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PHYSICOCHEMICAL PROPERTIES OF SPRAY DRIED HONEY PREPARATIONS*

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Summary. The aim of work was to characterise the physical and chemical properties of spray dried honey preparations and the changes in these properties during storage. Spray drying was performed at inlet air temperature 160 and 200°C, atomising disk speed 32 000 and 38 000 rpm, with the use of two types of carriers: dextrin and maltodextrin. The resulting powders had the desirable physical properties: low water content and activity, complete solubility and low cohesiveness. The powders produced with the use of dextrin had higher hygroscopicity and poorer solubility, they were also characterised by the highest water absorption during storage. Powders obtained with the use of reduced atomisation speed were the most stable in terms of water absorption and the changes of hygroscopicity during storage. Solubility of all powders was stable during storage.

Key words: honey, spray-drying, carriers, atomisation speed, hygroscopicity, bulk density

INTRODUCTION

Since honey is usually a supersaturated sugar solution, the characteristic property of this product is the susceptibility for spontaneous crystallisation. During crystallisation a certain amount of free water is released from the material, which contributes to the creation of an environment beneficial to microbial growth and fermentation. Moreover, crystallised honey is often not accepted by consumers, and in its natural liquid form is difficult in trade and handling. The use of honey in a powder form greatly reduces these

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problems. Dried honey, like the powders produced after drying of fruit juices, can be used for direct consumption, applied as an additive to a range of food products such as yogurts, beverages, sauces, edible coatings, snacks, as well as dietary supplements.

The use of dried honey as an additive for cakes and breads enhance their attractiveness, improves their flavour, colour, aroma, texture and helps to maintain high product quality. According to Ram [2011] honey powder may be used as a substitute for sucrose to be added during bread baking. The use of dried honey in certain types of candy, such as honey nougats, sponges, and caramels would eliminate the flavour damaging high-temperature cooking that is otherwise necessary to remove water in their preparation [Hebbar et al. 2008]. Antony et al. [2006] tested the addition of honey to turkey breast meat before processing to retard production of oxidation products related to off-flavour. The addition of honey enhanced the oxidative stability of meat, as indicated by lower TBA values, hexanal content, and oxidative stability index. The presence of honey decreases the amount of oxidized off-flavour volatiles produced and strongly points to an antioxidative effect of honey in processed turkey meat. Greater stability and product quality for processed meat with added honey can lead to better consumer acceptance, benefiting the poultry meat industry.

Honey as a product of high content of glucose and fructose is a difficult material to dry, which is mainly due to low glass transition temperature T_g of these sugars. During drying the material remains in the form of syrup or sticky particles, even at low water content [Tonon et al. 2009]. The main method to avoid this undesirable effect is the addition of carriers characterised by high T_g values, such as starch, maltodextrin, gum Arabic [Goula and Adamopoulos 2010]. The selection of appropriate drying parameters is also very important. In the recent literature a few examples of works on the drying of honey can be found. Cui et al. [2008] proposed a method of microwave-vacuum drying and found that the best drying parameters, resulting in a material with a water content of 3%, were the pressure of 30 mbar and a thickness of less than 8 mm. The content of sugars and aromatic substances did not change after the drying process. Sahu [2008] carried out vacuum drying (710–750 mm Hg, 70°C) of honey using maltodextrin as drying agent, glycerol monostreate as flowability agent and tricalcium phosphate as anti-caking agent. Amounts of additives required to reduce powder stickiness and caking and increase powder flowability were optimized based on the commercially available honey powder properties. The products obtained in these works were not in a form of powder immediately after drying and required additional treatment to impart flowability. A preferred form of powdered honey can be obtained after spray drying with the addition of suitable carrier substances [Yoshihide and Hideaki 1993, Hebbar et al. 2002, Samborska et al. 2011, Jedlińska et al. 2012, Samborska and Czelejewska 2012]. Spray drying is a method that, in addition to the primary objective – the removal of water, also allows microencapsulating labile substances present in the dried product.

The aim of present work was to investigate the influence of spray-drying conditions and the kind of carrier material used on the physical and chemical properties of dried honey preparations and changes in these properties during storage.

MATERIALS AND METHODS

Materials

Basic research material was multifloral honey derived directly from the apiary in Supraśl. Two types of carriers were applied: dextrin and maltodextrin DE 9,6 (Hortimex, Poland).

Technological methods

Preparation of solutions for drying. Solutions intended for drying consisted of honey and carrier (dextrin or maltodextrin) in the dry matter mass ratio 1 : 1, the rest were completed with distilled water, so that the resulting solution had a concentration of 20% dry basis. Ingredients were mixed using a mechanical stirrer to obtain a uniform solution.

Drying. The prepared solutions were spray dried using a laboratory spray drier (Anhydro, Denmark) at inlet air temperature 160 and 200°C, atomising disk speed 38 000 and 32 000 rpm. Variants of experiments performed are shown in Table 1.

Storage. After drying the samples were stored 9 weeks at 25°C in sealed plastic bags.

Table 1. Experimental plan for spray drying of honey with dextrin and maltodextrin

Tabela 1. Plan eksperymentów suszenia rozpyłowego roztworów miodu z dekstryną i maltodekstryną

Variant Wariant	Air temperature Temperatura powietrza [°C]		Atomisation speed [rpm] Szybkość obrotowa dysku [obr./min]	Feed rate Szybkość zasilania surowcem [$cm^3 \cdot s^{-1}$]
	inlet wlotowego	outlet wylotowego		
D160	160	95	38 000	0.42
D200	200	102	38 000	0.42
M160	160	96	38 000	0.42
M200	200	106	38 000	0.42
M160*	160	91	32 000	0.42
M200*	200	99	32 000	0.42

Analitical methods

Water content. Determination of water content in honey was performed by refractometric method [PN-88/A-77626]. Determination of water content in the powders was carried out by an oven method: approximately 1 g of powder was dried at 105°C/4 h. The change in weight after treatment caused by water loss was expressed in percent by weight [Chegini and Ghobadian 2005].

Water activity. The water activity of powders was measured using Hygroskop DT (Rotronic, Switzerland).

Bulk loose and tapped density. Loose d_L and tapped d_T bulk densities of powders were measured using an automatic tapper STAV (Engelsmann AG, Germany) by determining the volume occupied by 100 g of powder (tapped density after 100 taps).

Cohessivieness. Cohesiveness of the powders was evaluated in terms of Hausner ratio (HR), calculated from the bulk loose (d_L) and tapped (d_T) densities: $HR = d_T/d_L$.

Apparent density. Apparent density of the spray-dried powders was analysed using helium pycnometer Stereopycnometer (Quantachrome, Germany).

Hygroscopicity. Approximately 1 g samples of powder were placed in a desiccator under the following conditions: 25°C and 75% relative humidity (saturated NaCl solution). The gain in weight after 2 h was recorded, the hygroscopicity was expressed as the amount of water absorbed by 1 g of powder solids [Goula and Adamopoulos 2010].

Solubility. The solubility of powders was carried out by adding 2 g of the material to 50 ml of distilled water in a low form glass beaker 100 ml. The mixture was agitated with a magnetic stirrer at 890 rpm (stirring bar 4 mm × 10 mm), the time required for the material to dissolve completely was recorded [Goula and Adamopoulos 2010].

Amylolytic enzymes activity. Diastase activity in fresh honey was measured photocolorimetrically according to the Schade method presented in the Harmonised Methods of the International Honey Commission [Bogdanov 2002], based on the hydrolysis of the starch present in a standard starch solution by a diastase contained in honey during 1 h at 40°C. The remaining starch was measured by quantifying the color developed by reaction with iodine. Diastase activity was expressed as a diastase number DN in Shade scale.

A procedure for the measurement of the activity of amylolytic enzymes in a dried honey preparation was presented by Samborska and Czelejewska [2012], but in their work gum Arabic was used as a carried for spray drying. In the current work, because of the use of dextrin and maltodextrin, which are the substrates for amylolytic enzymes, the procedure had to be modified. The determination was based on the hydrolysis of the starch present in a powder (coming from dextrin or maltodextrin). The remaining starch was measured by quantifying the color developed by reaction with iodine. Enzymes activity was expressed as the amount of starch hydrolysed by enzymes coming from 1 g of powder solids during 1 h reaction at 40°C.

Microphotographs. Powders were suspended on a slide in isopropanol and covered with a coverglass. Microphotos of powders were taken at magnifications 10× and 40× by stereoscopic microscope MST 131 (PZO, Poland) cooperating with a digital camera and software MultiScan.

Statistical methods

All results were obtained in duplicate and statistically analysed by analysis of variance, using software Statgraphics Centurion XV. The multiple range tests with least significant difference, with significance level 0.05, were applied.

RESULTS AND DISCUSSION

Honey characteristics

Water content in fresh honey was 19.6%, this result met the requirements from the legislation related to honey: Polish Standard [PN-88/A-77626], Codex Alimentarius [Anon 1981] and Council of European Union Directive [Anon 2002], because it did not reach the maximum allowable level (20%). Diastase activity, which is a measure of amylolytic enzymes in honey, in fresh honey was 13.9, so it was higher than a minimum level required by standards.

The properties of dried honey preparations after drying

Water content and activity. Water content of the powders obtained after spray drying of honey solutions ranged from 1.0 to 2.1% (Fig. 1A), and water activity ranged from 0.055 to 0.125 (Table 2). The values were typical for spray dried sugar-rich products, such as fruit juices and honey. In a study conducted by Nurhadi et al. [2012] water content of honey powder spray dried with maltodextrin (carrier to honey ratio 1 : 1) was 2.3%, while the use Arabic gum as a carrier gave water content 4.4%. Samborska et al. [2011] after drying of 20 and 30% honey solutions with maltodextrin obtained the products which contained 0.9 and 1.1% of water, and which had water activity 0.027 and 0.028 respectively.

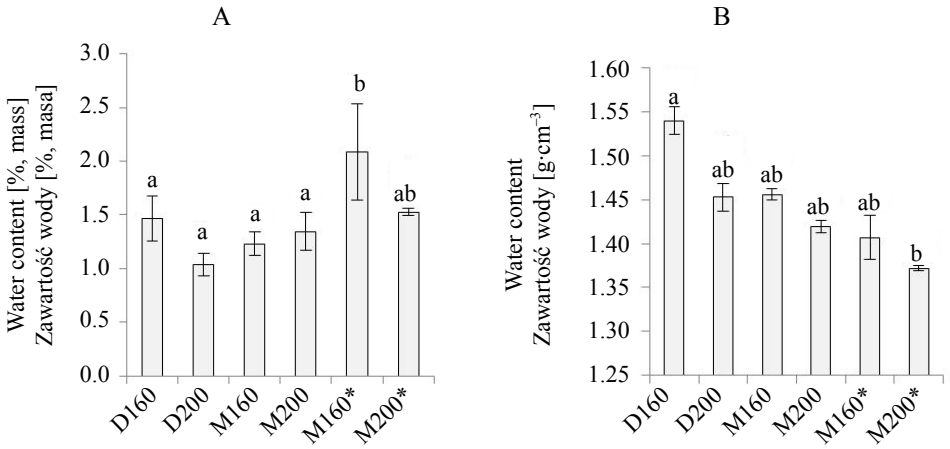

Fig. 1. Water content (A) and apparent density (B) of spray dried honey preparations, mean values followed by a different letter were significantly different at $p < 0.05$ (symbols as described in Table 1)

Rys. 1. Zawartość wody (A) i gęstość pozorna (B) suszonych rozpyłowo preparatów miodowych, wartości średnie oznaczone inną literą były istotnie różne przy $p < 0,05$ (symbole wariantów suszeń zgodne z tabelą 1)

Table 2. Physical properties of spray-dried honey preparations
Tabela 2. Właściwości fizyczne suszonych rozpyłowo preparatów miodowych

	Water activity Aktywność wody	Bulk density Gęstość nasypowa [g·cm^{-3}]		Hausner Ratio Współczynnik Hausnera	Hygroscopicity [g·g^{-1} solids] Higroskopijność [g·g^{-1} s.s.]	Solubility Rozpuszczalność [s]
		loose luźna d_L	tapped utrzęsiona d_T			
D160	0.059 ±0.015^{a}	0.46 ±0.01^{a}	0.54 ±0.01^{a}	1.18 ±0.01^{b}	0.041 ±0.001^{b}	59 ±10^{b}
D200	0.055 ±0.016^{a}	0.56 ±0.03^{b}	0.63 ±0.01^{b}	1.12 ±0.02^{ab}	0.031 ±0.002^{a}	148 ±11^{c}
M160	0.069 ±0.006^{a}	0.41 ±0.01^{a}	0.47 ±0.01^{a}	1.15 ±0.01^{ab}	0.030 ±0.006^{a}	37 ±2^{a}
M200	0.077 ±0.007^{a}	0.52 ±0.04^{ab}	0.54 ±0.02^{ab}	1.05 ±0.04^{a}	0.034 ±0.001^{ab}	61 ±4^{b}
M160*	0.125 ±0.025^{b}	0.51 ±0.01^{ab}	0.57 ±0.01^{ab}	1.11 ±0.01^{ab}	0.027 ±0.003^{a}	57 ±5^{b}
M200*	0.084 ±0.003^{a}	0.44 ±0.02^{a}	0.50 ±0.02^{a}	1.15 ±0.02^{ab}	0.026 ±0.003^{a}	28 ±7^{a}

$^{a–c}$ – mean values followed by a different letter were significantly different ($p < 0.05$)

$^{a–c}$ – wartości średnie oznaczone inną literą były istotnie różne przy $p < 0,05$

The lowest water content and activity was in variant D200, and the highest in variant M160*. In variants D160, D200, M160 and M200 the variable parameter was the kind of carrier and the inlet air temperature. Analysis of variance showed no significant effect of these two parameters on the water content and activity in powders. On the contrary, the change of atomisation speed significantly affected the powders water content and activity (compare M160 with M160* and M200 with M200*). Reducing this speed resulted in increased water content and activity in the powders. It was the result of the fact that the lower the atomisation speed, the larger droplets are formed, resulting in deterioration of heat and mass transfer conditions, so powder particles contain more water [Masters 1991, Rodriguez-Hernandez et al. 2005].

Bulk density. Bulk and tapped density of the powders obtained after spray drying of honey solutions ranged from 0.41 to 0.56 g·cm^{-3} and from 0.47 to 0.63 g·cm^{-3} respectively (Table 2). In Goula and Adamopoulos' [2010] study the bulk density of powders obtained after spray drying of orange juice with the addition of maltodextrin was between 0.14 and 0.41 g/ml, while Jedlińska et al. [2012] after spray drying of honey solutions with maltodextrin obtained values from 0.48 to 0.51 g·cm^{-3}. The lowest bulk density was in variant M160, and the highest in variant D200. Inlet air temperature had a significant impact on the bulk density, but only when dextrin was used. This dependence could arise from the fact that the loose bulk density is strongly linked to the water content of the powder. The higher the humidity (and such samples were obtained after drying at lower temperatures), the more particles are combined into larger clusters, leaving open spaces between them, which in turn lowers the bulk density [Goula and Adamopoulos 2005]. Although lower values of bulk density were obtained with maltodextrin, the differences were not significant. The influence of atomisation speed was also not significant.

Cohessivieness. Hausner ratio (HR) values of obtained powders ranged from 1.05 to 1.18 (Table 2). According to the classification given by Geldart et al. [1984] powders of HR below 1.25 are classified as low cohesive. Cohesiveness of powders determines their consistency and flow properties – the lower the cohesiveness the better the flowability of

powders [Domian and Poszytek, 2005]. The highest value of HR (but still below 1.25) showed the sample D160, while the smallest was for sample M200, the difference between these two values was the only significant difference. Samborska et al. [2011] in the studies on spray drying of honey solutions maltodextrin at 180°C, received powders with an average cohesiveness as the HR values ranged from 1.2 to 1.4.

Apparent density. Apparent density of the powders obtained after spray drying of honey solutions ranged from 1.37 to 1.54 $g \cdot cm^{-3}$ (Fig. 1B). The highest density had the variant D160, the value was the smallest in variant M200*, and the difference between these two values was the only significant difference. Abadio et al. [2004], drying the pineapple juice, obtained an average value of powder particles apparent density 1.52 $g \cdot cm^{-3}$. Jedlińska et al. [2012] described the physical properties of multifloral honey spray dried with the addition of maltodextrin (20 and 30% solids solutions). The apparent density of powders particles was in a range between 1.32 and 1.43 $g \cdot cm^{-3}$.

Hygroscopicity. Hygroscopicity of the powders ranged from 0.026 to 0.041 $g \cdot g^{-1}$ solids (Table 2). Analysis of variance showed a significant effect of the type of carrier and drying parameters on this parameter. The most susceptible to moisture absorption sample was D160, while the lowest hygroscopicity was obtained in the variant M200*. The relationship between the drying temperature and hygroscopicity was significant only when the dextrin was used, and the type of carrier affected the hygroscopicity significantly only in case of drying temperature 160°C. The lowest values of hygroscopicity were recorded in variants performed with the application of reduced atomisation speed. This relationship is likely to be associated with an increase in particle size in these variants, leading to reduction of total powder surface through which the water may be absorbed.

In a study by Goula and Adamopoulos [2010], on orange juice spray drying with maltodextrin (inlet air temperature 110–140°C), the powders hygroscopicity ranged from 0.040 to 0.065 $g \cdot g^{-1}$ solids. The authors found that the inlet air temperature increase leads to lower hygroscopicity, which is consistent with some results obtained in a current work. Rodriguez-Hernandez et al. [2005] worked on spray drying of cactus juice with maltodextrin at inlet air temperature 205 and 225°C and obtained hygroscopicity between 0.036 and 0.049 $g \cdot g^{-1}$ solids. No relationship was found between the concentration of maltodextrin and hygroscopicity.

Solubility. The powders obtained by spray drying honey solutions were easily reproducible in water and completely soluble. Solubility ranged from 28 to 148 s (Table 2). The shortest time in which the powder was dissolved completely achieved sample M200*, and the longest – sample D200. Analysis of variance revealed the significant effect of drying parameters and the type of carrier on the solubility of powders. The powders obtained after drying at higher temperature had poorer solubility (except powders dried at lower atomisation speed), and the time required for complete dissolution of powders containing maltodextrin was significantly shorter than those obtained with the use of dextrin. Atomisation speed also contributed significantly to the value of the solubility, but this correlation was not ambiguous.

Goula and Adamopoulos [2005], who studied the properties of spray dried tomato powder, received longer times needed to dissolve the same amount of powder: from 121 to 245 s. They found that increasing inlet air temperature results in better powder solubility, what was proven in case of a pair of powders M160* and M200*. Moreover, accord-

ing to these researchers, the lower the moisture content of the powders the better is the solubility. In the current work an inverse relationship was observed: the powder D200 with the lowest water content was characterised by the worst solubility.

Amylolytic enzymes activity. The amount of starch hydrolysed during the deterimantion of the activity of amylolytic enzymes in dried honey preparations varied from to 0.008 to 0.112 g (Fig. 2). The increase of drying temperature and decrease of atomisation speed resulted in decreased enzymes activity, but the differences were not statistically signifficant due to high values of standard deviations, which suggest that the applied method for the determination of amylolytic enzymes activity was not perfect. The main problem in this procedure is the fact that the carrier materials used (dextrin and maltodextrin) are the substrates for amylolytic enzymes. Dextrin and maltodextrin can behave different as an enzymatic reaction substrate. Moreover, it is not sure that in every powder sample weight taken to the determination the ratio of honey to substrate was the same, what can cause high differences in the obtained results. In addition, it is not possible to compare the activity of enzymes before and after drying, due to the fact that the procedure is different, cause in case of dried preparations the substrate comes from the dried products. Due to these reasons there is still a need to work on the improvement of the determination method. In other work on honey drying [Nurhadi et al. 2012] authors show the results of diastase activity in dried honey powders, but they do not descbibe the procedure for this determination. Higher value obtained in powder compared to fresh honey can suggest thet the procedure was also not correct. Samborska et al. [2012] presented also the results of diastase activity in spray dried honey preparatons, but in this case the carrier used for drying was Arabic gum, which is not a substrate for amylolytic enzymes present in honey. In this work the values of diastase activity in spray dried products were at the same level as in fresh honeys (multifloral and rape honey). The authors explain that it was the effect of well-known fact that removal of water enhances enzymes thermal stability by reducing the freedom of movement of the protein molecules and thus inhibiting conformational changes, leading to activity deterioration. Therefore, during spray drying, when the water evaporation is very fast, heat stability of enzymes rapidly increase as a result of water removal. Nevertheless the above described problems, it can be concluded that spray drying is a method which preserve the enzymatic activity of honey, the degree of this preservation depends on drying parameters, and there is a need for further work to improve the determination method.

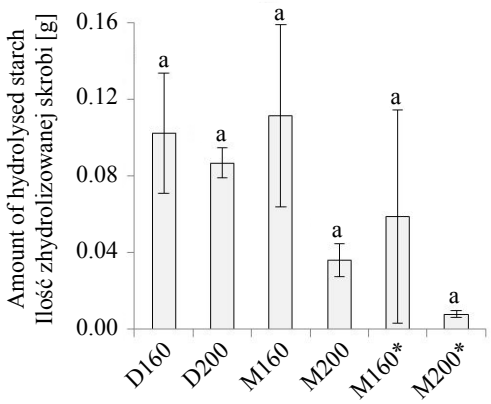

Fig. 2. Amount of starch hydrolysed during the deterimantion of the activity of amylolytic enzymes in dried honey preparations (variants as described in Table 1)

Rys. 2. Ilość skrobi zhydrolizowanej w czasie oznaczania aktywności enzymów amylolitycznych w suszonych rozpyłowo preparatach miodowych (symbole wariantów suszeń zgodne z tabelą 1)

Microphotographs. Microscopic images of powders particles directly after drying are shown in Fig. 3 and 4. Particles of dried honey preparations had a spherical shape with a smooth surface and different sizes. The local clusters of particles were formed, but particles were not stuck together. The use of dextrin and reduction of the atomisation speed resulted in larger particles of powder (Fig. 4). This relationship (the lower the atomisation speed, the larger droplets are formed) was presented before etc. by Masters [1991] and Rodriguez-Hernandez et al. [2005].

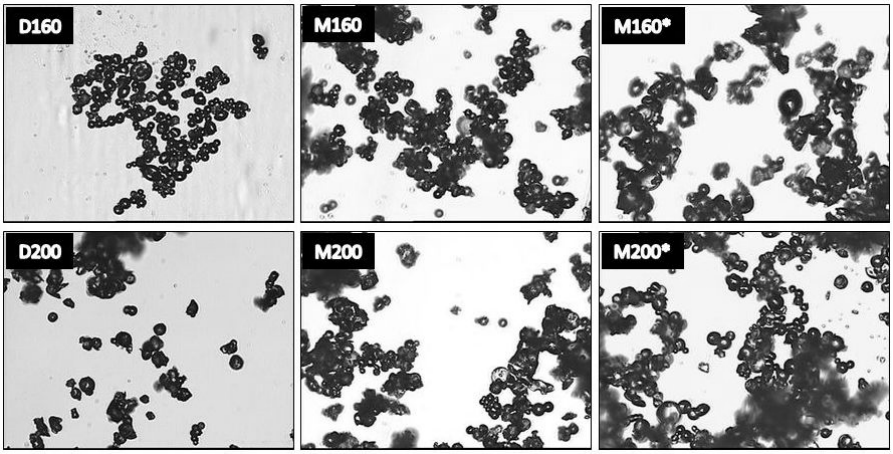

Fig. 3. The particles of powders obtained by spray drying of honey solutions with dextrin and maltodextrin (symbols as described in Table 1), mag. 10×

Rys. 3. Cząstki proszków otrzymanych poprzez suszenie rozpyłowe roztworów miodu z dekstryną i maltodekstryną (symbole wariantów suszeń zgodne z tabelą 1), pow. 10×

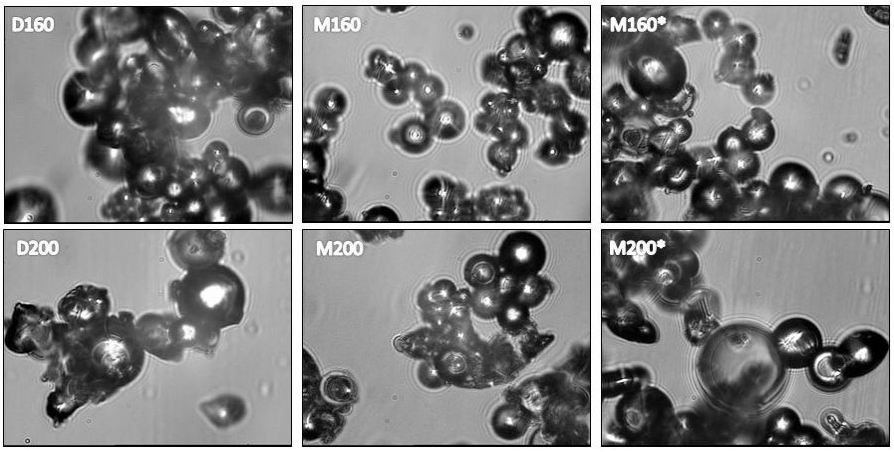

Fig. 4. The particles of powders obtained by spray drying of honey solutions with dextrin and maltodextrin (symbols as described in Table 1), mag. 40×

Rys. 4. Cząstki proszków otrzymanych poprzez suszenie rozpyłowe roztworów miodu z dekstryną i maltodekstryną (symbole wariantów suszeń zgodne z tabelą 1), pow. 40×

The properties of dried honey preparations after storage

Water content and activity. Water content and activity of honey powders significantly increased during the storage period (Fig. 5). Moisture content after 9 weeks of storage ranged from 1.8 to 2.9%, water activity was between 0.151 and 0.215. There was a strong relationship between the kind of carrier, atomisation speed and the intensity of water absorption. The highest relative change in water content after 9 weeks of storage was observed in case of dextrin/honey powders, while minimum water absorption was in case of maltodextrin/honey powders dried at reduced atomisation speed. This correlation could be caused by the increase of particle size of powders obtained with the use of reduced atomisation speed. According to Unde et al. [2011] particle size is inversely related to moisture absorption: in case of jaggery powder the maximum moisture increase after 6 months of storage was observed for fine jaggery powder while minimum water absorption was observed in coarse particle sized jaggery powder.

There was also a strong relationship between the initial water content and the relative water content increase during storage. Sample D200, which had the lowest water content directly after drying, had the highest water content increase after storage, while

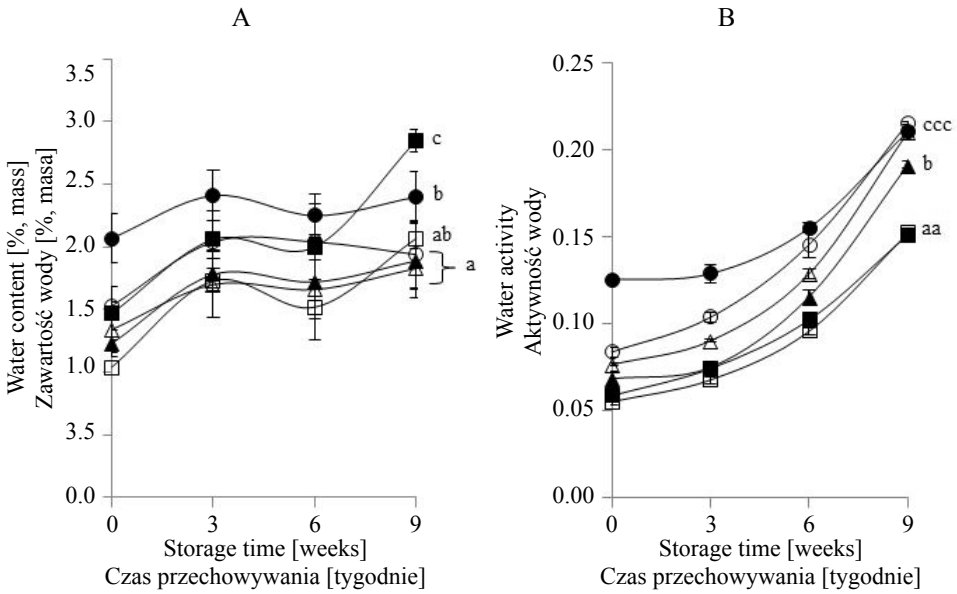

Fig. 5. Water content (A) and water activity (B) changes during storage of spray dried honey preparations D160 (■), D200 (□), M160 (▲), M200 (Δ), M160* (●), M200* (○), mean values after 9 weeks of storage followed by a different letter were significantly different at $p < 0,05$

Rys. 5. Zmiany zawartości wody (A) i aktywności wody (B) w czasie 9 tygodni przechowywania suszonych rozpyłowo preparatów miodowych D160 (■), D200 (□), M160 (▲), M200 (Δ), M160* (●), M200* (○), wartości średnie oznaczone inną literą były istotnie różne przy $p < 0,05$

the sample M160* of the highest water content after drying had the lowest water absorption properties.

The course of water content and water activity increase during storage was different. In case of water content, there was a stabilisation between 3 and 6 weeks of storage, all values recorded after 6 weeks were lower than after 3 weeks. On contrary, the increase of water activity during storage was more regular. There are too possible reasons for the increase of water activity in powders during storage. The first is connected with the increase of water content, and the second is connected with the crystallisation of substances which are in the amorphous state after drying. Usually fast evaporation in spray drying produces the particles in the amorphous form. During the phase transition from the amorphous state to the crystalline state some amount of water is released, causing the increase of water activity, even if water content is stable [Truong et al. 2005, Das and Langrish 2012). This phenomenon could be responsible for the differences in water content and water activity increase observed, especially in samples M160* and M200*. The water content in these samples was the most stable during storage, while the increase of water activity was as high as in other samples.

Microphotographs. Micro images of powders particles after 9 weeks of storage are shown in Fig. 6 and 7. Comparing the morphology and particle size of powders obtained directly after drying and after 9 weeks of storage, it is clear that the storage had an impact on the structure of the powders. After storage particles stick together to form larger clusters, what could be a result of the creation of liquid bridges between particles due to crystallisation, which cause a release of excess water from the amorphous material [Das and Langrish 2012].

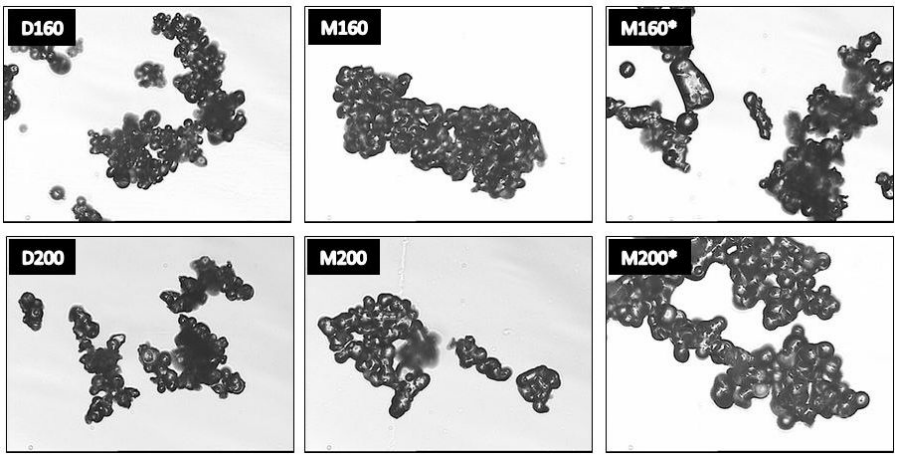

Fig. 6. The particles of powders obtained by spray drying of honey solutions with dextrin and maltodextrin after 9 weeks of storage (symbols as described in Table 1), mag. 10×

Rys. 6. Cząstki proszków otrzymanych poprzez suszenie rozpyłowe roztworów miodu z dekstryną i maltodekstryną po 9 tygodniach przechowywania (symbole wariantów suszeń zgodne z tabelą 1), pow. 10×

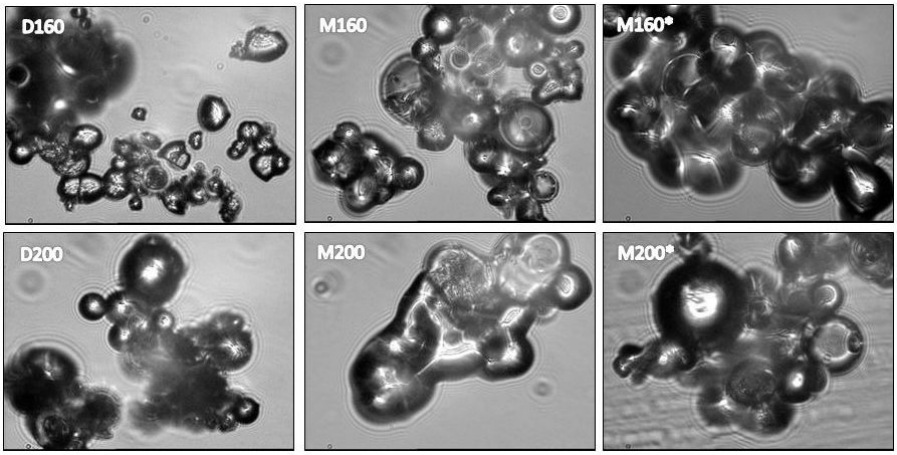

Fig. 7. The particles of powders obtained by spray drying of honey solutions with dextrin and maltodextrin after 9 weeks of storage (symbols as described in Table 1), mag. 40×

Rys. 7. Cząstki proszków otrzymanych poprzez suszenie rozpyłowe roztworów miodu z dekstryną i maltodekstryną po 9 tygodniach przechowywania (symbole wariantów suszeń zgodne z tabelą 1), pow. 40×

Hygroscopicity and solubility. The changes of hygroscopicity and solubility of honey powders during storage are presented in Table 3. The kind of the carrier material and the drying parameters had a significant effect on the course of these changes. After 9 weeks of storage the most hygroscopic were samples containing dextrin (D160 and D200). Maltodextrin/honey samples dried at higher atomisation speed (M160 and M200) had medium hygroscopicity, while the lowest values were obtained for maltodextrin/honey samples

Table 3. Physical properties of spray – dried honey preparations during storage

Tabela 3. Właściwości fizyczne perparatów miodowych suszonych rozpyłowo w czasie przechowywania

	Hygroscopicity [g·g^{-1} solids] Higroskopijność [g·g^{-1} s.s.]			Solubility Rozpuszczalność [s]		
Storage time [weeks] Czas przechowywania [tygodnie]	3	6	9	3	6	9
D160	0.092 ±0.010^{c}	0.042 ±0.006^{a}	0.068 ±0.015^{d}	59 ±5^{ab}	61 ±3^{ab}	59 ±4^{ab}
D200	0.077 ±0.006^{bc}	0.037 ±0.007^{a}	0.054 ±0.012^{cd}	135 ±28^{c}	113 ±11^{c}	124 ±12^{c}
M160	0.085 ±0.005^{bc}	0.037 ±0.010^{a}	0.046 ±0.003^{bc}	43 ±8^{ab}	36 ±5^{a}	35 ±3^{a}
M200	0.072 ±0.010^{b}	0.034 ±0.009^{a}	0.038 ±0.001^{abc}	67 ±12^{b}	68 ±4^{b}	75 ±8^{b}
M160*	0.033 ±0.002^{a}	0.044 ±0.007^{a}	0.028 ±0.007^{a}	51 ±3^{ab}	38 ±3^{ab}	41 ±2^{ab}
M200*	0.027 ±0.001^{a}	0.038 ±0.007^{a}	0.031 ±0.002^{ab}	39 ±9^{a}	43 ±6^{ab}	49 ±5^{ab}

$^{a–d}$ – mean values followed by a different letter were significantly different ($p < 0.05$)

$^{a–d}$ – wartości średnie oznaczone inną literą były istotnie różne przy $p < 0,05$

dried at decreased atomisation speed (M160* and M200*). All samples dried with the use of higher atomisation speed showed the maximum hygroscopicity after 3 weeks of storage, and after 6 weeks the values decreased to the same level as for variants M160* and M200*. In general, amorphous materials have high hygroscopicity and a thermodynamic tendency to convert to a crystal lattice. During crystallisation some amount of water trapped in the molecular arrangement is released, what leads to the water activity increase and hygroscopicity decrease [Das and Langrish 2012]. This phenomenon was probably the reason for a sudden change of hygroscopicity of samples D160, D200, M160 and M200 observed between 3 and 6 week of storage. Variants M160* and M200* were in general less hygroscopic, probably due to inversed relationship between particle size to moisture absorption.

The solubility of honey powders was stable during storage, after 9 weeks it ranged from 35 to 124 s (Table 3). The longest time in which the powder was dissolved completely was recorded, the same as directly after drying, for sample D200. The relationships between the kind of carrier, drying parameters and solubility were similar as observed after drying: the powders obtained after drying at higher temperature had poorer solubility, the time required for complete dissolution of powders containing maltodextrin was significantly shorter than those obtained with the use of dextrin.

CONCLUSIONS

1. Spray drying can be used to produce honey preparations in a powder form characterised by good physical properties: low water content and activity, low cohesiveness and hygroscopicity, complete solubility.
2. Dry honey preparations obtained with the use of dextrin as a carrier material have higher hygroscopicity and worse solubility than those obtained with maltodextrin. These powders are also the most susceptible for water absorption during storage.
3. The atomisation speed has the biggest impact on the powder properties during storage. Powders obtained with the use of reduced atomisation speed are the most stable in terms of water absorption and the changes of hygroscopicity during storage.
4. Taking into account the properties of powders after drying and during storage, the best properties have maltodextrin/honey powders dried at reduced atomisation speed.
5. The method for the determination of amylolytic enzymes activity in dried honey preparations still needs improvement.

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WŁAŚCIWOŚCI FIZYKO-CHEMICZNE PREPARATÓW MIODOWYCH SUSZONYCH ROZPYŁOWO

Streszczenie. Celem pracy było określenie właściwości fizycznych i chemicznych preparatów miodowych suszonych rozpyłowo oraz zmiany tych właściwości w czasie przechowywania. Suszenie rozpyłowe przeprowadzono przy temperaturze powietrza wlotowego 160 do 200°C, szybkość obrotowa dysku rozpylającego wynosiła 32 000 i 38 000 obrotów na minutę, użyto dwóch rodzajów nośników: dekstrynę i maltodekstrynę. Otrzymane proszki miały pożądane właściwości fizyczne: niską zawartość i aktywność wody, całkowitą rozpuszczalność i niską spójność. Proszki wytworzone z wykorzystaniem dekstryny miały wyższą higroskopijność i gorszą rozpuszczalność, charakteryzowały się najwyższą ilością wchłoniętej wody w czasie przechowywania. Proszki otrzymane z wykorzystaniem zmniejszonej szybkości obrotowej dysku rozpylającego były bardziej stabilne pod względem absorpcji wody i zmiany higroskopijności podczas przechowywania. Rozpuszczalność wszystkich proszków była stabilna w czasie przechowywania.

Słowa kluczowe: miód, suszenie rozpyłowe, nośniki, higroskopijność, gęstość nasypowa