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Infrared drying of bee pollen: effects and impacts on food components

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Abstract: Infrared radiation drying being one of the innovative drying methods was chosen to perform comparative study at different infrared power levels at 50, 62, 74 and 88 W. Quality attributes such as protein, fat, ash, carbohydrate, vitamin C content, solubility index and colour of infrared dried bee pollen samples were evaluated. The infrared power has a significant effect on the drying and quality characteristics especially colour. Drying time was reduced from 170 to 50 min when the infrared power level increased from 50 W to 88 W. Morphological changes on the surface of bee pollen grains increased with increasing the infrared power. The bee pollen infrared dried at 50 W retained its quality characteristics better than the bee pollens infrared dried at other power levels.

Keywords: colour; drying time; infrared power level; moisture; quality attributes; solubility index

Bee pollen is made by worker bees as the result of the agglutination of flower pollen, collected at the entrance of the hive and contains nectar and honeybee salivary substances (Campos *et al.* 2008). Bee pollen with high moisture content is perishable after a short period of time from the harvest because it is highly susceptible to microbial attacks and encounters postharvest problems (Bogdanov 2004). Therefore, the moisture content of the bee pollen is regarded to be between 6–10 g water/100 g product or between 6.4–11.1 g water/100 g dry solid after the drying to obtain a shelf stable product (Campos *et al.* 2008).

Infrared drying is a very effective drying method employed for the drying of agricultural products. The advantages of infrared energy in food dehydration are decreased drying time, high quality food products, high energy efficiency and uniform temperature in the dried product (Sadin *et al.* 2014; Doymaz 2015). Infrared drying is used in the drying of several agricultural products including tomatoes (Doymaz 2012; Sadin *et al.* 2014), carrot (Doymaz 2015), strawberry (Adak *et al.* 2017) and red pepper (Cao *et al.* 2016). However, no study on infrared drying of bee pollen has been reported in literature. Hence, the main objectives of this study were to investigate the effect of infrared power levels on the drying time, and determine the effect of infrared drying power levels on some physicochemical properties of bee pollen.

MATERIAL AND METHODS

Material. Fresh bee pollen used in this study was obtained from Kemaliye-Erzincan region of Turkey where Asteraceae, Fabaceae, Lamiaceae, Salicaceae and Scrophulariaceae were the most observed botanical families in the bee pollens. Bee pollens were transferred to the laboratory under chilled conditions within the same day they were harvested, and kept in a refrigerator (+4°C) prior to the drying experiments. Moisture content of the fresh and dehydrated bee pollens was determined using the AOAC method

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925.10 (2005). The initial moisture content of bee pollen was found to be 0.28 ± 0.003 g water/g dry solid.

Experimental procedure. A moisture analyser with a 250 W halogen lamp (Snijders moisture balance; Snijders b.v., Holland) was used for infrared drying experiments. Prior to the drying trials, the samples weighing approximately 25 ± 0.5 g were separated evenly and homogeneously over the pan, having a thickness of about 4 millimetres. The drying experiments were performed at infrared power levels between 50–88 W. The infrared power level was set in control unit of the equipment, and it was measured using an energy meter (PeakTech 9035; PeakTech®, Germany). During the drying trials, the pan was taken out at 10-min interval, and the weight loss was recorded using a digital balance (Ohaus Scout®Pro; Ohaus Corp., USA) with an accuracy of ± 0.01 g. All the trials were conducted in triplicate until the final moisture content of bee pollens reached to 0.081 ± 0.003 g water/g dry solid. The dried products were packed under vacuum with a composite film containing an aluminium layer barrier to oxygen and water vapour.

Determination of chemical and physical properties. The moisture contents of the bee pollen at any given time during drying were computed according to the Equation (1):

$$M_t = (W_t - W_s) / W_s \quad (1)$$

where: M_t – moisture content at any given time (g water/g dry solid); W_t – weight of sample at any time (g); W_s – weight of dry solid content of sample (g)

The bee pollen samples were analysed for crude protein content as described in the AOAC method 984.13 (2005). The crude protein content is calculated according to formula given below:

$$\text{Crude protein (g/100g)} = \text{nitrogen (g/100g)} \times 6.25 \quad (2)$$

The crude fat content in each sample was determined according to the procedure given in the AOAC method 920.39 (2005). The ash content of the bee pollen samples was determined according to the AOAC method 968.08 (2005). The total carbohydrates are obtained as suggested by Estevinho *et al.* (2012):

$$\text{Total carbohydrates (g/100g)} = 100 - (\text{ash} + \text{proteins} + \text{fats}) \quad (3)$$

Vitamin C contents of bee pollens were determined based on the AOAC method 967.21 (2005) modified by Jiang *et al.* (2014) and Oliveira *et al.* (2009). The vitamin C content of the samples is calculated from the formula given below:

$$\text{Vit C (mg/100 g)} = \frac{100\,[(V - V_0)\,T]}{m} \quad (4)$$

where: T – amount that every millilitre of 2,6-dichlorophenol-indophenol (DCIP) can titrate the standard ascorbic acid solution (0.02 mg/ml); V – volume of DCIP used in this experiment; V_0 – blank; m – mass of sample in the solution (g)

The solubility index, which is defined as the amount of dried pollen that can dissolve in water, is determined as described by Barajas *et al.* (2012):

$$SI = (W_d - W_r) / (W_0 - W_d) \times 100 \quad (5)$$

where: SI – solubility index (dried pollen that can dissolve in water) of dried bee pollen; W_r – weight of the sample after immersion (g); W_d – weight of the sample after drying (g); W_0 – initial weight of the sample (g)

The instrumental colour parameters of bee pollen samples were determined using a Konica Minolta CR-400 (Sensing Inc., Japan) Chroma meter equipped with a D_{65} illuminant and operating with CIE $L^*a^*b^*$ (L^* 0–100; a^* – green to + red; b^* – blue to + yellow) colour space. Calibration was performed with the white colour calibration tile prior to the colour measurements. Ten separate measurements were randomly taken from the surface of the bee pollen samples inside the quartz cell, and the results were given as the average of ten separate measurements. The total colour difference (ΔE) of bee pollen samples is characterized by using the following formula (Rayaguru *et al.* 2011; Cao *et al.* 2016):

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (6)$$

$$\Delta L = L^* - L^*_0;\ \Delta a = a^* - a^*_0 \text{ and } \Delta b = b^* - b^*_0 \quad (7)$$

where: L^*_0, a^*_0 and b^*_0 – fresh bee pollen; L^*, a^* and b^* – dried bee pollen

Scanning electron microscopy (SEM) analysis. The structure and morphology of fresh and dried bee pollen samples were analysed using a scanning electron microscope (Philips XL30 FEG; Philips, USA) operating at a voltage of 5 kV. The bee pollen samples were mounted on SEM stubs, and sputter coated with a thin layer of gold using a sputter coater (Quorum SC7620; Quorum Technologies, UK).

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Statistical analysis. One-way analysis of variance (ANOVA) followed by post hoc analysis using Tukey's multiple range test with a significance level (a) of 0.05 was performed to determine statistical differences between the means of the results for the crude proteins, fats, ash, total carbohydrates, vitamin C, solubility index and colour for the bee pollen samples. The differences between the means are regarded as statistically significant at $P \leq 0.05$. All statistical analyses were performed using Minitab 16.1 software (Minitab Inc., USA).

RESULTS AND DISCUSSION

Drying characteristics. The drying curves representing the variation of moisture content with time at different infrared power levels are shown in Figure 1. The results showed that drying time decreased greatly when the infrared power increased. Drying of the bee pollen samples at the infrared power levels of 50, 62, 74 and 88 W to the final moisture content took 170, 130, 80 and 50 min, respectively. The drying time was shortened by 70.6% when the infrared power was increased from 50 W to 88 W. This is because the rate of mass transfer is higher at higher power levels. Similar results have also been observed for the drying of some agricultural products (Doymaz 2015; Olanipekun *et al.* 2015; Cao *et al.* 2016).

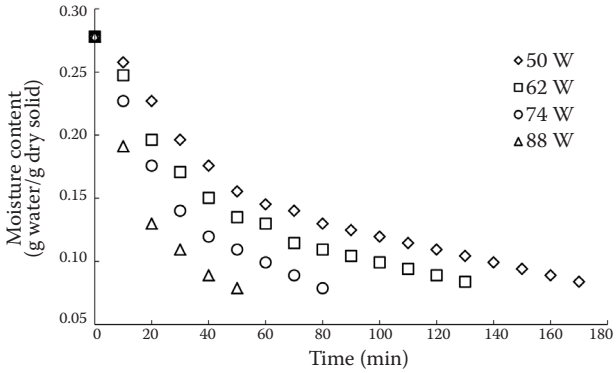


Figure 1. Drying curves of bee pollen samples at different infrared powers

Effect of infrared power on quality parameters. The change in the physicochemical properties of bee pollen dried at different infrared power levels is given in Table 1. The crude protein of fresh bee pollen was 30.36 ± 0.63 g/100 g while the crude protein content of the infrared dried bee pollen samples varied from 17.44 ± 0.50 to 24.38 ± 0.35 g/100 g. The crude protein content of bee pollens dried at 50 W, 62 W, 74 W, and 88 W infrared powers was significantly different ($P \leq 0.05$) from that of the fresh bee pollen. The crude protein content decreased with increasing the infrared power level. The most significant decline in the amount of protein was observed at 88 W.

The fat content of fresh bee pollen was 5.50 ± 0.04 g per 100 g. The fat content of bee pollens dried at different infrared powers varied from 5.99 ± 0.17 to 7.50 ± 0.14 g per 100 g. The fat content of the fresh bee pollen was statistically different ($P \leq 0.05$) than those of the infrared dried bee pollen samples except the bee pollen sample infrared dried at 50 W. Fat content values for the infrared dried bee pollens in this study were similar to those reported by Almeida-Muradian *et al.* (2005) who found a fat content of 5–9 g/100 g for the dried bee pollen pellets collected in the south region of Brazil.

Ash content is an account of the inorganic matter found in bee pollen. The infrared power level did not affect the ash content of the bee pollen. This result is consistent with the results of Almeida-Muradian *et al.* (2005) and Barajas *et al.* (2012).

Carbohydrates constitute the biggest fraction of the total weight of the bee pollen (Villanueva *et al.* 2002). Statistically significant differences ($P \leq 0.05$) were observed between the total carbohydrates of fresh and dried bee pollen samples. A high infrared power allows faster heating of the bee pollen samples and shortens

Table 1. Physicochemical composition of fresh and dried bee pollens at various infrared powers*

Treatment (g/100 g)	Fresh	50 W	62 W	74 W	88 W
Crude proteins	30.36 ± 0.63^{a}	24.38 ± 0.35^{b}	22.85 ± 0.18^{b}	20.36 ± 0.53^{c}	17.44 ± 0.50^{d}
Fats	5.50 ± 0.04^{a}	5.99 ± 0.17^{ab}	6.07 ± 0.26^{b}	6.31 ± 0.03^{b}	7.50 ± 0.14^{c}
Ash	2.18 ± 0.02^{a}	2.18 ± 0.01^{a}	2.16 ± 0.02^{a}	2.20 ± 0.01^{a}	2.17 ± 0.02^{a}
Total carbohydrates	61.96 ± 0.59^{a}	67.45 ± 0.34^{b}	68.92 ± 0.24^{b}	71.13 ± 0.55^{c}	72.89 ± 0.60^{d}
Vitamin C (mg/100 g)	38.48 ± 0.69^{a}	37.05 ± 0.36^{a}	34.04 ± 0.17^{b}	27.02 ± 0.37^{c}	20.26 ± 0.41^{d}

*Values are expressed as mean ± standard deviation; values with different letters within the same row are statistically significant at $P \leq 0.05$

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the time needed to reach dryness, which may reduce metabolic losses of carbohydrates (Pelletier *et al.* 2010). Total carbohydrates in infrared dried bee pollens in this study ranged from 67.45 ± 0.34 to 72.89 ± 0.60 g per 100 g while the carbohydrate content in dried Brazilian pollen samples was found to be 52.10 g per 100 g (Carpes *et al.* 2009) and the carbohydrate content in dried Portuguese bee pollen samples changed between 60.82–70.76 g/100 g (Estevinho *et al.* 2012).

Vitamin C contents of infrared dried bee pollen samples decreased with increasing the infrared power. There is a significant difference ($P \leq 0.05$) between the vitamin C contents of infrared dried and fresh bee pollens. Among the infrared dried bee pollen samples, the bee pollen infrared dried at 50 W retained almost 96% of its vitamin C as compared with that of fresh one. As the infrared power was increased from 50 W to 88 W the loss in vitamin C content of the bee pollen samples increased from 4% to 47%. Vitamin C is a very thermosensitive compound, and an increase in the infrared power speeds up the oxidation of vitamin C resulting in loss in vitamin C content of the dried bee pollen.

The solubility index of infrared dried bee pollen samples after 50 s of dissolution was between 8 and 8.5 (Figure 2). These values revealed that the infrared dried bee pollen had a high solubility index because the bee pollen samples had dissolution times around 50 seconds. Barajas *et al.* (2012) reported that after 50 s of dissolution, the solubility index values of two different hot air dried Colombian bee pollens were 3.5 and 5.5, respectively, which were lower than the solubility index values of infrared dried bee pollen samples in this study. This means that the infrared dried bee pollen samples are more easily soluble in water than the hot air dried Colombian bee pollen samples.

Colour values of the bee pollen samples dried at four different infrared powers are shown in Figure 3. All the

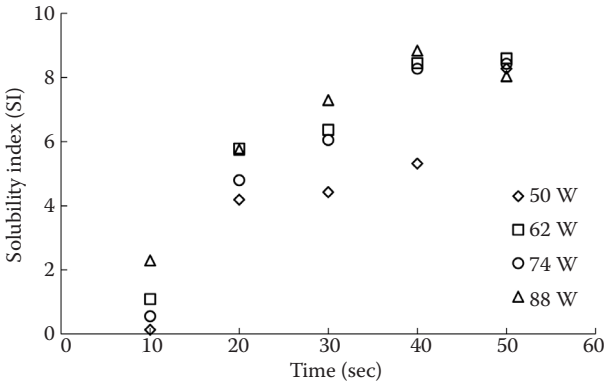


Figure 2. Solubility index of the bee pollen dried at various infrared powers

infrared dried bee pollen samples showed lower L^* and b^* values than the fresh bee pollen while a^* values of the infrared dried bee pollen samples were slightly higher than that of the fresh bee pollen, but the difference was not statistically significant ($P > 0.05$). The increase in a^* value and decrease in L^* value could result from non-enzymatic browning (Maillard reaction) during the drying process (Mireles-Arriaga *et al.* 2016; Doymaz 2018). The parameter L^* indicates

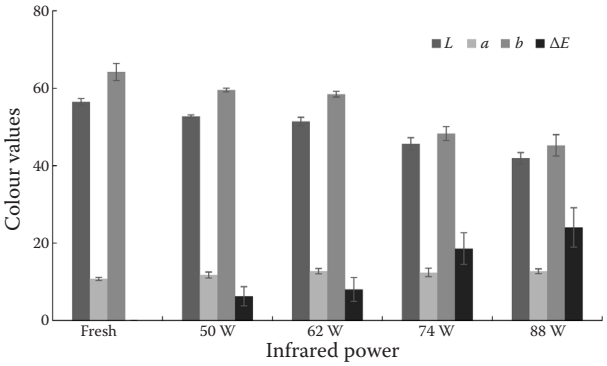


Figure 3. Effect of infrared power on colour parameters. Error bars represent ± standard deviations

the darkness or lightness of the colour, and L^* value decreased from 52.72 to 41.95 when the infrared power was increased from 50 W to 88 W, respectively. The decrease in b^* value is interpreted as a decrease in yellow colour. The b^* values of the infrared dried bee pollens decreased with increasing the infrared power. Compared with the b^* value of the fresh bee pollen, there was no statistically significant difference ($P > 0.05$) between the b^* values of the bee pollen samples infrared dried at 50 W and 62 W. The analysis of ΔE values of the infrared dried bee pollen samples indicated that ΔE was the lowest for the bee pollen infrared dried at 50 W while the highest ΔE was attained for the bee pollen dried at 88 W in which higher infrared power levels led to larger ΔE values. As lower ΔE values are favourable, the colour of the bee pollen infrared dried at 50 W is the closest to the colour of the fresh bee pollen.

Scanning electron microscopy. Fresh bee pollen grains varied in size from 28μm to 35 μm, and were bilaterally symmetrical and mostly had an elliptical shape with a longitudinal crevice (Figure 4A). The surface of the fresh bee pollen grains is mostly smooth as compared with those of the infrared dried bee pollens. The morphological changes on the surface of bee pollen grains increased with increasing the infrared power (Figure 4B–4E). This was due to the fact that

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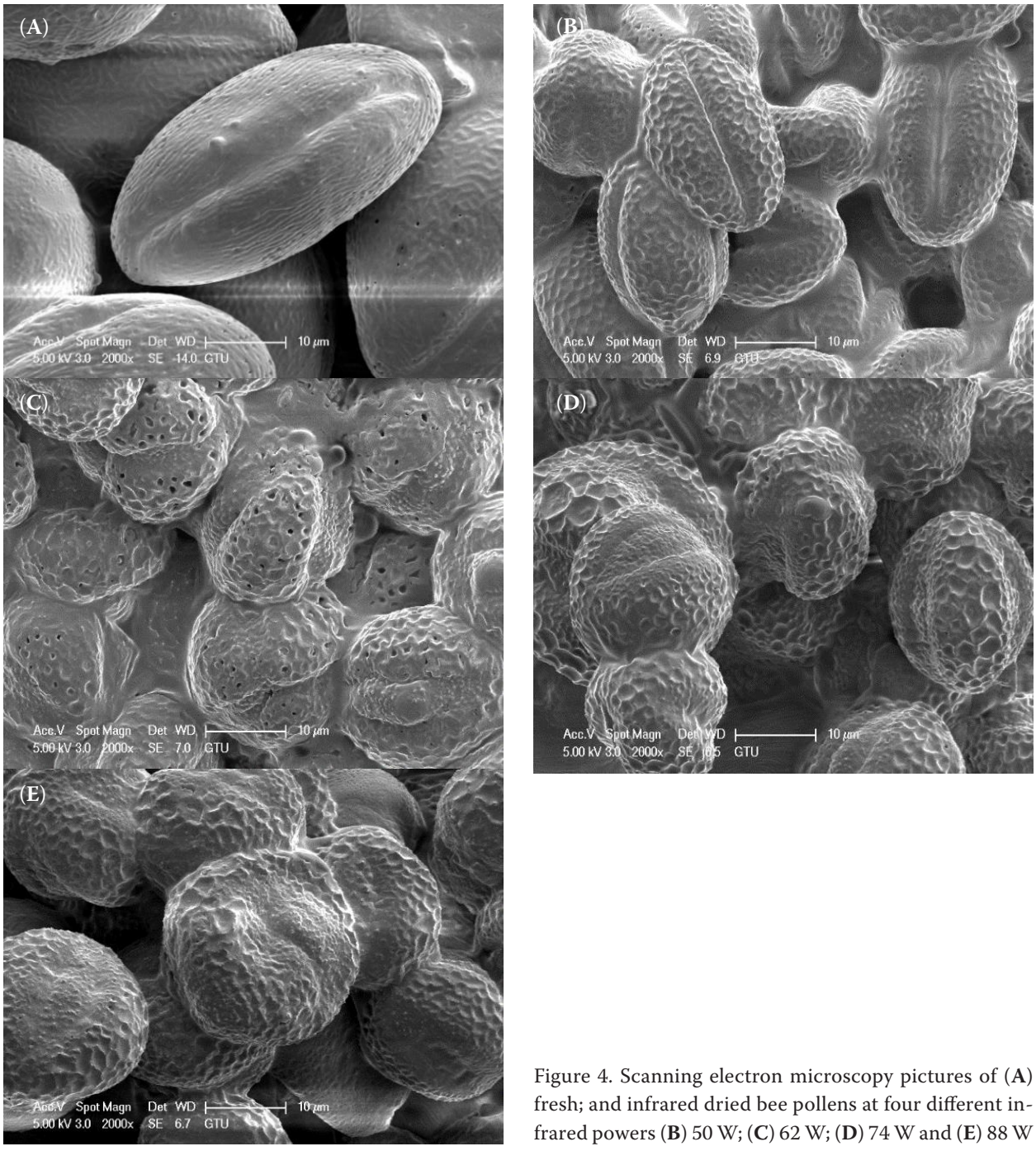


Figure 4. Scanning electron microscopy pictures of (**A**) fresh; and infrared dried bee pollens at four different infrared powers (**B**) 50 W; (**C**) 62 W; (**D**) 74 W and (**E**) 88 W

more water was evaporated as the infrared power level increased that resulted in increased morphological changes on the surface of the bee pollen grains.

CONCLUSIONS

In this study, the drying and quality characteristics of the bee pollen samples were investigated in an infrared dryer at different infrared powers. Higher infrared powers reduced the drying time, but they affected the physicochemical properties of the bee pollen. Crude proteins, fat, total carbohydrate and vitamin C of the dried bee pollen samples were affected by the infrared power, but the ash content was not affected by the infrared power. Infrared dried bee pollen samples after 50 s of dissolution were found to be highly soluble in aqueous solution. All the infrared dried bee pollen samples showed lower L^* and b^* values than the fresh bee pollen while a^* values

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of the infrared dried bee pollens were not statistically significant ($P > 0.05$) as compared with a^* value of the fresh bee pollen. ΔE was the lowest for the bee pollen dried at 50 W. Morphological changes occurred on the surface of the dried bee pollens as the infrared power increased. Overall analyses of the drying behaviour and evaluation of the physicochemical properties of the dried bee pollen samples showed that the bee pollen infrared dried at 50 W retained its quality attributes much better than the bee pollen samples dried at other infrared power levels. Therefore, drying at an infrared power level of 50 W is recommended for the infrared drying of the bee pollen.

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