EFFECT OF TEMPERATURE ON THE DRYING PROCESS OF BEE POLLEN FROM TWO ZONES OF COLOMBIA

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ABSTRACT

The influence of the drying temperature (35 and 45C) on bee pollen is evaluated based on the physical, chemical and nutritional characteristics of dried bee pollen from two zones in Colombia (La Calera and Zipaquira). The methods used to establish the effect of the treatment are: determination of chemical composition, measurement of water activity, solubility index, mean particle size, vitamin C content and carotene content. The results confirm that the drying process of bee pollen at 45C has the shorter drying time (156–198 min), moisture content (7–8%) and water activity (0.3), but higher levels of carotene and vitamin C losses. The protein, fiber and ash contents are not affected by the drying temperature. The observed higher carotene content of the pollen from La Calera is probably because of the flora composition in this zone. The vitamin C content decreases as the drying temperature increases, but there are no significant differences between zones.

PRACTICAL APPLICATIONS

Bee pollen can be sold as both fresh and dried products. However, refrigeration with temperature between 5 and 10C is required for storage of the

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fresh bee pollen to preserve quality. The bee pollen drying allows preserving the product at room temperature, making the product marketing easier and increasing the profits of beekeepers. The drying process of bee pollen in Colombia is done by sun, solar and oven-drying methods. But hot-air drying is considered as a suitable drying method because it decreases drying time and improves the hygienic quality of the dried product. The chemical, physical and nutritional properties of dried bee pollen were studied in order to evaluate the effect of drying temperature on pollen from different origins. Thus, the results of this investigation can help the apiarists to use the best drying conditions to produce dried bee pollen.

INTRODUCTION

Bee pollen consists of pellets. During collecting trips, bees pack pollen into pollen baskets on their hind legs. The pollen is stored inside the hive separately from the nectar cells (Almeida-Muradian *et al.* 2005). The pollen grains, which are gathered by worker bees, come in a wide variety of shapes (most often spherical), sizes, color and surface.

Pollen composition depends on various factors. Honey bees mix pollen with regurgitated nectar or honey for transport on their legs. Thus, the "pollen pellets" often subjected to chemical analyses contain both pollen and nectar or honey, and it is difficult to estimate the concentration of the chemical constituents in pollen itself (Roulston and Cane 2000). The composition and production of pollen are dependent upon which plants the worker bees are gathering the pollen from, and the climate and soil factors. The main are pollinate plants in Colombia: *Citharexylum fruticosum*, *Weinmannia tomentosa* (Cunoniaceae), *Vallea stipularis* L. (Eleocarpaceae), *Miconia squamosa* (Melastomataceae), *Gaultheria sclerophyla* (Ericaceae), *Eucalyptus globulus* L. y *Myrciantes leucoxyla* (Myrtaceae), *Zea mays* (Poaceae), *Brasicca campestris* (Cruciferae), *Acacia decurrens* W. (Mimosaceae), *Hesperomeles goudiana* (Rosaceae), *Oreopanax floribundum* (Araliaceae), *Dodonaea viscosa* (Sapindaceae), *Alnus acuminata* H.B.K. (Betulaceae) y *puya* sp. (Bromeliaceae) (Salamanca-Grosso *et al.* 2008).

The bee pollen production in Colombia has three peaks per year: May, October and December. However, the zone called "Altiplano Cundiboyacense" has a continuous production all over the year. The income of 300 beekeeper families, which manage approx. 6,000 hives, depend on the yield of bee pollen. The beekeeper can sell 1 kg of pollen at around US$5, and the final consumer can buy the same product at US$12 (MADR 2006).

The beekeeper obtains pollen with the installation of a trap in front of the hive entrance, so that the worker bees, when coming home, lose their pollen

pellets which are then withdrawn into a container (Barth and Luz 1998). The yield of the collected pollen depends on the container capacity, pollen moisture content, climate and size of the hive.

When pollen is not stored properly, they lose much of their nutritional value, and the development of molds and bacteria occur because of the high moisture of product. Therefore, drying bee pollen is necessary to extend its shelf life. In some places, the sun drying of bee pollen is used, which is inappropriate because of the considerable process time, increased microbial spoilage during the drying process and lower with sanitary conditions. The hot-air drying is a suitable process and frequently used in a commercial product because of the reasonable process time, better sanitary conditions and control of the drying conditions (Crapiste and Rotstein 1997). The tray dryer comprises a chamber with trays located one above another on which the food material is loaded. The heat from the drying medium (hot air) to the food product is transferred mainly by convection. Because of its versatility and good control of drying conditions, these dryers are relatively widespread in the food industry (Ramaswamy and Marcotte 2006).

Bee pollen can be sold as both fresh and dried products; however, the storage of fresh product requires refrigeration with temperature between 5 and 10C. The objective of bee pollen drying is to remove water to a level at which microbial spoilage is minimized. In addition, there is a significant reduction in weight and volume that also contributes to reducing the cost of handling, storage and distribution (Sokhansanj and Jayas 1995). Thus, the aim of this work was to study the effect of drying temperature and the origin of product on the chemical, physical and nutritional properties of dried bee pollen pellets.

MATERIALS AND METHODS

Materials

The bee pollen was obtained from two towns of the Altiplano Cundiboyacense: La Calera and Zipaquira. Both towns have a similar temperature at around 14C (average daily temperature), even though, the zones, where the hives are placed, are different. The La Calera zone is mountainous with higher humidity and native woods, whereas the Zipaquira zone is clean pasture suitable for grazing by livestock. The bee pollen was a mixture of multifloral source. The bee pollen sample of 1 kg/week of experimentation was used because of the yield of two apiaries. The experiments were performed between July and August 2008.

Drying Equipment and Procedure

The sample (1 kg) was brought from each apiary to the drying laboratory in a glass sealed jar at room temperature. The bee pollen was cleaned to eliminate the stray chaff, bees, leaves, etc.; 500 g of bee pollen pellets was used for the hot-air drying process, and the rest was used in the chemical analysis. The dehydration process of cleaned pollen pellets was carried out by a tray dryer with hot air without air recirculation (FIQ Ltda, Bogota, Colombia), at 35 and 45C (temperature range suggested by the apiarists) to a final moisture content below 12% wet basis. The relative humidity in Bogotá is usually between 60 and 70%. This parameter was not controlled inside the dryer. The constant parameters during the drying process were: (1) air velocity (3 m/s), which depends on the equipment configuration and its fan; (2) thickness of sample (0.02 m) due to the amount of sample used in the process (250 g per tray); and (3) drying area (0.07 m^2) according to the tray area.

Methods

Raw Material and Product Characterization. Protein (960.52), fat (963.15), fiber (991.43), ash (920.181) and moisture content (925.45B) were determined (AOAC 1997).

Drying Curves. The weight loss of sample was recorded during the process by a data acquisition system, which was connected to the tray dryer. The registered weights were become in terms of free moisture contents using Eqs. (1) and (2) (Geankoplis 1993).

$$X_t = \frac{W - W_s}{W_s} \tag{1}$$

where W is the sample weight at any time (kg), W_s is the dry matter weight (kg) and X_t is the moisture and dry matter ratio at any time (kg water/kg dry matter). Then, the free moisture content was calculated by using equilibrium moisture content for each X_t (Eq. 2):

$$X = X_t - X^* \tag{2}$$

where X^* is the equilibrium moisture content (kg water/kg dry matter), X is the free moisture content for each X_t (kg water/kg dry matter).

Water Activity. The water activity (A_w) of the samples was measured using a water activity meter (model ms1, Novasina AG, Lachen, Switzerland). The calibration was performed using a salt standard (Gleiter *et al.* 2006). Measurements were made in triplicate.

Carotene Content. The extraction process of the pollen carotene was made using hexane as solvent and by open column chromatography with absorbents (calcium triphosphate and sodium sulfate anhydrous) according to the procedure by Bernal (1998). The absorbance at 450 nm was measured on an aliquot of this extract by spectrophotometer (Helios alfa, Termo Spectronic, Rochester, NY, USA). Measurements were made in triplicate. The calibration curve was carried out to determine the carotene content.

Vitamin C Content. The extraction process of the pollen vitamin C was made using oxalic acid (0.15% w/v) according to the procedure by Bernal (1998). The absorbance at 540 nm was measured by the spectrophotometer previously described. Triplicate determinations were conducted. The vitamin C content was determined by calibration curve.

Solubility Index. The solubility index in this study represents the amount of dried pollen that can dissolve in a given aqueous solution. The solubility index was determined by a method adapted from Meda and Ratti (2005). The pollen sample (5 g) was put on a metal strainer and immersed in distilled water (100 mL) at 20C. After 10 s of the immersion, the sample was let to drain and weighted. This procedure was done during 50 s. The solubility index was assessed by Eq. (3).

$$SI = \frac{W_d - W_r}{W_o - W_d} * 100 \tag{3}$$

where SI is the solubility index of dried bee pollen pellets, W_r is the sample weight after immersion (g), W_d is the sample weight after drying process (g), W_o is the initial sample weight before the drying process (g).

Mean Particle Size. The pollen particle size distribution was determined, in triplicate, by sifting 50 g of bee pollen pellets on a Ro-Tap sieve shaker (model B., W.S. Tyler Co, Gastonia, NC) equipped with sieves of 150, 250, 355, 425, 500 μm and 850 μm. Samples were shaken for 10 min, and the material remaining on the respective sieves was weighed and recorded (Zhang and Moore 1997). Mean pollen particle size was calculated using the formula proposed by Ensor *et al.* (1970).

Statistical Analysis

A factorial design of two factors (sample origin and drying temperature) was used in this study (Montgomery 2001). The total treatments were 12, including three repetitions. Experimental data were submitted to ANOVA at a 5% significance level, and least significant differences were used to compare treatments when significant differences were found. Statistical analysis was performed using Statgraphics Plus 5.1. The data were given as means ± SD.

RESULTS AND DISCUSSION

Drying Curves

Figures 1 and 2 show the typical drying curves of the pollen from La Calera and Zipaquira zones, respectively, at 35 and 45C. The drying curves obtained were similar to drying curves obtained for food materials (Garau *et al.* 2007; Kingsly *et al.* 2007; Doymaz 2009).

The drying curve at 35C presented higher process time compared with that at 45C. Although the initial moisture of samples was not similar, higher drying temperature reduces the time process. The total drying time of pollen from La Calera zone at 35C was 297 min, and from Zipaquira zone at the same

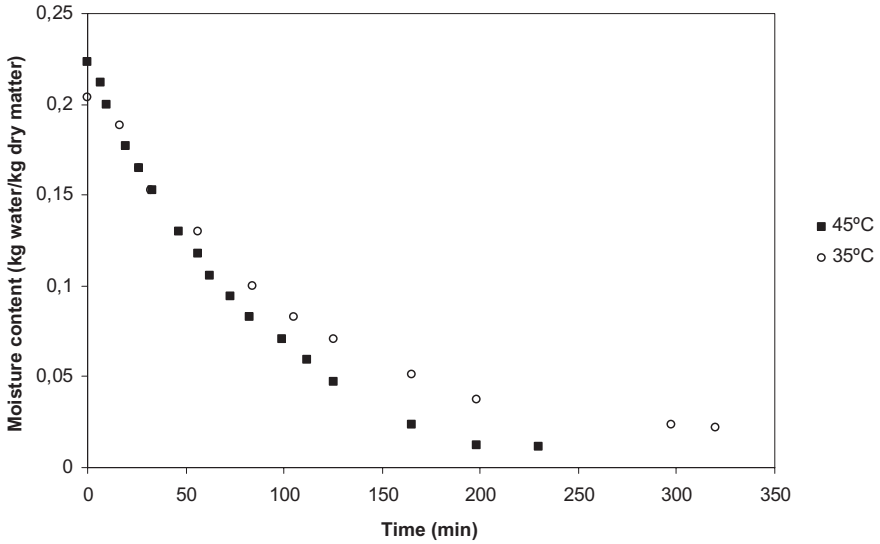

FIG. 1. DRYING CURVES OF BEE POLLEN FROM LA CALERA ZONE AT 35 AND 45C

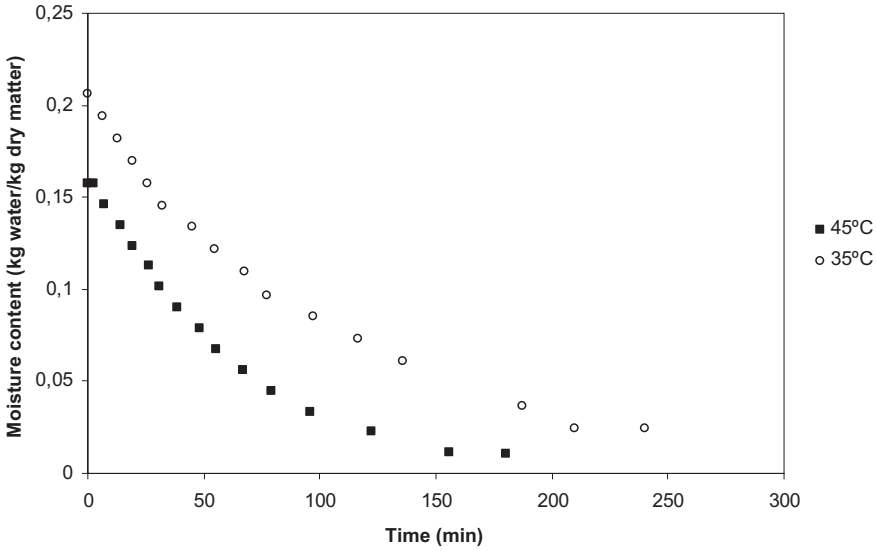

FIG. 2. DRYING CURVES OF BEE POLLEN FROM ZIPAQUIRA ZONE AT 35 AND 45C

temperature was 210 min, whereas at 45C, the drying time of pollen from La Calera zone was 198 min, and from Zipaquira was 156 min. Air drying temperature had an important effect on the drying rate. As expected, longer drying periods were required at lower drying temperatures, whereas higher temperatures promoted shorter drying times (Garau *et al.* 2007). Vizcarra-Mendoza *et al.* (1998) studied the drying of bee pollen by fluidization from 40 to 55C, and reported the strong effect of the temperature on the drying rate. The time process at 45C was 216 min, which was higher than that of this study.

Water Activity and Moisture Content

Dehydrated foods are preserved because water activity is at a level where no microbiological activity can occur and where deteriorative chemical and biochemical reaction rates are reduced to a minimum (Toledo 2007). As expected, the water activity and the moisture content of pollen from both zones decreased after the drying process (Table 1). Reducing A_w below 0.7 would prevent microbiological spoilage; however, other deteriorative reactions, such as an enzyme activity, non-enzyme browning, lipid oxidation, can be prevented in a dried food with A_w values near 0.3 (Ramaswamy and Marcotte 2006).

There were significant differences ($P < 0.05$) between A_w values according to the treatment, fresh (0.73–0.78), dried at 35C (0.46–0.5) and dried at

TABLE 1.
MOISTURE CONTENT AND WATER ACTIVITY OF BEE POLLEN SAMPLE*

Zone	Treatment	Water activity*	Moisture content* (%)
La Calera	Fresh	0.78 ± 0.01	23.82 ± 1.3
	35C	0.46 ± 0.02	9.31 ± 0.79
	45C	0.39 ± 0.1	8.29 ± 1.86
Zipaquira	Fresh	0.73 ± 0.05	19.41 ± 3.46
	35C	0.50 ± 0.08	11.23 ± 2.08
	45C	0.33 ± 0.05	7.09 ± 2.04

* Means ± SD.

TABLE 2.
CHEMICAL COMPOSITION OF BEE POLLEN SAMPLES (DRY BASIS)*

Zone	Treatment	Protein (%)	Fat (%)	Ash (%)	Fiber (%)
La Calera	Fresh	27.38 ± 1.9	3.8 ± 2.1	2.16 ± 0.4	0.48 ± 0.8
	35C	28.19 ± 1.4	4.1 ± 1.4	2.09 ± 0.4	0.46 ± 0.4
	45C	28.85 ± 3.0	5.1 ± 1.8	2.89 ± 0.3	0.43 ± 0.5
Zipaquirá	Fresh	28.17 ± 2.2	1.14 ± 1.1	3.0 ± 0.04	0
	35C	28.45 ± 1.2	1.37 ± 2.2	3.33 ± 0.1	0
	45C	28.20 ± 1.9	2.2 ± 1.8	3.20 ± 0.3	0

* Means ± SD.

45C (0.33–0.39), but not between zones. The drying process at 45C resulted in water activity values close to 0.3. The water activity of pollen from La Calera zone is slightly higher, maybe by the geographical location of apiary (native woods), but the data variation is not higher than 0.1, being similar at experimental level. The dried pollen at 45C reached moisture contents between 7 and 8%. The objective of drying is to decrease the moisture content below ±8% to prevent the microbiological growth and the infestations of mites and insects in the product (Barbosa-Cánovas and Vega-Mercado 1996).

Chemical Composition

Table 2 shows the chemical composition of bee pollen in dry basis (d.b.) from both zones. The treatment and the origin did not significantly affect the protein content of bee pollen. The protein content of pollen was close to 28%. Rogala and Symas (2004) studied the nutritional value of the protein contained in pollen substitute to be used in honeybee nutrition, and reported 24–27% protein content of pollen loads, values close to the result of this study. On the other hand, Almeida-Muradian *et al.* (2005) obtained the values of 21%

protein content (d.b.) of dried pollen mixture of multifloral source from the south region of Brazil, and Salamanca-Grosso *et al.* (2008) determined 17% protein content of dried pollen mixture from the Boyacá region of Colombia. Szczêsna (2006a) investigated the protein composition of honeybee-collected pollen from a single floral source, and found that the concentration of crude protein content was dependent on the floral origin of pollen and was in the range of 13–24.5%.

The fat content (d.b.) increased slightly as the drying temperature increased. The bee pollen from La Calera zone had a fat content in the range of 4–5%, similar to the data (5.5%) of bee pollen from *Aloe greatheadii* var. *davyana*, which is the most important indigenous South African bee plant (Human and Nicolson 2006). Almeida-Muradian *et al.* (2005) reported the values of 7% fat content of dried pollen from the south region of Brazil. In contrast, the fat content of bee pollen from Zipaquira zone was between 1.1 and 2.2%, in agreement with the results reported elsewhere (Salamanca-Grosso *et al.* 2008). The fat content of multifloral bee pollen from Poland, Korea and China was around 8.67, 5.47 and 6.19%, respectively (Szczêsna 2006b). The predominating fatty acids, measured by gas chromatography, are linoleic acid, palmitic acid, oleic acid and arachidic acid (Bastos *et al.* 2004; Szczêsna 2006b). The fat content of bee pollen from La Calera zone (3.8–5.1%) was higher than that from Zipaquira zone (1.1–2.2%).

The drying temperature did not significantly affect the ash content of pollen. The ash content of bee pollen from Zipaquira zone (3.0–3.33%) for the three treatments were higher compared with those from La Calera zone (2.1–2.89%). The results of ash content in this study were lower compared with the data reported by Human and Nicolson (2006), which ranged from 3.6 to 4.5%. The ash content of pollen from La Calera zone was in agreement with Almeida-Muradian *et al.* (2005) and Salamanca-Grosso *et al.* (2008), which were in the range of 2.2–2.7%.

The pollen from Zipaquira zone did not have any fiber. The percentage of fiber of pollen from La Calera zone was not affected significantly by the drying temperature. The fiber content of pollen in this study is much lower compared with the results reported elsewhere (Rogala and Symas 2004; Salamanca-Grosso *et al.* 2008).

Vitamin C and Carotene Contents

This study has primarily investigated and compared the effect of drying conditions on the vitamin content to determine the efficacy of dehydration (Jayaraman and Das Gupta 1995). The vitamin C content and carotene content are shown in Table 3. Vitamin C is a water-soluble vitamin that is stable in dried form, but vitamin C solution can be easily oxidized. The term “vitamin

TABLE 3.
VITAMIN C CONTENT AND CAROTENE CONTENT IN BEE POLLEN SAMPLES*

Zone	Treatment	Vitamin C (mg/100 g sample)	Carotene (mg/g sample)
La Calera	Fresh	40.22 ± 5.5	0.77 ± 0.2
	35C	31.75 ± 3.3	0.78 ± 0.3
	45C	27.35 ± 1.6	0.51 ± 0.03
Zipaquirá	Fresh	40.37 ± 3.7	0.21 ± 0.08
	35C	32.79 ± 2.0	0.22 ± 0.08
	45C	28.75 ± 1.4	0.17 ± 0.04

* Means ± SD.

C" should be used as the generic descriptor for all compounds exhibiting qualitatively the biological activity of ascorbic acid (IUNS 1970). Ascorbic acid degradation is often used as a general indicator of changes occurring in food because of its thermal sensibility. The amount of vitamin C decreased as the drying temperature increased, but there were no significant differences between pollen from the two zones (Table 3). The drying process might speed up ascorbic acid oxidation, and, accordingly, result in a loss of vitamin C in dried pollen (Yen *et al.* 2008). In this case, the results could point out that the vitamin C contents are mainly affected by the drying temperature and not by the pollen origin.

The provitamins are substances that can be converted into vitamins. Carotenes are intermediary or precursory compounds of vitamin A for humans and some other mammals, and can be stored in the liver and body fat. Carotenes are highly sensitive to oxygen and light. When these factors are excluded, carotenes in food are stable even at high temperatures. Their degradation is, however, accelerated by intermediary radicals occurring in food because of lipid oxidation (Belitz *et al.* 2004). Even though, the decrease in water activity during the drying process can concentrate the antioxidant and preserve the carotenoids. There was a significant difference between pollen from the two zones. The bee pollen from La Calera zone (0.51–0.78 mg carotene/g pollen) presented a higher carotene content compared with that from Zipaquira (0.17–0.22 mg carotene/g pollen), which depended on the botanical origin of the pollen pellets.

There was no significant difference between carotene content of fresh pollen and dried pollen at 35C; however, the dried pollen at 45C gave higher levels of carotene losses, mainly in pollen pellets from La Calera zone. The beneficial effects of carotene to human health have been well documented (Zamora *et al.* 1991; Borek 2005; Brandt and Goldbohm 2006). Thus, improving the stability of carotenoids during the drying process is an important objective to make the final product more nutritious and marketable.

Mean Particle Size and Solubility Index

The particle size of pollen pellets depended on the pollen origin as shown in Fig. 3 (Mitsumoto *et al.* 2009). The bee pollen from La Calera zone had a higher mean particle size (837–845 μm) with no significant difference between treatments. In the case of bee pollen from Zipaquira zone, the mean particle size was in the range of 824–828 μm, although not statistically significant differences, the dried pollen at 45C had higher particle size compared with the other samples of the same zone. Mitsumoto *et al.* (2009) analyzed the particle sizes of pollen grains from nine plant species by scattering of laser light and microscopic fluorescence image analysis. The authors reported that the mean size of the pollen grains was in the range of 20.7–34.1 μm. Vizcarra-Mendoza *et al.* (1998) determined the mean particle size (Sauter diameter) of bee pollen by sieve analysis, and found that the mean particle size was around 1,900–3,700 μm. The authors also reported that the smaller particle had the lower densities because the pollen particles are composed of pollen, nectar and bee saliva.

The dried pollen had a high solubility index because the samples presented dissolution times near to 50 s. The solubility index curves of pollen from La Calera zone are shown in Fig. 4, which were similar for both temperatures, but with slightly higher values at 35C. Figure 5 shows the solubility index curves of pollen from Zipaquira zone, and there is also no difference between the two drying temperatures. The dried pollen from Zipaquira had

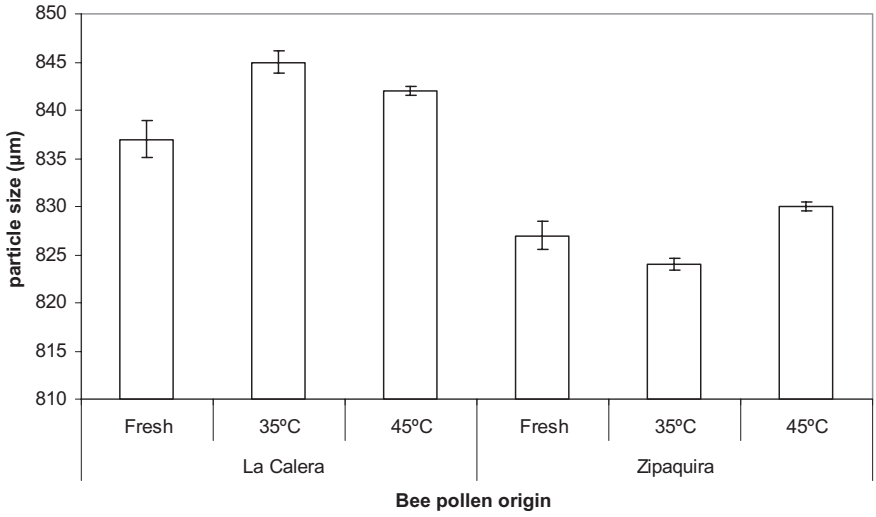

FIG. 3. MEAN PARTICLE SIZE OF BEE POLLEN PELLETS ACCORDING TO THE ORIGIN ZONE AND TREATMENT (MEANS ± SD)

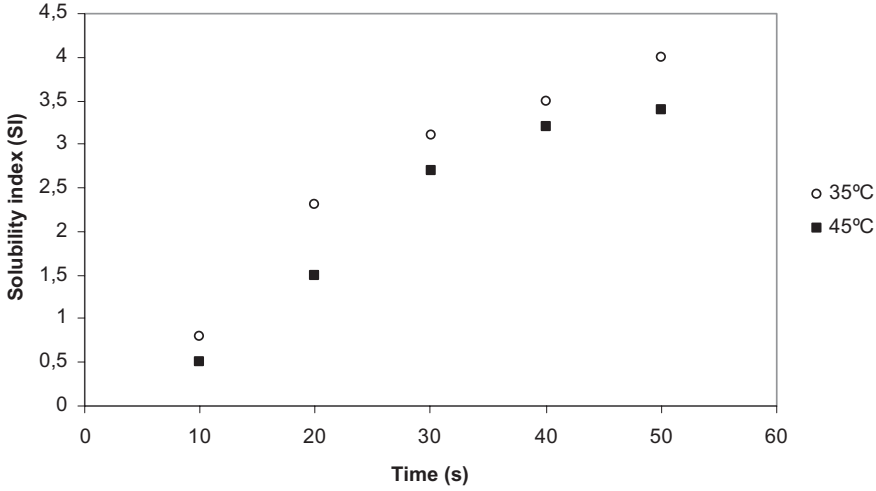

FIG. 4. SOLUBILITY INDEX OF DRIED BEE POLLEN FROM LA CALERA ZONE

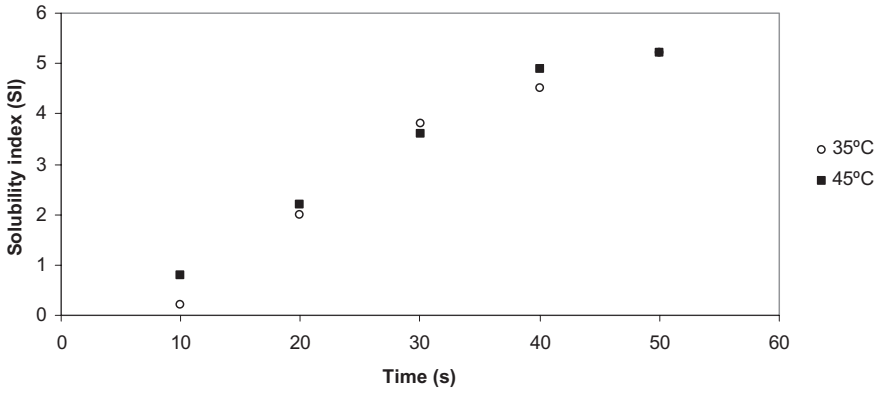

FIG. 5. SOLUBILITY INDEX OF DRIED BEE POLLEN FROM ZIPAQUIRA ZONE

higher solubility index than that from La Calera zone, possibly because of the lower mean particle size, which allowed easier dissolution of sample in aqueous solution at 20C.

CONCLUSION

The effect of drying temperature and bee pollen origin was studied. The protein content (28%), fiber content (0.4%) and ash content (2–3%) of samples

were not affected by the drying temperature. Higher drying temperature resulted in reduced drying times, moisture content and water activity. The carotene content of bee pollen depended on the botanical origin of the pollen pellets. There was no significant difference between carotene content of fresh pollen and dried pollen at 35C; however, the dried pollen at 45C had lower levels of carotene content, mainly in pollen pellets from La Calera zone. The vitamin C content decreased as the temperature drying increased. The solubility index of bee pollen from La Calera zone was lower because of its lower mean particle size.

The best conditions for the drying of bee pollen were not clearly determined. The drying process of bee pollen at 45C had shorter drying times, moisture content and water activity, but higher levels of carotene and vitamin C losses. Further studies on the range of drying temperatures, properties (color and porosity) of dried bee pollen, pollinate plants and different place of origin could be helpful to the beekeepers to find the best drying process conditions.

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REFERENCES

ALMEIDA-MURADIAN, L.B., PAMPLONA, L.C., COIMBRA, S. and BARTH, O.M. 2005. Chemical composition and botanical evaluation of dried bee pollen pellets. J. Food Compost. Anal. *18*, 105–111.

AOAC. 1997. *Official Methods of Analysis of AOAC International*, 16th Ed., 3rd Rev., Assoc. of Official Analytical Chemists, Gaithersburg, MD.

BARBOSA-CÁNOVAS, G.V. and VEGA-MERCADO, H. 1996. *Dehydration of Foods*, pp. 265–288, Chapman & Hall, New York, NY.

BARTH, O.M. and LUZ, C.F.P. 1998. Melissopalynological data obtained from a mangrove area near to Rio de Janeiro, Brazil. J. Apic. Res. *37*(2), 155–163.

BASTOS, D.H.M., BARTH, O.M., ROCHA, C.I., CUNHA, I.B.S., CARVALHO, P.O., TORRES, E.A.S. and MICHELAN, M. 2004. Fatty acids profile and palynological analysis of bee (*Apis*) pollen loads in the states of São Paulo and Minas Gerais, Brazil. J. Apic. Res. *43*(2), 35–39.

BELITZ, H.D., GROSCH, W. and SCHIEBERLE, P. 2004. *Food Chemistry*, pp. 232–234, Springer-Verlag, Berlin, Germany.

BERNAL, I. 1998. *Análisis de Alimentos*, pp. 71–105, Editorial Guadalupe, Bogotá, Colombia.

BOREK, C. 2005. Antioxidants and the prevention of hormonally regulated cancer. J. Mens Health Gend. *2*(3), 346–352.

BRANDT, P.A.V.D. and GOLDBOHM, R.A. 2006. Nutrition in the prevention of gastrointestinal cancer. Best Pract. Res. Clin. Gastroenterol. *20*(3), 589–603.

CRAPISTE, G. and ROTSTEIN, E. 1997. Design and performance evaluation of dryers. In *Handbook of Food Engineering Practice* (K. Valentas, E. Rotstein and R.P. Singh, eds.) pp. 125–166, CRC Press, New York, NY.

DOYMAZ, I. 2009. An experimental study on drying of green apples. Drying Technol. *27*, 478–485.

ENSOR, W., OSLON, H. and COLENBRANDER, V.F. 1970. A report. Committee on classification of particle size in feedstuffs. J. Dairy Sci. *53*, 689.

GARAU, M.C., SIMAL, S., ROSSELLÓ, C. and FEMENIA, A. 2007. Effect of air-drying temperature on physico-chemical properties of dietary fibre and antioxidant capacity of orange (*Citrus aurantium* v. Canoneta) by-products. Food Chem. *104*, 1014–1024.

GEANKOPLIS, C.J. 1993. *Transport Processes and Unit Operations*, pp. 579–634, Prentice Hall International, Englewood Cliffs, NJ.

GLEITER, R.A., HORN, H. and ISENGARD, H.D. 2006. Influence of type and state of crystallization on the water activity of honey. Food Chem. *96*, 441–445.

HUMAN, H. and NICOLSON, S.W. 2006. Nutritional content of fresh, bee-collected and stored pollen of *Aloe greatheadii* var. *davyana* (Asphodelaceae). Phytochemistry *67*, 1486–1492.

IUNS (INTERNATIONAL UNION OF NUTRITIONAL SCIENCES). 1970. Tentative rules for generic descriptors and trivial names for vitamins and related compounds. Nutr. Metab. *12*, 371–384.

JAYARAMAN, K.S. and DAS GUPTA, D.K. 1995. Drying of fruits and vegetables. In *Handbook of Industrial Drying* (A.S. Mujumdar, ed.) pp. 643–691, Marcel Dekker, New York, NY.

KINGSLY, R.P., GOYAL, R.K., MANIKANTAN, M.R. and ILYAS, S.M. 2007. Effects of pretreatments and drying air temperature on drying behaviour of peach slice. Int. J. Food Sci. Technol. *42*, 65–69.

MADR (MINISTERIO DE AGRICULTURA Y DESARROLLO RURAL). 2006. *La cadena de abejas y apicultura en Colombia*. In Documento de Trabajo No. 124, pp. 1–16, Bogota, Colombia.

MEDA, L. and RATTI, C. 2005. Rehydration of freeze-dried strawberries at varying temperatures. J. Food Process Eng. *28*, 233–246.

MITSUMOTO, K., YABUSAKI, K. and AOYAGI, H. 2009. Classification of pollen species using autofluorescence image analysis. J. Biosci. Bioeng. *107*(1), 90–94.

MONTGOMERY, D.C. 2001. *Design and Analysis of Experiments*, 5th Ed., pp. 218–276, John Wiley & Sons Inc., New York, NY.

RAMASWAMY, H. and MARCOTTE, M. 2006. *Food Processing Principles and Applications*, pp. 233–277, CRC Press, Taylor & Francis Group, Boca Raton, FL.

ROGALA, R. and SYMAS, B. 2004. Nutritional value for bees of pollen substitute enriched with synthetic amino acids. J. Apic. Sci. *48*, 19–27.

ROULSTON, T.H. and CANE, J.H. 2000. Pollen nutritional content and digestibility for animals. Plant Syst. Evol. *222*, 187–209.

SALAMANCA-GROSSO, G., PÉREZ-FIGUEREDO, C.R. and VARGAS, E.F. 2008. *Origen botánico, propiedades fisicoquímicas y microbiológicas del polen colectado en algunas zonas apícolas de la campiña de Boyacá*. CESIA-CIBSA 2008, pp. 406–411, Barcelona, Spain.

SOKHANSANJ, S. and JAYAS, D.S. 1995. Drying of foodstuffs. In *Handbook of Industrial Drying* (A.S. Mujumdar, ed.) pp. 589–626, Marcel Dekker, New York, NY.

SZCZÊSNA, T. 2006a. Protein content and amino acid composition of bee-collected pollen from selected botanical origins. J. Apic. Sci. *50*(2), 81–90.

SZCZÊSNA, T. 2006b. Long-chain fatty acids composition of honeybee-collected pollen. J. Apic. Sci. *50*(2), 65–79.

TOLEDO, R.T. 2007. *Fundamentals of Food Process Engineering*, pp. 431–473, Springer, New York, NY.

VIZCARRA-MENDOZA, M.G., RUIZ-MARTINEZ, R.S., MARTINEZ-VERA, C., IRUEGAS-EVARISTO, A. and CARRILLO-GUERRERO, J.M. 1998. Treatment of pollen by fluidization. Drying Technol. *16*(9 & 10), 1843–1853.

YEN, Y.H., SHIH, C.H. and CHANG, C.H. 2008. Effect of adding ascorbic acid and glucose on the antioxidative properties during storage of dried carrot. Food Chem. *107*, 265–272.

ZAMORA, R., HIDALGO, F.J. and TAPPEL, A.L. 1991. Comparative antioxidant effectiveness of dietary beta-carotene, vitamin E, selenium and coenzyme Q10 in rat erythrocytes and plasma. J. Nutr. *121*, 50–56.

ZHANG, D. and MOORE, W.R. 1997. Effect of wheat bran particle size on dough rheological properties. J. Food Sci. Agric. *74*, 490–496.