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# SORPTION PROPERTIES OF SELECTED POWDERED INSTANT PLANT BEVERAGES

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Abstract. The objective of this study was to evaluate sorption properties, to characterise selected physicochemical properties, and to conduct instrumental colour analysis during storage of four instant plant beverages purchased on the Czech market. The evaluation was conducted for four powdered instant plant beverages: oat (I), buckwheat (II), rice (III), and corn (IV) ones. The sorption properties of the investigated products were analysed with the static method by determining isotherms of water vapour sorption. The scope of the study included water activity in the range from 0.07 to 0.98 (25°C). The moisture equilibrium of the system settled within 45 days. Based on the initial weight of the product and changes in water content, equilibrium contents of water were computed and water vapour sorption isotherms were plotted. BET equation in water activity range of $0.07 \leq a_w \leq 0.33$ was used for mathematical interpretation of the course of water vapour sorption isotherms. Applicability of the BET model for the description of plotted isotherms was evaluated based on values of determination coefficient ($R^2$) and standard error of estimation (FitStdErr) that were determined with the use of Jandel-Table Curve 2D v 5.01 software. The evaluation of physicochemical properties of the analysed instant powdered products was carried out based on the assessment of granulometric composition, loose and tapped bulk density, Hausner ratio (HR), and Carr index ($I_{Carr}$). Colour parameters $L^*$, $a^*$, and $b^*$ were determined in the international CIE system using a Konica-Minolta CR 400 colorimeter for standard observer 2º and illuminant D 65. The conducted analyses demonstrated that differences in the sorption as well as physicochemical properties of the investigated instant plant beverages were determined, most of all, by the heterogeneous raw material composition of the analysed products.

Keywords: monolayer capacity, surface area, loose and tapped density, Hausner ratio, Carr's index

## LIST OF SYMBOLS

$m$ – mass of the empty cell (g),
$m_1$ – mass of the cell with the sample before drying (g),

$m_2$ – mass of the cell with the sample after drying (g).
$a_w$ – water activity (-),
$a$ – adsorption (g $g^{-1}$),
$a_{sp}$ – specific surface of sorption (m$^2$ $g^{-1}$),
$N$ – Avogadro number ($6.023 \cdot 10^{23}$ molecules·$mol^{-1}$),
$M$ – water molecular weight (18 g $mol^{-1}$),
$V_m$ – maximal adsorption size corresponding to total surface coverage with a monomolecular adsorbate layer (monolayer capacity), (g $g^{-1}$),
$\rho_L$ – loose bulk density (g $cm^{-3}$),
$\rho_T$ – tapped bulk density (g $cm^{-3}$).

## INTRODUCTION

Properties of granular materials are determined by many interactions occurring between properties of a single particle and of particle agglomerates and their structure. Each of these factors depends on process parameters a given food powder was produced in, and on conditions of its storage. Of special significance in this respect are, among others, humidity and temperature of environment and pressure of a particle agglomerate (Domian and Milczarski 2003, Szulc *et al.* 2012).

The diversity of instant food products of plant origin produced on the European market points to the need of enriching information on their physicochemical properties and on their stability influenced by the presence and state of water.

Powdered beverages produced from natural raw materials are an alternative to cow's milk substitute. Instant plant products are an example of gluten-free, lactose-free products used to prepare hot or cold milk beverages, soups, sauces or used as an additive to coffee. In view of the above, the aim of this study was to evaluate sorption properties and to characterise selected physicochemical properties, including instrumental evaluation of colour, during storage of four plant instant powders purchased on the Czech market.

## MATERIALS AND METHODS

Sorption properties were analysed in four powdered plant beverages: oat beverage (I), buckwheat beverage (II), rice beverage (III), and corn beverage (IV). The analysed products, imported from the Czech market, were purchased in one of the bio-shops in the city of Gdynia, Poland. The products were stored in original packages in a dry and cool place (following recommendations of producers: ASP CZECH company and Matador company, indicated on product labels). The experimental part of the study was conducted at the laboratory of the Department of Hotel and Tourism Management, Maritime Academy in Gdynia.

Information on the chemical composition of the analysed plant beverage powders originated directly from the unit packages and is presented in Table 1.

**Table 1.** Chemical composition of tested products declared by the producer on the wrapping

| Nutritional information | Product I | Product II | Product III | Product IV |
|---|---|---|---|---|
| | Nutritive value per 100 g of powder | Nutritive value per 100 g of powder | Nutritive value per 100 g of powder | Nutritive value per 100 g of powder |
| Energetic value (kJ kcal$^{-1}$) | 2101/502 | 2074/494 | 2022/482 | 2194/524 |
| Protein (g) | 2.8 | 2.7 | 2.6 | 0.3 |
| Carbohydrates (g) | 66.0 | 68.8 | 70.0 | 70.0 |
| Fat (g) | 25.0 | 23.2 | 21.3 | 27.0 |

Source: Own correlation.

### Analytical methods

The evaluation of sorption and physicochemical properties was conduced based on determinations and comparisons of selected parameters, each made in three replications.

### Determination of water content

Water content was determined by drying a sample of app. 2 g (weighed with accuracy to 0.0001 g) in earlier dried and weighed weighing dishes, at a temperature of 70$^{o}$C for 24 h. Then, the pre-dried samples were dried in $P_2O_5$ for 7 days (Krełowska-Kułas 1993). Afterwards, the closed dishes with the samples were weighed on an analytical scales. The water content ($X_1$) was calculated in grams per 100 g of dry matter, from the following equation:

$$X_1 = \frac{m_1 - m_2}{m_2 - m} \cdot 100 \tag{1}$$

where: $m$ – mass of the empty cell (g), $m_1$ – mass of the cell with the sample before drying (g), $m_2$ – mass of the cell with the sample after drying (g).

### Determination of water activity

Water activity was determined in an AquaLab apparatus, with accuracy to ±0.003 (Series 3 model TE, by Decagon Devices, USA) at a temperature of 25±1$^{o}$C.

**Determination of sorption isotherms**

Sorption isotherms of the analysed products were determined with the static method (Świtka 1992, Tyszkiewicz 1987, Peng *et al.* 2007). The samples pre-dried over $P_2O_5$, were fixed in dessicators containing hygroscopic factors (saturated solutions of salt). The range of constant relative humidity covered water activity of $0.07<a_w<0.98$. For each area of water activity, 3 parallel samples of the analysed products were weighed in 2-g portions (with accuracy to 0.0001 g). The samples were stored at a temperature of 25±1ºC, for 45 days. Hygrostats with water activity exceeding 0.63 contained crystalline thymol in order to protect the examined product against unfavourable microbiological changes. On the basis of the initial weight of the product and changes in water content, the equilibrium water content was calculated and adsorption isotherms were plotted (Palich *et al.* 2004).

**Sorption properties based on the BET model**

The isotherms obtained empirically constituted the basis for elaborating the characteristics of sorption properties with the use of the Brunauer, Emmet and Teller equation (BET equation) (2) (Ościk 1979, Paderewski 1999):

$$a = \frac{\nu_m c a_w}{(1-a_w)[1+(c-1)a_w]} \tag{2}$$

where: $a$ – adsorption (g $g^{-1}$), $\nu_m$ – maximal adsorption size corresponding to total surface coverage with a monomolecular adsorbate layer (monolayer capacity) (g $g^{-1}$), $c$ – constant, related in an exponential way with the difference between adsorption heat on the first and following layers, accepted as stable and equal to the condensation heat, $a_w$ – water activity (-).

Results achieved in respect of sorption properties were analysed with the computer software Jandel-Table Curve 2D v 5.01., which enabled determination of such parameters of the sorption process as: capacity of the monomolecular layer and energetic constant.

The fitting of empirical data to the BET equation was characterised based on determination coefficient ($R^2$) and standard error of estimation (FitStdErr).

On the basis of water content estimated in the monolayer adsorbed at a temperature lower than the boiling temperature and the so-called "water cross-section", the specific surface area of adsorbent was calculated according to the equation (Paderewski 1999):

$$a_{sp} = \omega \frac{V_m}{M} N \tag{3}$$

where: $a_{sp}$ – specific surface of sorption ($m^2 g^{-1}$), $N$ – Avogadro number ($6.023 \cdot 10^{23}$ molecules·mol$^{-1}$), $M$ – water molecular weight (18 g mol$^{-1}$), $\omega$ – water settling surface ($1.05 \cdot 10^{-19} \cdot m^2$ molecules$^{-1}$).

**Determination of granulometric composition**

The granulometric composition of the analysed plant beverages was determined using the sieve method on a set of sieves with mesh size of $0.2 \cdot 10^{-3}$ m, $0.43 \cdot 10^{-3}$ m, $0.6 \cdot 10^{-3}$ m, $0.8 \cdot 10^{-3}$ m, and $1.02 \cdot 10^{-3}$ m. The product was sieved on a laboratory shaker for 10 minutes. Product bulk obtained on each sieve was weighed and the result was converted into percentage content of particular fractions in the total mass of the product.

**Determination of loose and tapped bulk density**

Determination was carried out accordingly to the Polish Standard PN-ISO 8460-1999. The Hausner ratio (HR) was computed as the ratio of tapped bulk density $\rho_t$ to loose bulk density $\rho_l$, whereas the Carr's index was determined from formula 4:

$$I_{Carr} = \frac{(\rho_T - \rho_L)}{\rho_T} \cdot 100 \tag{4}$$

**Colour analysis**

Colour parameters $L^*$, $a^*$, and $b^*$ were determined in the international CIE system, with the use of a Konica-Minolta CR 400 colorimeter, at standard observer 2° and illuminant D 65. Colour measurements were carried out in a measuring pan made of optic glass, with a diameter of 34 mm. In the applied measuring system, L* denotes brightness which is a spatial vector, whereas a* and b* are coordinates of trichromacy. Positive values of a* correspond to red colour, and negative a* value to green colour, whereas positive b* values to yellow colour and negative b* values to blue colour. Colour measurements were conducted in material collected directly from the packages and in the material stored for 45 days under conditions of constant relative humidity at $0.07 \leq a_w \leq 0.98$ (Tomaszewska and Neryng 2007).

## RESULTS

The evaluation of the chemical composition declared by the Czech producers on the packages of the analysed powdered plant preparations demonstrated that the corn powder IV was characterised by the highest calorific value and contents of fat and carbohydrates, and by the lowest content of protein compared to the other analysed powdered instant plant beverages, i.e. oat (I), buckwheat (II) and rice (III) beverages (Tab. 1).

The study involved also determinations of water content and water activity in the powdered plant products. Food powders are included amongst the assortment of food products characterised by a low initial content and activity of water, in a water activity range of $a_w$ = 0.15-0.40. Simultaneously, they exhibit high hygroscopicity and they easily absorb water from the environment, which determines their quality and stability (Kowalska *et al.* 2011). The evaluation of the analysed products demonstrated the highest water content and activity for the oat beverage I (Tab. 2), whereas the lowest water content and activity for the buckwheat beverage II (Tab. 2). Based on the comparative analysis of study results, it was found that the products of the ASP CZECH company (plant beverages I and IV) were characterised by higher values of the evaluated parameters, i.e. content and activity of water (Tab. 2.). In the analysed products, the content and activity of water were, probably, determined by the resultant of water volume and the degree of its binding with product matrix, as well as with the technological process applied by particular producers.

**Table 2.** Water content and water activity of investigated products

| Product | Moisture content (g (100 g d.m.)$^{-1}$) ± SD | Water activity (–) ± SD |
|---|---|---|
| I | 4.78 ±0.03 | 0.291±0.003 |
| II | 1.89±0.06 | 0.178±0.002 |
| III | 2.37±0.02 | 0.212±0.016 |
| IV | 4.50±0.03 | 0.252±0.010 |

SD – standard deviation, Source: Own correlation.

The sorption properties of the analysed plant beverages were characterised based on the course of sorption isotherms (Fig. 1). The plotted isotherms demonstrated the physical character of the sorption process on porous bodies (Erbas *et al.* 2005). This process resulted in the shape of curves typical of type II isotherms. The sigmoidal sorption curves pointed to the phenomenon of the formation of multi-molecular water layers on the surface of particles of the investigated plant preparation powders.

The sorption of water vapour by the analysed plant powders was increasing along with an increase of $a_w$. The phenomenon of water vapour sorption from the environment was, probably, determined by the presence of high-molecular substances in the examined plant beverage powders which, by being rich in polar sites (–OH groups), enable considerable sorption of water vapour.

The preliminary evaluation of sorption properties was conducted by comparing the reciprocal position of water vapour sorption isotherms. At water activity of $a_w$ = 0.07-0.75, the highest sorption capacity was determined for the oat beverage I, whereas above $a_w$ = 0.75 a higher sorption capacity was revealed by product IV – corn beverage (Fig. 1). Depending on the type of product, its components, affinity to water and active surface, the shape and position of water vapour sorption isotherm may be diversified. It the analysed case, it may be assumed that the shape and position of sorption isotherms resulted from differences in the chemical composition of the analysed plant preparations and technologies applied. Once $a_w$ = 0.75 was exceeded, the effect of humidity sorption became especially apparent. It may be speculated that above this $a_w$ level, the phenomenon of capillary condensation occurred in the analysed samples as a result of the exceeded level of critical humidity that determines the loss of stability by the product. This was especially tangible in the evaluation of sorption capacity of beverages II and III, i.e. the buckwheat and the rice ones. At $a_w$ = 0.07-0.75, a higher sorption capacity was revealed by the rice beverage (III), whereas above $a_w$ = 0.75, which is in a water activity range of $a_w$ = 0.85-0.98, a higher sorption capacity was demonstrated by the buckwheat beverage (II).

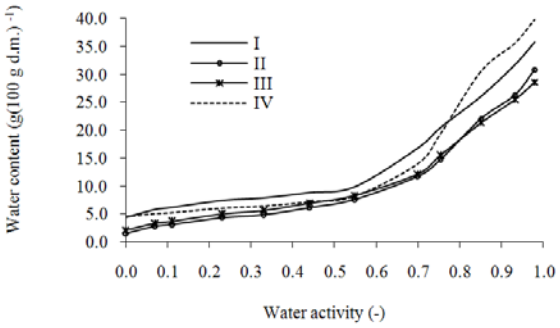


**Fig. 1.** Adsorption isotherms of products I, II, III and IV at temperature of 25ºC

Based on empirical data (water activity range of $a_w$ = 0.07-0.33), BET equation was determined by assaying the degree of its fitting and $V_m$ and $c$ parameters. Results obtained are presented in Table 3.

The capacity of monolayer indicates the volume of water adsorbed by the specified active sites of the matrix, and is claimed to be the optimal value at which food remains stable. Results achieved in the study demonstrated that the highest monolayer capacity (5.34 g (100 g d.m.)$^{-1}$) was found for the oat beverage (I), and that water filling the monolayer was characterised by the lowest activity ($a_w$ = 0.194). Taking into account the differences in the chemical composition of the analysed products, it may be speculated that the main cause of the high monolayer capacity in product I was a relatively high content of hydrophilic components, including proteins as well as starch (Tab. 1). Water activity corresponding to the monolayer attained the lowest value in product I. Considering the significant capacity of the monolayer of product I – oat beverage, it may be presumed that during storage changes will proceed in this product with a lesser intensity than in the other plant beverages.

**Table 3.** The BET equation parameters

| Product | $V_m$ | $c$ | $a_w$ | $R^2$ | FitStdErr | Specific surface of sorption ($m^2 g^{-1}$) |
|---|---|---|---|---|---|---|
| I | 5.34 | 57.67 | 0.194 | 0.94 | 0.301 | 187.57 |
| II | 3.45 | 37.26 | 0.231 | 0.99 | 0.145 | 121.31 |
| III | 3.99 | 48.48 | 0.218 | 0.99 | 0.155 | 140.23 |
| IV | 4.25 | 51.64 | 0.214 | 0.71 | 0.423 | 149.29 |

where: $R^2$ – determination coefficient; FitStdErr – standard error, Source: Own correlation.

Strong adsorbent-adsorbate interactions, exothermal in character, contribute to changes in the c value. The enthalpy value of the physical adsorption process reaches ca. 20 kJ mol$^{-1}$. The enthalpy of chemisorption is significantly higher and accounts for ca. 200 kJ mol$^{-1}$ (Atkins 2003).

Based on the capacity of monolayer $V_m$, the specific surface of sorption was calculated. Results obtained (Tab. 3) demonstrated that out of the plant powders examined, the greatest specific surface was determined for the oat beverage (I).

The granulometric composition of food powders has a great impact on their stability, because the extent of water sorption may depend on the structural properties of food (Nowak and Krzywoszyński 2007, Ocieczek 2007). The granulometric composition of material is linked with particle distribution and indicates mass contribution of particular fractions in the total mass of the powder. The evaluation of the granulometric composition of the investigated powdered plant beverages demonstrated various contents of particular fractions in

the products (Fig. 2). For the plant beverage I, the size of majority of particles fitted within the range of f < 0.2 mm (63.16%) and 0.2<f<0.43 (34.08%). A similar distribution of particle size was obtained for products II and IV, where respectively ca. 71.93% and as much as 90.77% of the fractions corresponded to particle size of f < 0.2. The evaluation of the granulometric composition showed also that product III – rice beverage, was characterised by a high heterogeneity that could, probably, affect the low sorption capacity of this product (Figs. 1-2).

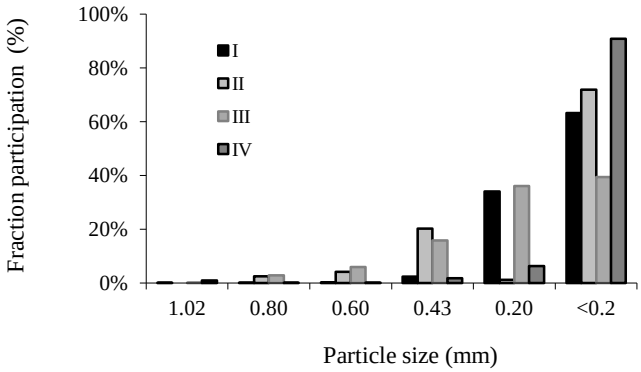


**Fig. 2.** Granulometric distribution of studied products I, II, III and IV (f (mm))

Another evaluated physicochemical parameter was the loose and tapped bulk density. The bulk density determines the ratio of particles mass to their volume together with free compartments. This parameter constitutes a significant indicator characterising the degree of filling of apparatuses and packages with loose materials, and is determined by the packing, size, shape and arrangement of particles (Domian *et al.* 2005). Values of the loose and tapped bulk density and these of the Hausner ratio (HR) and Carr's index ($I_{Carr}$) are presented in Table 4. The conducted evaluation showed that product III was characterised by the highest loose bulk density out of all investigated products. This could have been due to greater heterogeneity of the product. In turn, product I achieved the highest value of tapped bulk density amongst all analysed powdered plant beverages.

The loose and tapped bulk density is related to the Hausner ratio (HR) that determines the ratio of tapped bulk density $\rho_T$ to loose bulk density $\rho_L$. The HR constitutes one of the indicators of powder flowability. The powder having HR higher than 1.4 exhibits characteristics of a homogenous powder, whereas that

with HR values lower than 1.25 is characterised by good flowability (Domian and Poszytek 2004, Hausner 1967). In the conducted study, based on the evaluation of the HR, it was noted that the powdered plant preparations II, III, and IV were characterised by good flowability. The lowest HR value, and thus the best flowability, was reported for the rice beverage (III) (Tab. 4). Only for the oat beverage (I) was the HR value higher than 1.4, and thereby the product demonstrated all properties of a homogenous powder. A higher value of the Hausner ratio may indicate greater homogeneity of powder that is, probably, caused by intermolecular interactions, consequently leading to agglomeration (caking). Product I (oat beverage) was, therefore relatively homogenous, which could have been due to the higher water content in this powder, because water is responsible for the transition of particles with amorphous structure from the glassy state into the gummy state, which is accompanied by the caking of these particles, which, in turn, limits powders flowability (Ocieczek and Ruszkowska 2012).

The loose and tapped bulk density is related to another indicator of flowability – Carr's index $I_{Carr}$ (Szulc and Lenart 2007, Szulc et al. 2012). An $I_{Carr}$ value below 15% is typical of powders with a very good flowability, whereas $I_{Carr}$ values in the range of 18% $I_{Carr}$ < 25% are typical of good flowability, and these in the range of 20% $I_{Carr}$ <35% indicate powders with poor flowability (poor flow properties) (Domian and Poszytek 2004, Hausner 1967). Based on the obtained values of Carr index (Tab. 4), it was concluded that the analysed rice beverage (III) demonstrated very good flowability, whereas buckwheat beverage (II) and corn beverage (IV) were characterised by good flowability.

**Table 4**. Density characteristics of the products

| Item | Test feature | Measure | I | II | III | IV |
|---|---|---|---|---|---|---|
| 1. | $\rho_L$ (g cm$^{-3}$) | mean value | 0.47 | 0.52 | **0.54** | 0.48 |
| | | coefficient of variation | 0.02 | 0.01 | 0.01 | 0.02 |
| 2. | $\rho_T$ (g cm$^{-3}$) | mean value | **0.67** | 0.63 | 0.63 | 0.60 |
| | | coefficient of variation | 0.01 | 0.01 | 0.02 | 0.01 |
| 3. | HR (–) | mean value | **1.43** | 1.21 | 1.17 | 1.24 |
| | | coefficient of variation | 0.02 | 0.02 | 0.03 | 0.03 |
| 4. | $I_{Carr}$ (%) | mean value | **29.80** | 17.20 | 14.30 | 19.30 |
| | | coefficient of variation | 0.03 | 0.07 | 0.16 | 0.10 |

Source: Own correlation.

**Table 5.** System CIELab of colour scale

| The CIELab system parameters | Water activity $a_w$ | I | II | III | IV |
|---|---|---|---|---|---|
| L* | before storage | 91.31 | 89.81 | 90.52 | 94.91 |
| | 0.07 | 91.82 | 87.83 | 91.09 | 93.18 |
| | 0.11 | 92.28 | 88.60 | 90.62 | 93.96 |
| | 0.22 | 92.14 | 88.80 | 91.65 | 94.40 |
| | 0.33 | 91.21 | 89.20 | 92.10 | 94.95 |
| | 0.44 | 91.76 | 87.84 | 91.06 | 92.82 |
| | 0.53 | 89.10 | 85.25 | 89.72 | 88.53 |
| | 0.69 | 61.23 | 66.14 | 72.70 | 71.97 |
| | 0.75 | 51.62 | 58.09 | 68.03 | 67.25 |
| | 0.84 | 46.21 | 46.19 | 54.31 | 40.91 |
| | 0.92 | 56.45 | 37.16 | 37.10 | 52.62 |
| | 0.98 | 49.33 | 31.34 | 36.15 | 58.43 |
| a* | before storage | –0.25 | –0.66 | –0.91 | –0.47 |
| | 0.07 | 0.02 | –0.03 | –1.56 | –0.97 |
| | 0.11 | 0.07 | –0.60 | –1.45 | –1.31 |
| | 0.22 | –0.51 | –0.60 | –1.37 | –1.18 |
| | 0.33 | –0.53 | –0.61 | –1.37 | –1.22 |
| | 0.44 | –0.58 | –0.54 | –1.37 | –1.19 |
| | 0.53 | 0.40 | –0.74 | –0.99 | –1.39 |
| | 0.69 | 0.44 | 0.38 | –0.64 | –2.07 |
| | 0.75 | 0.49 | 1.13 | –0.84 | –2.13 |
| | 0.84 | 0.53 | 1.91 | –0.85 | –2.85 |
| | 0.92 | 0.87 | 1.38 | –0.94 | –2.97 |
| | 0.98 | 1.89 | 1.20 | –1.65 | –3.02 |
| b* | before storage | 6.09 | 13.88 | 13,74 | 2.21 |
| | 0.07 | 7.56 | 14.28 | 16.02 | 5.99 |
| | 0.11 | 7.43 | 15.28 | 15.06 | 6.35 |
| | 0.22 | 7.42 | 15.33 | 15.74 | 6.92 |
| | 0.33 | 7.59 | 15.48 | 15.04 | 7.13 |
| | 0.44 | 7.99 | 14.95 | 16.50 | 7.60 |
| | 0.53 | 9.52 | 17.23 | 17.33 | 7.80 |
| | 0.69 | 17.62 | 23.00 | 24.19 | 8.17 |
| | 0.75 | 18.08 | 24.10 | 24.27 | 8.65 |
| | 0.84 | 17.03 | 23.07 | 24.64 | 8.25 |
| | 0.92 | 16.15 | 15.69 | 14.84 | 6.02 |
| | 0.98 | 16.75 | 14.19 | 14.92 | 3.49 |

Source: Own correlation.

Changes in the values of a* and b* coordinates are strictly correlated with changes in the L* coordinate (Sikorski 2004), whereas the instrumental measurement of colour is superior to the visual one, most of all, owing to greater repeatability.

Changes in the values of a* and b* coordinates are strictly correlated with changes in the L* coordinate (Ahmed 2004). A special correlation is observed between L* and a* colour components, a simultaneous decrease in value of L* parameter and an increase in a* coordinate are indicative of the reaction of non-enzymatic browning of food products (Tomaszewska and Neryng 2007). The conducted analyses demonstrated that, at $a_w$= 0.07-0.98, the decreasing values of L* component during storage of oat (I) and buckwheat (II) powders were accompanied by increasing values of a* coordinate (Tab. 5).

## CONCLUSIONS

1. Sorption isotherms of the analysed powdered plant preparations had a sigmoidal shape, being consistent with type II isotherms acc. to Brunauer's classification.
2. Adsorption of water vapour was increasing along with an increase in water activity, and in the conducted study the shape and position of sorption isotherms resulted, probably, from differences in the chemical composition of the analysed plant beverages and technology applied.
3. In water activity range of $a_w$ = 0.07-0.75, a higher sorption capacity was reported for the oat beverage (I), and the lowest one – for the buckwheat beverage (II). After exceeding $a_w$ = 0.75, i.e. in a water activity range of $a_w$ = 0.85-0.98, a higher sorption capacity was noted for the corn beverage (IV).
4. The highest capacity of the monomolecular layer, determined from the BET equation, was revealed by the powder of oat beverage (I), which resulted also in the higher value of specific surface of sorption than in the other analysed products .
5. Water activity corresponding to monolayer capacity attained the lowest value for the powder of oat beverage (I), which may suggest higher storage stability of the oat product, determined by processes depending on water activity.
6. According to the evaluated parameters (Hausner ratio and Carr index), the analysed powders of buckwheat (II) and rice (III) beverages demonstrated good flowability, characterised by the Hausner ratio lower than 1.25 and Carr index lower than 18%.
7. Instrumental measurement of colour demonstrated a decrease in L* value and an increase in a* coordinate, being indicative of the reaction of non-enzymatic browning in oat (I) and buckwheat (II) products.

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# WŁAŚCIWOŚCI SORPCYJNE WYBRANYCH ROŚLINNYCH NAPOJÓW INSTANT

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Streszczenie. Celem podjętych badań była ocena właściwości sorpcyjnych, charakterystyka wybranych właściwości fizykochemicznych oraz instrumentalna ocena barwy w czasie przechowywania czterech roślinnych napojów instant zakupionych na rynku czeskim. Ocenie poddano roślinne produkty w proszku instant: owsiany (I), gryczany (II), ryżowy (III) oraz kukurydziany (IV).W badanych produktach ocenę właściwości sorpcyjnych dokonano metodą statyczną poprzez wyznaczenie izoterm sorpcji pary wodnej. Zakres badań obejmował aktywność wody od 0,07 do 0,98 (25$^{o}$C). Czas ustalania równowagi wilgotnościowej układu wynosił 45 dni. Na podstawie początkowej masy produktu oraz zmian zawartości wody obliczono równowagowe zawartości wody i wykreślono izotermy sorpcji pary wodnej. Do matematycznej interpretacji przebiegu izoterm sorpcji pary wodnej zastosowano równanie BET w zakresie aktywności wody $0,07 \leq a_w \leq 0,33$. Przydatność modelu BET do opisu uzyskanych izoterm oceniono na podstawie wartości współczynnika determinacji ($R^2$), błędu standardowego estymacji (FitStdErr), wyznaczonych za pomocą programu Jandel-Table Curve 2D v 5.01. Ocenę właściwości fizykochemicznych badanych produktów w proszku instant przeprowadzono w oparciu o ocenę składu granulometrycznego, gęstości luźnej i utrzęsionej, współczynnika Hausnera HR oraz indeksu Carra $I_{Carr}$. Parametry barwy $L^*$, $a^*$, $b^*$ oznaczono w systemie międzynarodowym CIE za pomocą kolorymetru Konica-Minolta CR 400 dla standardowego obserwatora 2º i iluminatu D 65. Na podstawie przeprowadzonych badań stwierdzono, że różnice właściwości sorpcyjnych jak również właściwości fizykochemicznych badanych roślinnych napojów instant determinowane były przede wszystkim heterogenicznym składem surowcowym badanych produktów.

Słowo kluczowe: pojemność monowarstwy, powierzchnia właściwa, gęstość luźna i utrzęsiona, współczynnik Hausnera, indeks Carra