Bulgarian Journal of Agricultural Science, 21 (Supplement 1) 2015, 27–30
Agricultural Academy

SORPTION CHARACTERISTICS OF EXTRUDED FEED FOR CARP STOCKING MATERIAL

N. TOSHKOV*, M. DUSHKOVA and A. SIMITCHIEV
University of Food Technologies, BG – 4003 Plovdiv, Bulgaria

Abstract

TOSHKOV, N., M. DUSHKOVA and A. SIMITCHIEV, 2015. Sorption characteristics of extruded feed for carp stocking material. *Bulg. J. Agric. Sci*., Supplement 1, 21: 27–30

Equilibrium sorption isotherms of extruded feed for carp stocking material in three variants were experimentally obtained. The study was conducted by the static gravimetric method at 20°C and water activities from 0.11 to 0.85. It was established that the isotherms have a typical S-shaped profile and there are no statistically significant differences in the sorption capacity for all variants. A suitable model was selected to describe the sorption isotherms. The monolayer moisture content of the extrudates was determined.

Key words: sorption characteristics, extrusion, carp stocking material.
Abbreviations: P – mean relative error; SEM – standard error of moisture; VMC – vitamin-mineral complex; BET – Brunauer-Emmett-Teler

Introduction

The fish is a major protein source from animal origin, which ensures the complete nutrition. The feed produced for successful breeding of freshwater fish is very important. The fishes with the highest economic importance in Bulgaria are the carp and the trout. Extrusion process is used to obtain more than 90% of the produced fish feed (Hardy and Barrows, 2002).

The challenge for the aquaculture industry is to identify economically viable and environmentally friendly alternatives to fish meal and fish oil, and the investigation of the process and product characteristics of the obtained extruded feeds (Gatlin III et al., 2007). Sunflower meal has found an application in the diet for fish because it is widely available on the market and its inclusion could diminish the diet costs (Sánchez-Lozano et al., 2007).

Moisture content of extrudates, as a hygroscopic material, greatly affects their quality and technological properties (Penov, 2000; Durakova, 2005).

Equilibrium isotherms of the food products show the relationship between the equilibrium moisture content and the water activity of the product at a certain temperature. Sorption isotherms of the material show the connection of the water with the hard skeleton.

For description of the sorption isotherms the literature offers a large number of empirical and theoretical models summarized in (Van der Berg and Bruin, 1981). Chen and Morey (1989) have concluded that there is no model to be considered universal. Usually, several models are used, such as using defined criteria the most suitable is selected. Criteria mostly used for evaluation of the models are mean relative error (P, $g.kg^{-1}$) and standard error of moisture (SEM).

A number of studies have shown that products with moisture content corresponding to the monolayer are stored for long periods without altering their properties (Bell and Labuza, 2000; Labuza et al., 1985).

The knowledge for the sorption characteristics of the extrudates (equilibrium and monolayer moisture content) permits to define the appropriate regimes for their storage and treatment.

The objectives of this study are: 1 – to obtain experimental equilibrium sorption isotherms of feed for carp stocking

**E-mail: nesho.t@abv.bg*

material, 2 – to compare the obtained sorption isotherms; 3 – to choose a suitable model describing the sorption isotherms, 4 – to define the monolayer moisture content and the water activity corresponding to this moisture.

Material and Methods

The objects of this study are extruded feeds for carp stocking material, made in three variants:

– Variant I – Control feed: fish meal, soybean meal, sunflower meal, wheat, corn, VMC (vitamin-mineral complex).

– Variant II – Experimental feed: plant protein component "Sunpro", soybean meal, sunflower meal, wheat, VMC.

– Variant III – Experimental feed: fish meal, plant protein component "Sunpro", soybean meal, sunflower meal, wheat, VMC.

The composition of variant II is balanced only on plant ingredients and the fish meal was replaced with "Sunpro-46", which is high protein plant feed with low cellulose content. It was made in Bulgaria on the basis of sunflower meal.

The nutritional value of the experimental feeds is shown in Table 1.

Extrusion is carried out on a laboratory single-screw extruder Brabender 20DN (Germany) under the following operation conditions: nozzle diameter 2.5 mm, compression ratio 2:1; temperatures in the first zone 100ºC, the second zone 110ºC and the third zone 120ºC. For variant I the screw speed was 150 min^{-1} and the feed rate – 60 min^{-1}, for variants II and III – 200 and 80 min^{-1} respectively. Different speeds were used to keep a stable extrusion of each variant with different composition.

The static gravimetric method recommended for food products was applied to obtain experimental equilibrium sorption isotherms of extrudates, (Bell and Labuza, 2000). Samples of 1 ± 0.05 g were weighed in weighing bottles. The weighing bottles were then put in hygrostats over saturated salt solutions (LiCL, CH_3COOK, $MgCL_2$, K_2CO_3, NaBr, NaCL, KCL), used to keep the water activities of the product in the range 0.11 to 0.85 (Greenspan, 1977). The hygrostats were kept in thermostats at 20 ± 0.1°C. Equilibrium was reached when three consecutive measurements showed a difference of less than 0.001 g (20 to 30 days). The moisture of the samples was determined by the oven method (24 h at 105°C). All measurements were done in triplicate.

Data analysis

For description of the sorption isotherms, two-parameter models of Chung – Pfost, Halsey, Oswin and Henderson, recommended in (ASAE, 1997), were used:

Chung-Pfost $$\ln(a_w) = -A\exp(-BM) \quad (1)$$

Halsey $$a_w = -\exp(-AM^B) \quad (2)$$

Oswin $$M = B\left[\left(\frac{a_w}{1-a_w}\right)\right]^C \quad (3)$$

Henderson $$\ln(1-a_w) = -AM^B, \quad (4)$$

where M is the moisture content, $g.kg^{-1}$ dry matter;
a_w – the water activity;
A, B, C – coefficients.

The monolayer moisture contents were calculated using the Brunauer-Emmett-Teler (BET) equation with the experimental data for water activities up to 0.4 (Bell and Labuza, 2000):

BET $$M = \frac{M_m C a_w}{(1-a_w)(1-a_w+Ca_w)}, \quad (5)$$

where M_m is the monolayer moisture content, $g.kg^{-1}$ dry matter,
C– coefficient.

Table 1

Nutriotional value of the experimental feed

Components, $g.kg^{-1}$	Var. I (E-1)	Var. II (E-2)	Var. III (E-3)
	Control (FM)	Experiment (Sunpro)	Experiment (FM+Sunpro)
Nutritional value, $g.kg^{-1}$			
Crude protein	346.7	340.3	343.7
Crude lipids	38.8	14.3	28.7
Crude fibers	45.6	75.7	56.3
Crude ash	55.0	52.2	55.4
NFE (nitrogen-free extract)	412.7	414.0	414.2
Digestible energy, Kcal.кg^{-1}	3164.4	2930	3066.7
Total energy, Kcal.кg^{-1}	4069.9	3806.1	3963.1

Results and Discussion

The experimental sorption isotherms are presented in Figure 1. The figure shows that the isotherms have an S-shape profile i.e. they are type II according to the Brunauer's classification (Bell and Labuza, 2000). Extrudates of variant I have the highest fat content (38.8 $g.kg^{-1}$), which are hydrophobic and therefore at low water activities, the equilibrium moisture content in this variant has the lowest values. At high water activity (above 0.5) the trend is reversed, extrudates of variant I have the highest equilibrium moisture content. An explanation for these results may be the different sorption hysteresis of the three variants. In our study, the hysteresis effect is not reported, the sorption isotherms in the range of water activity up to 0.5 are captured by desorption and then by adsorption. Taking into account the influence of sorption hysteresis will be a baseline in future research on the sorption properties of the three variants of feeds stocking material.

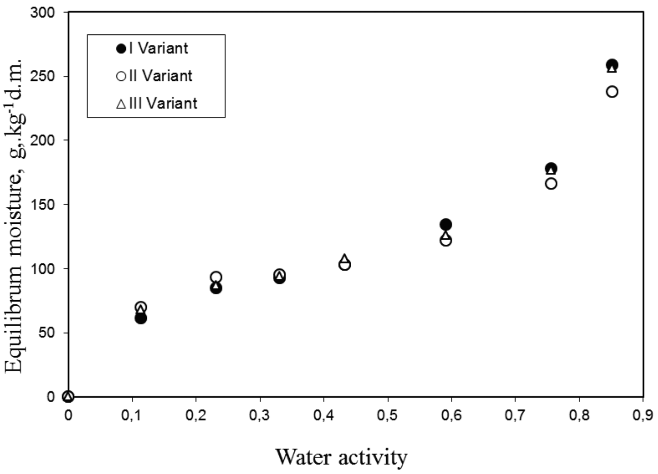

Fig. 1. Equilibrium isotherms of extrudates intended for feed of adoscelent carp

For description of the coefficients in the models from (1) to (4), they are transformed in linear (Menkov, 1999):

Chung-Pfost $\ln[-\ln(a_w)] = \ln A - BM$ (6)

Halsey $\ln[-\ln(a_w)] = \ln A - B\ln M$ (7)

Oswin $\ln M = \ln A + B[\ln(a_w/(1 - a_w))]$ (8)

Henderson $\ln[-\ln(1 - a_w)] = \ln A - B\ln M$ (9)

The coefficients in the linear equations were determined by the method of least squares. Coefficients, the mean relative error *P* and standard error of moisture *SEM* of the models from (1) to (4), for the three investigated variants respectively, are shown in Tables 2, 3 and 4.

Table 2

Coefficients in the models (*A, B*), mean relative error (*P*, $g.kg^{-1}$) and standard error of moisture (*SEM*) for extrudates obtained for variant I

Model	*A*	*B*	*P*	*SEM*
Chung-Pfost	3.835501	0.1321	125.6	1.8
Oswin	0.3632	12.35919	59.9	1.34
Halsey	72.7188	–1.8947	33.4	0.62
Henderson	0.004832	1.9298	104.9	2.06

Table 3

Coefficients in the models (*A, B*), mean relative error (*P* , $g.kg^{-1}$) and standard error (*SEM*) for extrudates obtained for variant II

Model	*A*	*B*	*P*	*SEM*
Chung-Pfost	4.836542	0.1541	128.1	1.89
Oswin	0.3003	12.26439	80	1.67
Halsey	167.8549	–2.2331	47.7	0.96
Henderson	0.002277	2.2342	123.5	2.15

Table 4

Coefficients in the models (*A, B*), mean relative error (*P*, $g.kg^{-1}$) and standard error (*SEM*) for extrudates obtained for variant III

Model	*A*	*B*	*P*	*SEM*
Chung-Pfost	4.071046	0.1362	133.8	2.03
Oswin	0.3339	12.50714	72.3	1.7
Halsey	107.2326	–2.039	34.9	0.87
Henderson	0.003507	2.0466	117.4	2.29

The results show that the Halsey model is most suitable to describe the sorption isotherms of the three investigated variants because the mean relative error is in the range of 30 to 50 $g.kg^{-1}$ and the standard error of moisture from 0.6 to 1.

Equation (5) can be transformed in linear for calculating the monolayer moisture content:

$$\frac{a_w}{M(1 - a_w)} = \frac{1}{MmC} + \frac{(C - 1)\, a_w}{MmC} \quad (10)$$

From the slope of the straight line, by the method of least squares, the coefficients of the linear equation (10) can be determined, and hence monolayer moisture content Mm and coefficient *C*. The linear dependence $a_w/[M(1 - a_w)] = f(a_w)$, with experimental data for variant I at $a_w < 0.40$ is shown in Figure 2. The data for the other two variants are processed in the same way, but the results are not shown in the graph.

The received monolayer moisture content and correlation coefficients for the three investigated variants are presented in Table 5. The results show that monolayer moisture content of the three variants has similar values (around 65 $g.kg^{-1}$).

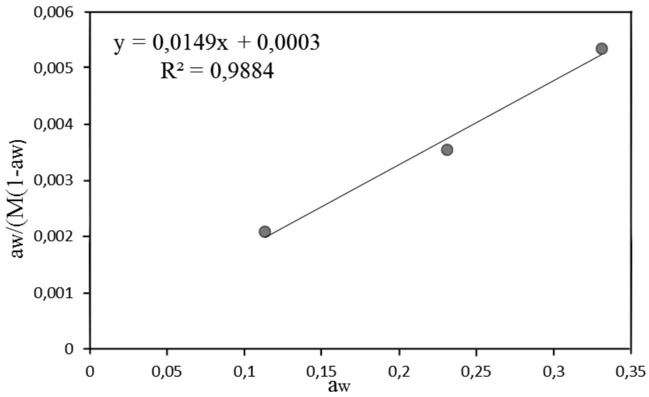

Fig. 2. Dependence $a_w/[M(1 - a_w)] = f(a_w)$ for extrudates from variant I

Table 5

Monolayer moistures (Mm), correlation coefficients (R^2) and water activities relevant to monolayer (a_{wm})

Extrudates	Mm	R^2	a_{wm}
Variant I	6.56	0.9884	0.123
Variant II	6.51	0.9789	–
Variant III	6.45	0.9934	0.112

The BET model permits to define the water activity of the product, which should be respected in the period of storage, for to be with monolayer moisture content:

$$a_{wm} = (\sqrt{C} - 1) / (C - 1) \quad (11)$$

The obtained values of a_{wm} are presented in Table 5. The results show that it is necessary to store the feeds at water activity 0.11–0.12 to obtain moisture content close to the monolayer.

Conclusion

Equilibrium sorption isotherms of extruded feeds for carp stocking material were experimentally obtained. Isotherms are type II according to the Brunauer's classification. The Halsey model is suitable for their description. There are no significant differences in monolayer moisture content of the three investigated variants. It is necessary to store the feeds at water activity 0.11 – 0.12 to obtain moisture content close to the monolayer.

Acknowledgments

This study was conducted with the kind support of Scientific Research Sector in the University of Food Technologies – Bulgaria.

References

ASAE, 1997. Standard D245.5. Moisture relationships of plant-based agricultural products, St. Joseph, Michigan.

Bell, L. N. and T. P. Labuza, 2000. Moisture Sorption: Practical Aspects of Isotherm Measurement and Use. *American Association of Cereal Chemists*, Inc.

Chen, C and R. V. Morey, 1989, Comparison of four EMC/ERH equations. *Transactions of ASAE*, **32**: 983–990.

Durakova, A., 2005. Sorption charactersistics of some flours for prophylactic and therapeutic feeding. Thesis, UFT, Plovdiv, Bulgaria (Bg).

Gatlin III, D. M., F. Barrows, P. Brown, K. Dabrowski, G. Gaylord, R. Hardy, E. Herman, G. Hu, A. Krogdahl, R. Nelson, K. Overturf, M. Rust, W. Sealey, D. Skonberg, E. Souza, D. Stone, R. Wilson and E. Wurtele, 2007. Expanding the utilization of sustainable plant products in aqua feeds: a review. *Agriculture Research*, **38**: 551–579.

Greenspan, L., 1977. Humidity fixed points of binary saturated aqueous solutions. *Journal of Research of the National Bureau of Standards*, **81A**: 89–96.

Hardy, R. W. and F. T. Barrows, 2002. Diet formulation and manufacture. In: Fish Nutrition, 3rd ed. (ed. By J. E. Halver and R. W. Hardy), Academic press, New York, USA, pp. 507–600.

Labuza, T. P., A. Kaanane and J. Y. Chen, 1985. Effect of temperature on the moisture sorption isotherms and water activity shift of two dehydrated foods. *Journal of Food Science*, **50:** 385–391.

Menkov, N., 1999. Sorption Equilibrium Moisture Content of the Seeds of Several Tobacco Varieties. *Journal of Agricultural Engineering Research,* **72:** 347–353.

Penov, N., 2000. Investigation of the extrusion of mixtures of spinach and semolina flour for instant food. Thesis, UFT, Plovdiv, Bulgaria (Bg).

Sánchez-Lozano, N. B., A. Tomás Vidal, S. Martínez-Llorens, S. Nogales Mérida, J. Espert Blanco, A. Moñino López, M. Pla Torres, M. Jover Cerdá, 2007. Growth and economic profit of gilthead sea bream (*Sparus aurata* L.) fed sunflower meal. *Aquaculture*, **272:** 528–534.

Van der Berg, C. and S. Bruin, 1981. Water activity and its estimation in food systems: theoretical aspects. In: Rockland, L. B. and Stewart, G. F. (Eds.). Water Activity: Influences on Food Quality. *Academic Press*, London, pp. 189–200.