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Modelling of the Desorption Characteristics of a Mixture of Linseed and Fruit Granules

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Abstract. A growing tendency in the production and in the application of ready mixtures, fully composed of dry components is observed in the last years. Their use does not require mixing, homogenizing and preservation of their components separately, which makes easier their application in the so-called craft bakeries, as well as in home conditions in the preparation of bread, pastry and confectionery. The desorption capacity of a ready mixture of golden linseed – 46%; brown linseed – 25%; plum granules – 9% and date palm granules – 8% - biological farming ingredients is examined in the present research. The research is conducted in three temperatures 10°C, 25°C and 40°C and eight water activities in the range of 0.11 to 0.85. The achievement of equilibrium moisture content is followed, a mathematical analysis of the results is done and the monolayer moisture content (MMC) of the examined product is calculated through Brunauer-Emmett-Teller (BET) model linearization. The received results indicate dependences which are proved in the years, namely that the temperature increase in constant water activity, leads to the reduction of the equilibrium moisture content. The sorption isotherms are of the characteristic type III for nutrients according to the Brunauer et al classification. According to the common suitability criteria – average relative error, standard deviation and residues distribution, two three parametrical modified models are recommended for the desorption isotherms description, as the Chung–Pfost model is the first suitable model and the Henderson model is the second one. The MMC calculated values of the ready mixture for the three temperatures with experimental points for water activity $a_w < 0.5$ are the following: 10°C – 4.37% d.m., 25°C – 3.54% d.m. and 40°C – 3.15% d.m.

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INTRODUCTION

The stress, the dynamic way of life, the timelessness of proper and healthy nourishment led the humanity to serious health problems. The situation made us stop and pay attention to our way of life and the food we consume. The different seeds, fruits and vegetables, fresh and dry, are the so-called natural nutrients with proved favorable influence on the human organism [1-2]. The linseed, the plums and the date palms are one of them.

The linseed is extremely rich of omega-3 fatty acids, lignans and fibre, for which it is already proved that they have a lot of potential favors for the health. It contains to 800 times more lignans than other plant nutrients. The lignans are plant compounds which have antioxidants and estrogen properties, as they both can help to reduce the risk of cancer disease. Another advantage of the seeds is their capacity to lower the cholesterol levels. In the research for people with high cholesterol, the consumption of 3 table spoons (30 grams) of powdered linseed daily for a period of three months, lowers the total cholesterol with 17%, and the "bad" LDL cholesterol with almost 20% [3-5]. In a research for people with diabetes it is established that the in-take of 1 table spoon (10 grams) of powdered linseed daily for a period of one month leads to 12% increase of the "good" HDL cholesterol and decrease of the blood sugar level with 8-20%. That effect of the blood sugar is due mostly of the content of the insoluble fibre in the linseed, which slows down the sugar secretion in the blood. Diabetes 2 is a main health problem of world importance [6-7].

Plums are rich in proteins, carbohydrates, useful fibre, organic acids, copper, calcium, sodium, phosphorus, magnesium, chromium, zinc, iodine, and a lot of vitamins - A, B1, B2, B6, PP, C and E. The Coumarin which is also part of their content, has the ability to protect the blood vessels from thrombi formation, help to cure thrombosis and expand the blood vessels. Plums have low glycemic index that is why they are a wonderful food for the suffering from diabetes type 2, because they help to regulate the blood sugar levels. They strengthen the immune system and protect from colds and infections. The content of magnesium helps the muscles development and supports the nervous system [8-9].

In the last several years the palm dates became popular in Bulgaria. We can define their specific caramel taste and viscosity as their distinguishing features and we use their sweetness as proper alternative of the sugar in the preparation of different types of cheesecake, row candies, muffins and other desserts. They ensure satisfying sweet alternative of the refined sugar, for which it is proved that its extreme consumption can increase the risk of diabetes type 2. The palm dates are invaluable source of calcium and phosphorus and their regular consumption is one of the ways with which we can increase the intake of those two minerals. They contain copper, magnesium, selenium and manganese, which are also important for the strong bones support and osteoporosis protection. The palm dates are rich in potassium and fibre, which stabilize the blood sugar levels and lower the blood pressure. The exotic fruits contain a large amount of antioxidants and their regular consumption can lower the risk of neurodegenerative diseases, oxidative stress and inflammation in the brain [10-12].

The rich literature reference indicates the exclusive properties of the three products on the human health. The fact that the linseed, the plums and the palm dates and respectively their combination is an alternative food for people suffering from diabetes type 2, is interesting for us. In the research and papers of the world scientific collectives' survey we did not find data of the modelling of the desorption characteristics of a mixture of the three components, which gave us basis for fulfillment of the present analysis, namely modelling of the desorption capacity of the product. The sorption characteristics supply the necessary information about the treatment conditions, preservation, package and transportation of the different nutrients [13].

MATERIALS AND METHODS

Raw Material

Bio linseed with fruit granules of plums and palm dates - purchased in Bulgaria by "Internet café-BG" ltd, packed by "Zoya bg Organic Shop".

Method

Sorption Characteristics Database

Modelling of the sorption characteristics for nutrients of biological origin is of extreme importance in the choice of the regimes of their treatment and preservation [14]. A main sorption characteristic for the nutrients is the equilibrium moisture content [15-18]. The correlation between the equilibrium moisture content (*M*) and the water activity a_w is described throughout experimentally built sorption isotherm for a precisely determined temperature (t) – $M = f(a_w,t)$. The time for reaching the equilibrium moisture content for the different nutrients is extremely different [19-20]. The moisture value corresponding to the monolayer moisture content (MMC) is a sorption characteristic which influence the stability of the product [21-22]. It is proved in the many researches, that bending down the product to a moisture corresponding to MMC, a preservation of its qualitative indexes is achieved [23- 24].

Preparation of the Sample

In 2002 *Al-Muhtaseb et al.*, classify the methods of experimental receipt of the sorption isotherms in three categories: gravimetrical, mano-metrical and higrothermical [13]. In the present study, the static gravimetrical method is used, accepted and standardized for nutrients [25]. The examined product – ready mixture of linseed of fruit granules of plums and date palms was preliminary hydrated for 10 days over distilled water ($H_2O_Δ$) with the purpose to examine the process of desorption. For the analysis are used aluminum weight pots in which samples with a mass of 1±0.01g are weighted. The samples are put in constant higrothermical conditions – hygrostats. There are used eight saturated solutions of salts in the hygrostats (LiCl, CH_3COOK, $MgCl_2$, K_2CO_3, Mg $(NO_3)_2$, NaBr, NaCl, KCl) with the purpose to maintain a constant relative moisture in the range of 11% to 85%. In the hygrostats with water activity over 50% crystals of thymol are placed, for the prevention of microbiological insemination of the product. The constant temperature of 10°C, 25°C and 40°C was maintained as the hygrostats were placed in thermostats. In the static method the equilibrium moisture content sample measure is accomplished after a stay in the conditions of constant temperature values and relative air moisture for a period of 20 days, time which is enough to reach the equilibrium according to many researches. The equilibrium moisture content (*M*, % to a dry mass) is determined by a drying method – for 24 h in 105°C by standard method [26].

Mathematical Modelling of the Data

There were used the modified three paramethrical models of Chung-Pfost, Halsey, Oswin and Henderson, proposed by the American Society of Agricultural Engineers - ASAE, for the ready mixture desorption isotherms modelling and description [27-28]. The correctly chosen and recommended valid models can be used for the prediction of the equilibrium moisture content reported under different conditions. Objective and common criteria of defining the validity of the model are the average relative error (P, %), the standard deviation (SEM) and the residues distribution [29-30].

A detailed description of the whole methodic of the sorption characteristics examination is made by Durakova et al., (2020) [31].

All the analyses are made in three times repeatability.

RESULTS AND DISCUSSION

The nutrient value and the physico-chemical indices of the ready mixture of golden linseed – 46%; brown linseed – 25%; plums granules – 9% and palm dates granules – 8% - ingredients of biological farming for a 100 g product is as follows: energy value - 1988kJ/480kcal; omega-3 fatty acids – 12 g; proteins - 19 g; carbohydrates - 19 g, of which sugars – 7.8 g; fats - 30 g, of which saturated – 2.8 g and monosaturated fatty acids – 4.1 g; fibre - 29 g and salt < 0,01 g.

For the examination of the desorption capacity of the ready mixture, the analyzed product is hydrated from 8.23% dry mass to moisture 16.45% dry mass. The equilibrium moistures content for temperatures 10°C, 25°C and 40°C in the eight different water activities are given in table 1.

TABLE 1. Equilibrium moisture content *M, %* d.m. in desorption for different temperatures *t (°C)* and water activities a_w

Sel	10°C			25°C			40°C		
	a_w	M^*	sd**	a_w	M^*	sd**	a_w	M^*	sd**
LiCl	0.113	3.51	0.20	0.113	2.11	0.12	0.112	1.45	0.05
CH_3COOK	**0.234**	**3.84**	**0.17**	**0.225**	**3.13**	**0.03**	**0.201**	**2.21**	**0.18**
$MgCl_2$	0.335	4.11	0.06	0.328	3.26	0.14	0.316	2.46	0.02
K_2CO_3	**0.431**	**6.06**	**0.12**	**0.432**	**4.65**	**0.18**	**0.432**	**3.37**	**0.12**
$MgNO_3$	0.574	7.34	0.09	0.529	5.55	0.14	0.484	4.75	0.08
NaBr	0.622	7.48	0.15	0.576	6.18	0.20	0.532	5.59	0.12
NaCl	0.757	10.64	0.17	0.753	9.49	0.12	0.747	8.98	0.13
KCl	0.868	14.04	0.18	0.843	12.95	0.14	0.823	12.04	0.18

* Average out of three repetitions, ** Average deviation of three repetitions

It is clear from the results analysis that the linseed and fruit granules ready mixture equilibrium moisture content is in the range between 1.45% and 14.04%. The established dependencies show that with the increase of temperature the value of the equilibrium moisture content lowers in the range between 1.63 d. m. and 2.69% d. m. The lowest percentage value is in water activity $a_w = 0.234$, and the highest in $a_w = 0.431$, for the rest water activities it is about and under 2% d. m. The dependency is observed in the whole range of the research [15-18].

On figure 1 there is a comparison of the received desorption isotherms for the conditions of the experiment.

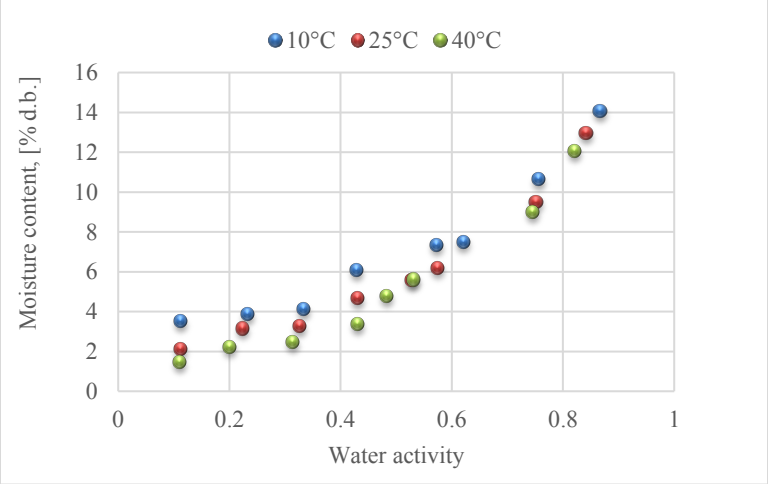

FIGURE 1. Desorption isotherms for eight different water activities and temperatures 10°C, 25°C and 40°C

The figure indicates that the isotherms are of type III of the Brunauer et al. classification. Hysteresis effect is available and statistically important in the experiment points for water activity 0.431 for the three temperatures [13, 18, 31]. The coefficients of the three parametrical models received after modelling and statistic treatment of the results and the relevant values of the commonly accepted criteria for estimation the models' validity, average relative error (*P*, %), standard deviation (*SEM*) and distribution of the residues are presented in tables 2 and figure 2.

TABLE. 2 Coefficients of the models (A, B, C), average relative error (*P*, %) and standard deviation (*SEM*) for the process desorption.

Model	A	B	C	*P*	*SEM*
Oswin	214.299	0.253	47.518	17.60	0.94
Halsey	2.255	-0.018	1.327	13.28	1.83
Henderson	0.0009	52.4088	1.3295	14.08	**0.92**
Chung-Pfost	6.129	-0.025	0.495	**10.96**	**0.69**

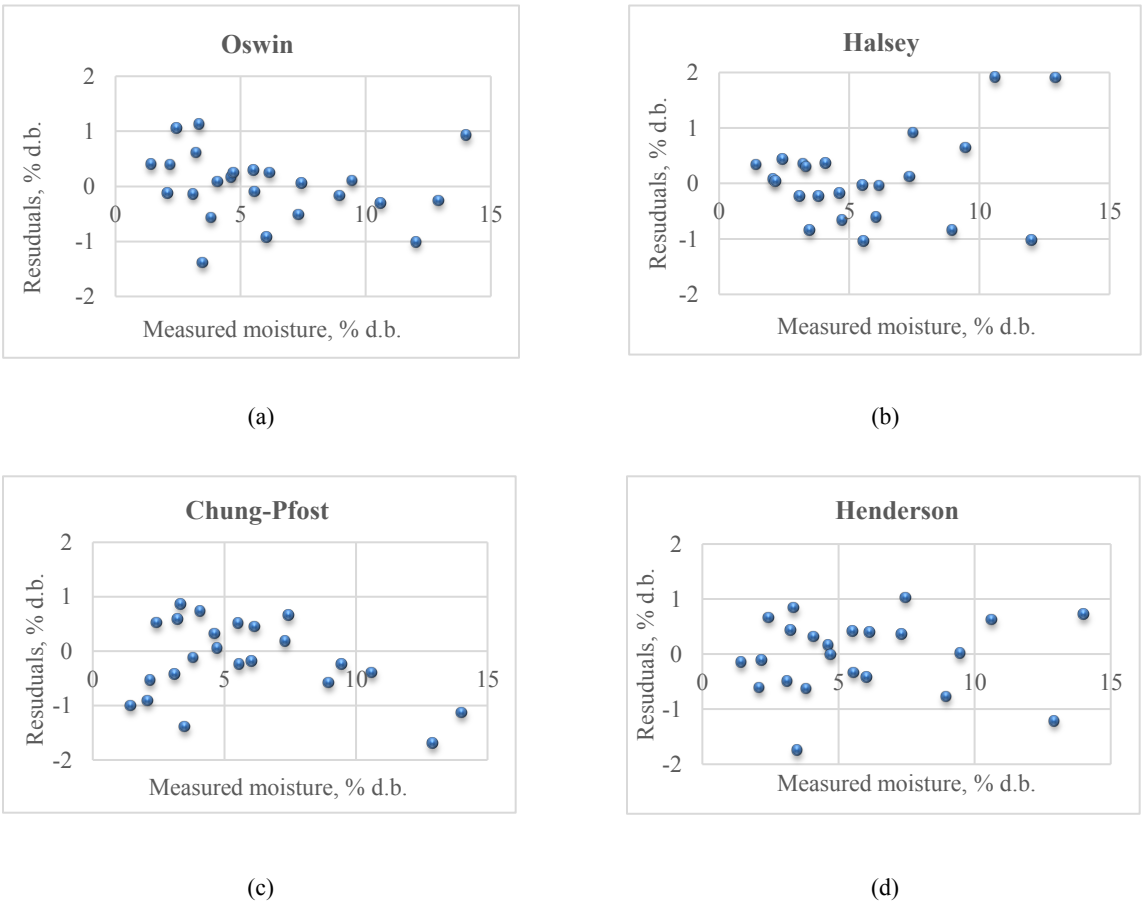

FIGURE 2. Distribution of the residues

Due to the indicated dependencies, according to the criteria of validity of the models, the lowest values of average relative error (*P*, %) – 10.96 and standard deviation (*SEM*) – 0.69 are received with the modified model of Chung-Pfost. Accidental distribution of the residues is observed in Henderson model, which is with relatively low value of standard deviation – 0.92. The received results give us the grounds to recommend two modified three parametrical models for sorption isotherms description, as the first valid model is the model of Chung-Pfost, and the second is the model of Henderson.

For monolayer moisture content (MMC) calculation the Brunauer-Emmett-Teller (BET) equation is indicated in linear type. The linearization is indicated on figure 3 with experimental data for $a_w < 0.5$ [23-24].

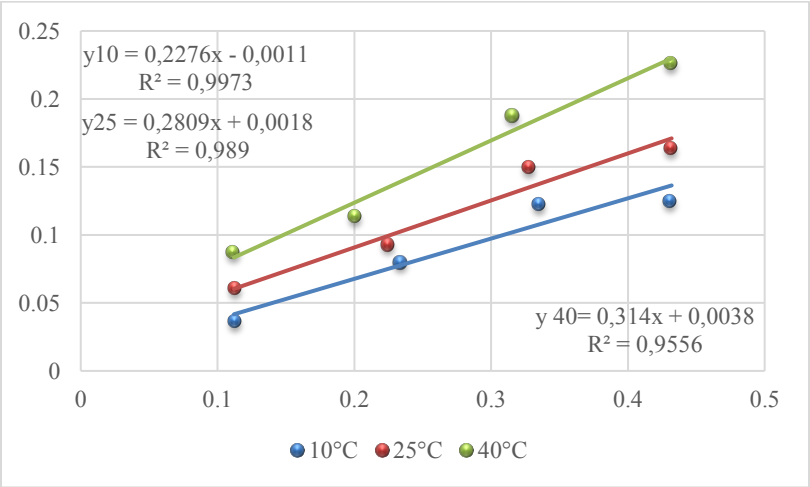

FIGURE 3. Linearization of the BET model for desorption

The values of the MMM for the three temperatures – 10ºC – 4.37% d. m.; 25ºC – 3.54% d. m. and 40ºC – 3.15% d. m. are calculated throughout the coefficients of the received linear equations. The results indicate that the temperature is inversely proportional of the moistures. With its increase the MMC from 10ºC to 40ºC decreases with 1.22% d. m..

CONCLUSIONS

The equilibrium moistures content of a ready mixture of linseed and fruit granules of plums and date palms are received for three temperatures 10°C, 25°C and 40°C and eight equilibrium moistures content in the range between 0.11 to 0.85. It is established that with the increase of temperature the value of the equilibrium moisture content lowers in the range of 1.63% d. m to 2.69% d. m. The desorption isotherms are of type III according to Brunauer et al classification. The hysteresis effect is available and statistically important in the experimental points for water activity 0.431 for the three temperatures. Two modified three parametrical models for the ready mixture sorption isotherms description are recommended according to the commonly accepted criteria for validity – average relative error, standard deviation and residues distribution, as the first valid model is the model of Chung-Pfost, and the second is the model of Henderson. The monolayer moisture content (MMC) of the ready mixture of linseed and fruit granules of plums and palm dates is calculated throughout Brunauer-Emmett-Teller model linearization for the three temperatures – 10°C – 4.37% d. m.; 25°C – 3.54% d. m. and 40°C – 3.15% d. m. with experimental points for water activity $a_w < 0.5$. The received results indicate that the temperature influences the MMC, and with its increase the values lower with about 1.22% d. m.

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REFERENCES

1. S. H. Nile and S. W. Park, *Nutrition* **30** (2), pp 134-144 (2014).
2. M. N. Shashirekha, S. E. Mallikarjuna and S. Rajarathnam, *Crit. Rev. Food Sci. Nutr.* **55** (10), pp 1324-1339 (2015).
3. M. Zuk, D. Richter, J. Matuła and J. Szopa, *Ind Crops Prod.* **75**, pp 165-177 (2015).
4. H. Chhillar, P. Chopra and M. A. Ashfaq, *Crit. Rev. Food Sci. Nutr.*, 1-23 (2020).

5. D. A. Abid, N. Mokhtari-soulimane, H. Merzouk and M. Narce, *Int. j. pharm. pharm. sci.* **8** (3), pp 194-200 (2016).
6. N. M. Shakuntala, M. Kammar, S. N. Vasudevan, S. A. Biradar and S. A. Rajeshwari, *J Progress Res Soc Sci* **11** (8), pp 5634-5638 (2016).
7. B. Kumar and R. N. Kewat, *J. Pharmacogn. Phytochem.* **10** (2), pp 207-210 (2021).
8. M. Stacewicz-Sapuntzakis, *Crit. Rev. Food Sci. Nutr.* **53** (12), pp 1277-1302 (2013).
9. F. A. Tomás-Barberán, D. Ruiz, D. Valero, D. Rivera, C. Obón, C. Sánchez-Roca and M. Gil, *Bioactives in fruit: Health benefits and functional foods*, chapter **7** pp 125-167 (2013).
10. J. F. Dayang, C. R. Reuben and F. Raji, *Int J Food Sci Nutr* **3** (6), 63 (2014).
11. M. D. W. I. Saryono and E. Rahmawati, *IJRAMR* **3** (7), pp 1630-1633 (2016).
12. M. U. Nasir, S. Hussain, S. Jabbar, F. Rashid, N. Khalid and A. Mehmood, *Sci. Lett* **3** (1), pp 17-22 (2015).
13. A. H. Al-Muhtaseb, W. A. M. McMinn and T. R. A. Magee, *Food Bioprod Process* **80** (2), pp 118-128 (2002).
14. S. Furmaniak, A. P. Terzyk, R. Gołembiewski, P. A. Gauden and L. Czepirski, *Food Res. Int.* **42** (8), pp 1203-1214 (2009).
15. M. Dupas-Langlet, J. Dupas, S. Samain, M. I. Giardiello, V. Meunier and L. Forny, *J. Food Eng.* **184**, pp 53-62 (2016).
16. K. Muzaffar and P. Kumar, *Powder Technol* **291**, pp 322-327 (2016).
17. B. Nurhadi and Y. H. Roos, *J. Food Eng.* **210**, pp 76-82 (2017).
18. T. W. Y. Tham, C. Wang, A. T. H. Yeoh and W. Zhou, *J. Food Eng.* **175** pp 117-126 (2016).
19. R. Kulchan, W. Boonsupthip and P. Suppakul, *J. Food Eng.* **100** (3), pp 461-467 (2010).
20. P. B. Staudt, I. C. Tessaro, L. D. F. Marczak, R. D. P. Soares and N. S. M. Cardozo, *J. Food Eng.* **118** (3), pp 247-255 (2013).
21. E. O. Timmermann, *Colloid Surf A Physicochem Eng Asp* **220** (1-3), pp 235-260 (2003).
22. J. Troller, *Water activity and food,* Elsevier (2012).
23. A. L. Decagon, *Decagon Devices*, Pullman, WA Google Scholar (2011)
24. S. Kaya and T. Kahyaoglu, *J. Food Eng.* **71** (2), pp 200-207 (2005).
25. W. Wolf, W. E. L. Spiess and G. Jung, *COST-Project 90 and 90 bis*, Properties of Water in Foods in Relation to Quality and Stability Martinus Nijhoff, Dordrech, pp 661-679 (1985).
26. AOAC, *Official Methods of Analysis 960.39*, 15th ed., Association of Official Analytical Washington DC (1990).
27. C. Igathinathane, A. Womac, S. Sokhansanj and L. Pordesimo, *Transactions of the ASAE* **48** (4), pp 1449-1460. (2005).
28. L. Zhang, D.-W. Sun and Z. Zhang, *Crit Rev Food Sci Nutr* **57** (5), pp 1052-1058 (2017).
29. C.-C. Chen and R. V. Morey, *Transactions of the ASAE* **32** (3), pp 983-0990 (1989).
30. C. J. Lomauro, A. S. Bakshi and T. P. Labuza*, LWT-Food Sci Technol* **18** (2), pp 118-124 (1985).
31. A. Durakova, In *E3S Web Conf.*, EDP Sciences **180**, p 03008 (2020).