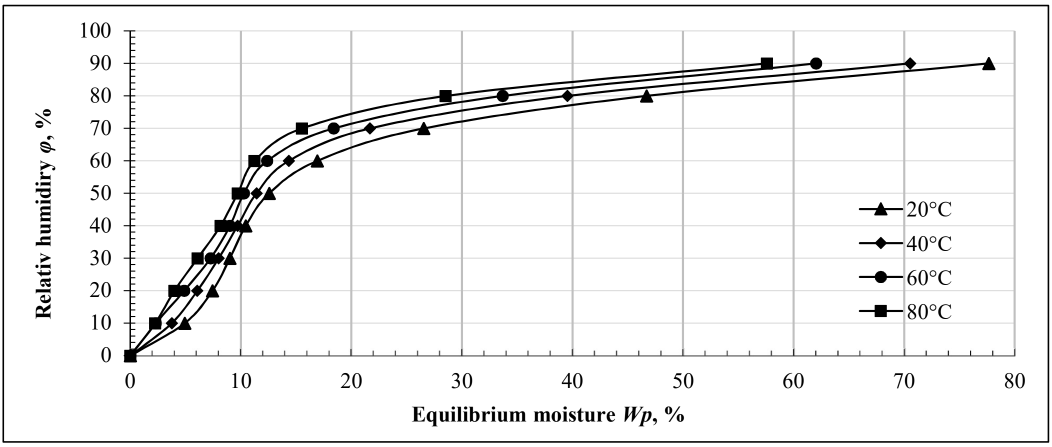

Fig. 1. Sorption isotherms of red beetroot at different temperatures

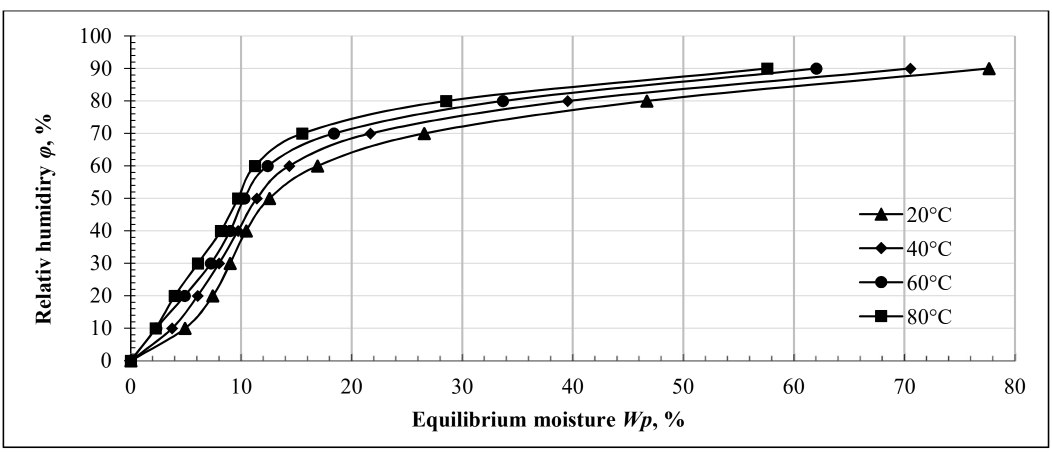

Fig. 2. Desorption isotherms of red beetroot at different temperatures

4 Conclusion

1. The equilibrium moisture content of red beets was determined experimentally for a temperature of 20°C. Its values for other temperatures (40, 60 and 80°C) was determined analytically by Pass and Slepchenko's methods (Table 2 and Table 3).

2. Based on the experimental results, an analytical dependence was derived for a range of relative humidity $0 < \varphi < 0.9$.

3. Sorption and desorption isotherms of red beetroot have been presented graphically.

4. The obtained results can be useful in determining the regime parameters for drying red beets and the storage conditions.

References

1. K. S. Sakhare, A. R. Sawate, R. B. Kshirsagar, A. T. Taur, IJCS. **7**, 283 (2019)
2. D. Masih, N. Singh, A. Singh, JPP. **8**, 162 (2019)
3. D. Babarykin, G. Smirnova, I. Pundinsh, S. Vasiljeva, G. Krumina, V. Agejchenko, JBM. **7**, 61 (2019)
4. P. Neha, S. K. Jain, N. K. Jain, H. K. Jain, H. K. Mittal, IJCS. **6**, 3190 (2018)
5. S. Straus, F. Bavec, M. Turinek, A. Slatnar, C. Rozman, M. Bavec, AJAR. **7**, 5653 (2012)
6. J. Vasconcellos, C. Conte jr., D. Silva, A. Paola Pierucci, V. Paschoalin, Th. S. Alvares, Food Sci. Biotechnol. **25**, 79 (2016)
7. J. Jastrebova, C. Witthöft, A. Grahn, U. Svensson, M. Jägerstad, HPLC determination of folates in raw and processed beetroots, Food Chem. **80**, 579 (2003)
8. A. Slavov, V. Karagyozov, P. Denev, M. Kratchanova, Ch. Kratchanov, Czech J. Food Sci. **31**, 139 (2013)
9. M. Paciulli, I. G. Medina-Meza, E. Chiavaro, G. V. Barbosa-Cánovas, Impact of thermal and high-pressure processing on quality parameters of beetroot (Beta vulgaris L.), LWT - Food Sci. Technol. **68**, 98 (2016)
10. P. C. Wootton-Beard, A. Moran, L. Ryan, Food Res. Int. **44**, 217 (2011)
11. L. Ceclu, Oana-Viorela Nistor, J. Nutr. Med. Diet. Care. **6**, 043 (2020)
12. J. F. Lechner, G. D. Stoner, Molecules. **24**, 1602 (2019)
13. T. Clifford, G. Howatson, D. J. West, E. J. Stevenson, Nutrients. **7**, 2801 (2015)
14. A. Figiel, J. Food Eng. **98**, 461 (2010)
15. O.-V. Nistor, L. Seremet, Food Chem. **236**, 59 (2017)
16. S. Malakar, M. Alam, V. K. Arora, Solar Energy. **233**, 246 (2022)
17. A. Ginzburg, *Fundamentals of the theory and technology of drying food products* (Food Industry, Moscow 1973) [in Russian]
18. M. Minchev, *Drying equipment*, (Academic Publishing House of UFT, Plovdiv 2012) [in Bulgarian]
19. N. Menkov, J. Food Eng. **44**, 205 (2000)
20. S. Nevenkin, *Drying and drying equipment*, (Engineering, Sofia 1993) [in Bulgarian]
21. N. Penov, T. Petrova, *Technology of dried fruits and vegetables,* (Academic Publishing House of UFT, Plovdiv 2013) [in Bulgarian]