Study of sorption behavior, shelf life and colour kinetics of vacuum puffed honey powder at accelerated storage conditions

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Abstract In the study, the storage life of vacuum puffed honey powder at accelerated storage environment (90 % relative humidity and 36 °C) was computed by determining the sticky-point moisture content as the critical parameter of the honey powder. The value of monolayer moisture content in the GAB model was calculated to be 0.081 kg water/kg dry solids by fitting water activity and moisture sorption data. Shelf life of the honey powder was predicted to be 222 days when the powder was packaged in aluminum foil-laminated polyethylene pouches with permeability value of 5.427×10^{-8} kg/m²//day/Pa. Actual shelf life of honey powder was experimentally determined as 189 days and analysis of mean relative percent derivation modulus (R_d) and root mean square (RMS) established the accuracy and acceptability of the technique for the prediction of shelf life of honey powder. Overall colour deviation pattern followed first order reaction kinetics with rate constant (k_1) as 0.037 day^{-1} . This study revealed overall colour difference of 18.1 till the end of shelf life with drastic change during initial storage period.

Keywords Vacuum puffing · Accelerated storage life · Hygroscopicity · Sticky point temperature · Shelf life · Colour kinetics

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Introduction

Honey has been acknowledged as a natural food product for human being since time immemorial. It is delicious and nutritious in comparison to sugar and has a great value in food and pharmaceutical industry (White 1975; Bogdanov et al. 2008). Dried honey powders are derived from fresh honey to which some processing aids and other ingredients are added and dried to low moisture content. Honey powder is used for dry mixes, seasonings and dry coating. The honey powder can be easily blended with dry ingredients and is consistency of its texture, aroma, flavor and color.

Fresh honey contains about 70 to 75 % of sugars (Sahu and Deepika 2013). Majority of sugars are fructose and glucose, consisting of about 85–95 % of total sugars. Fructose is more abundant than glucose in honey (Mitsukatsu et al. 1985; Sahu and Deepika 2013). This predominance of simple sugars and high percentage of fructose are responsible for most of the physical and nutritional characteristics of honey and makes it difficult for drying into a free-flowing, anti-caking and hygroscopicity free powder (Bhandari et al. 2008; Hebbar et al. 2008). Various wave applications including microwave has also successfully applied for honey processing but it caused increase in HMF and decrease in enzymatic activities (Bath and Singh 2001). Fructose and glucose are very hygroscopic in their amorphous state and lose their free flowing nature at high moisture content (Roos et al. 1996; Slade and Levine 1991). While drying at temperatures normally prevailing in a spray dryer at about 150 to 180 °C, they tend to stick to the inner wall of the drying chamber and give a paste like structure instead of free flowing powder (Masters 1985). To address this problem, vacuum puffing technique to produce free flowing powder from fresh honey was found as most effective in terms of quality attributes (Sahu 2008).

Sugars present in fresh honey exhibit low glass transition temperatures. Because of their low molecular weight, the molecular mobility of the materials is high when the temperature is just above the glass transition temperature (Roos and Karel 1991). A remarkable change in molecular mobility and physical properties in sugars takes place at the glass transition temperature (Slade and Levine 1991). Bhandari et al. (1993) and Roos (1995) reported that the temperature at which amorphous substances exhibit stickiness is about 10–20 °C higher than the glass transition temperature. Since low glass transition temperature increases the stickiness, it is required to increase the glass transition temperature of fresh honey by adding high molecular weight materials prior to its drying (Bhandari and Howes 1999). The stickiness in a sugar-rich product is caused due to plasticization of low molecular weight sugar because of water sorption and subsequent interparticle fusion (Roos et al. 1996; Bhandari et al. 2008). When the sticky-point temperature drops below room temperature, a food develops stickiness or caking (Roos 1995).

A relationship between moisture content and sticky-point temperature of honey powder can be developed by using the apparatus developed by Lazar et al. (1956). The storage life of the powder in a storage environment can be predicted by determining the sticky-point moisture content at the selected storage temperatures and by considering the sticky-point moisture content as the critical moisture content of the honey powder (Jaya and Das 2005).

Sugar-rich products such as honey and fruit juice powders require protection against ingress of moisture and oxygen and the loss of volatile flavorings and color. Fruit juice powders are usually packed in heat-sealable laminates containing a layer or layers of aluminum such as aluminum foil-laminated polyethylene. Accelerated storage involving high humidity and temperature can be used for developing moisture ingress and storage time relationships (Potter 1978). Therefore, the objective of the present study is to develop a predicted model for the shelf-life of vacuum puffed honey powder based on sticky-point temperature, moisture content and permeability of the packaging material under accelerated storage conditions.

Materials and methods

Fresh honey collected from a farm at Saiton, Imphal, in (Manipur), India was used for preparation of honey powder. The floral source of the honey was *Azadirachta indica* of family Meliaceae. Food grade pouches of aluminum coated high density polyethylene (HDPE) of standard quality with 100 µm thickness were used for shelf life study. All the reagents and chemicals used for analytical experiments were of Merck, Germany make.

Sample collection and conditioning

The honey was filtered with 0.5 mm sieve and stirred using a Mini Lab Mixer (RA–D/S/10,834, UK). The mixer was run at 500 rpm for 5 min in order to bring homogeneity of particles in the honey samples. The samples were pasteurized in an open steam jacketed scrapped surface vessel (PE/123/K, Pasteur Engineering Co. Pvt. Ltd., India) at 50 ± 1 °C for 25 min and cooled to room temperature for further analysis. At this condition, the HMF content of the honey sample as determined by the method described by Zappala et al. (2005) was 5.12 mg.kg⁻¹.

Physicochemical analysis

The sample was analyzed for moisture, total solids, total sugar, sucrose, fructose, glucose, total acid and bulk density as described by Ranganna (1987) and Sadasivam and Manickam (1996). The viscosity of honey sample was measured using a Brookfield RVDV-II+ viscometer (Brookfield Engineering, Middleboro, MA).

Color was measured using a Hunter Lab Colorimeter (Model Ultrascan Vis-Model, USA). The results of colour values were expressed in *L*, *a*, *b* system. *L* indicates degree of lightness or darkness (*L* = 0 indicates perfect black and *L* = 100 indicates most perfect white), *a* indicate degree of redness (+) and greenness (–), and *b* indicates degree of yellowness (+) and blueness (–). The instrument (45°/0° geometry, 10° observer) was calibrated with a standard black and white tile followed by measurement of the samples.

Incorporation of additives and sample preparation

Honey sample for vacuum puffing was prepared by adding different additives at the pre-optimized concentrations prescribed based on the quality criteria viz., hygroscopicity, degree of caking, flowability and sticky point temperature of final product. The optimum amount of maltodextrin, glycerol monostearate and tricalcium phosphate were added at the concentration of 0.6, 0.02 and 0.02 kg/kg of dry honey solids respectively (Sahu 2008). Maltodextrin was added to reduce the stickiness of the honey powder, tricalcium phosphate was added as anti-caking agent and glycerol monostearate was added to increase the flowability of the honey powder.

Vacuum puffing of honey mix

Puffing of honey mix was carried out in a vacuum dryer (VBK/22, Viskhi Boiler Co. Pvt. Ltd., India). The honey mix was spread in a laminated aluminum tray with a thickness of 0.003 m and the tray was kept inside the vacuum chamber. The vacuum chamber temperature was maintained at 75 °C. The thickness of the mix was computed from weight of the

mix, tray surface area and density of the mix. Absolute pressure maintained inside the vacuum chamber was $20\text{--}60 \pm 2$ mmHg. Initial weight of the tray and mix was noted. During puffing, the tray was taken out at 15 min interval with the help of a desiccating chamber and weighed using a digital electronic balance (Metler Toledo, UK). The moisture content of the puffed honey was calculated gravimetrically. Puffing was continued until the final moisture content of the product was reduced below 0.02 kg/kg dry solid. Three replicates for each of the experiments were carried out.

Measurement of quality parameters of the honey powder

The puffed honey flakes were kept in an environment maintained at 5–6 % relative humidity for a period of 30–45 min and then ground in a hammer mill (PE/23/K, Pasteur Engineering Co. Pvt. Ltd., India) at medium speed rate. The mill was fitted with a swinging hammer and a stationary sieve having sieve sizes of 0.2 mm. The milled product was further screened through a standard sieve of 100 μm mesh size.

The powder was analyzed for moisture, total solids, total sugar, sucrose, fructose, glucose, total acid, bulk density and optical parameters as described in "Physicochemical analysis" section. The quality parameters viz., hygroscopicity, degree of caking, flowability, sticky-point temperature, overall colour difference and moisture content of the honey powder were also measured.

Hygroscopicity was expressed as the final moisture content attained after exposing the powder in humid air having 79.5 % relative humidity (Pisecky 1985). Air at this relative humidity was allowed to pass through the powder kept for hygroscopicity analysis in a Gooch filter until a constant weight of the powder was obtained. A relative humidity of 79.5 % was developed using saturated salt solution of potassium nitrate at 20 ± 2 °C and maintained using air conditioning machine inside the measurement room. The hygroscopicity of the powder was calculated by using Eq. (1).

$$H_g = \frac{\frac{b}{a} + w_i}{1 + \frac{b}{a}} \quad (1)$$

where, b (g) is the increase in weight of the powder, a (g) is the amount of the powder taken for measurement and w_i % (wb) is the free water present in the powder before measurement. Generally, a powder having the hygroscopicity value less than 10 % is considered as good non-hygroscopic powder (Pisecky 1985).

After determination of hygroscopicity, the Gooch filter along with the wet sample was placed in a drying oven set at 102 ± 2 °C for 1 h (Pisecky 1985). After cooling the puffed honey sample, it was weighed and transferred into a sieve of

100 μ mesh size. The sieve was then shaken for 5 min in a shaking apparatus. The weight of the powder remaining in the sieve was measured. The degree of caking D_c (%) was calculated by using Eq. (2).

$$D_c = \frac{c}{d} * 100 \quad (2)$$

Where, d (g) is amount of the powder used for sieving and c (g) is amount of the powder left on the sieve after sieving.

Flowability was expressed as the time required for the powder to leave a rotary drum and was calculated as described by Haugaard et al. (1978). A sticky-point temperature measurement apparatus as developed by Jaya and Das (2005) was used to measure the sticky-point temperature of the powder.

For measurement of color of the powder, an amount of the powder having same level of total solids as in the liquid honey used for the powder production was reconstituted with water at 30 °C. The L , a and b values of the reconstituted powder were measured by using Hunter Lab Colorimeter (Model Ultrascan Vis-Model, USA). The total color difference ΔE_c between the liquid honey and the reconstituted honey powder was calculated by using Eq. (3).

$$\Delta E_c = \sqrt{(L_o - L_r)^2 + (a_o - a_r)^2 + (b_o - b_r)^2} \quad (3)$$

Where L_o , a_o and b_o are the L , a and b values of liquid honey and L_r , a_r and b_r are corresponding values of the reconstituted honey powder. Moisture content of the powder was determined as per the method described by AOAC (2000).

Determination of permeability of packaging material

To determine the water vapour permeability of the packaging material, 5 g of dehydrated silica gel was packed separately in two aluminium foil-laminated polyethylene (10 cmX10 cm) pouches. The two pouches were placed in an environment maintained at 90 % relative humidity and 36 ± 2 °C created using saturated potassium nitrate solution in an incubator. The temperature inside the incubator was maintained by using a contact thermometer-type temperature sensor controller. The weight of the pouches containing the silica gel was determined at 24 h intervals for 8 days and the mean weight gained by the silica gel was calculated for each day (Labuza 1984). The water vapour permeability K (kg/m²/day/Pa) of the aluminium foil-laminated polyethylene was calculated as below:

$$K = \frac{dw/d\theta p}{A_p p^*} \quad (4)$$

where, $(dw/d\theta_p)$ ($\text{kg}\cdot\text{day}^{-1}$) is the slope of linear plot between the time θ_p (day) of incubation and cumulative moisture gain, w (kg) is the weight of silica gel in the packaging material, A_p (m^2) is the surface area of the packaging material and p^* is the saturation pressure (Pa) of the water at 36°C i.e., the temperature of the environment during the experiment.

Sorption characteristics of honey powder and fitting of sorption data to GAB model

Water vapor permeability of packaging materials and hygroscopicity of honey powder lead to increase in moisture content. As the stickiness of hygroscopic powder is directly related to its moisture content and temperature, the powder exhibited stickiness after its moisture content was increased to a critical moisture content level corresponding to the temperature of the storage environment, i.e., $36 \pm 2^\circ\text{C}$. It was assumed that the particles of the powder inside the pouches gained moisture uniformly.

The static gravimetric technique based on isopiestic transfer of water vapor was adopted to fit the GAB model to moisture sorption data of the vacuum puffed honey powder (Suthar and Das 1997). Saturated salt solutions Lithium chloride, Potassium acetate, Magnesium chloride, Potassium carbonate, Magnesium nitrate, Potassium iodide, Sodium chloride, Ammonium sulphate and Potassium sulphate having relative humidity 16.5, 25.4, 31.8, 37.1, 45.8, 58.6, 65.6, 80.6 and 94.6 %, respectively, were prepared to generate controlled humidity environment in a closed chamber. The honey samples (triplicate) were weighed in the respective moisture boxes and then placed in the vacuum desiccators with a stopcock arrangement. Each desiccator had respective saturated salt solutions used to obtain constant relative humidity environment. Partial vacuum was created inside the desiccators to accelerate the sorption process. Samples were equilibrated for approximately 25–30 days as evident by constant values (± 0.001 g) of four consecutive weight reading. After equilibrium, the moisture content of each sample was determined by vacuum oven method (AOAC 2000). The equilibrium moisture content X_{emc} was determined as an average of three readings. The moisture sorption data were fitted to the GAB model as expressed in Eq. (5).

$$a_w = \frac{2 + \left(\frac{x_o}{x_{emc}} - 1\right)C - \left[\left(2 + \left(\frac{x_o}{x_{emc}} - 1\right)C_g\right)^2 - 4(1 - C_g)\right]^{0.5}}{2k_g(1 - C_g)} \quad (5)$$

where, a_w is water activity, X_{emc} (kg/kg dry solids) is the equilibrium moisture content, C_g and k_g are GAB model constants and X_o (kg/kg dry solids) is the monolayer moisture content of

the honey powder. A non-linear least square method was adopted to calculate the model constants (Ramesh 2003).

The accuracy of fit was evaluated by calculating root mean square RMS and mean relative percent derivation modulus R_d . The value of R_d is expressed by Eq. (6).

$$R_d = \frac{100}{N} \sum_{i=1}^N \frac{X_a - X_i}{X_i} \quad (6)$$

Where, X_a and X_i are the actual and predicted moisture content (derived from equation-7) of the powder, respectively and N is the total number of observations. A value of R_d less than 10 % is considered as a reasonably good fit for the model to the real experimental values (Lomauro et al. 1985; Das 2005).

Accelerated storage and determination of shelf-life of honey powder

Twenty grams of vacuum puffed honey powder with an initial moisture content of 0.022 kg/kg dry solid was packed by heat sealing separately in aluminium foil-laminated polyethylene ($10 \text{ cm} \times 10 \text{ cm}$) pouches. The pouches were placed in an environment maintained at 90 % relative humidity and $36 \pm 2^\circ\text{C}$ as mentioned in "Determination of permeability of packaging material" section. Eight such pouches were kept under the above environment conditions. The pouches were taken out at an interval of 15 days and analyzed for moisture content ($\text{kg water/kg dry solids}$), water activity and overall colour difference until the samples attained the maximum stickiness.

The change in moisture content ($dX/d\theta$) of the honey powder with respect to storage time θ is given as:

$$X_s \frac{dX}{d\theta} = K A_p (Rh p^* - a_w p^*) \quad (7)$$

Where, X_s (kg) is the dry weight of powder inside the pouch, X is the moisture content after θ days of storage time, K ($\text{kg/m}^2/\text{day/Pa}$) is the permeability of the packaging material, A_p (m^2) is the surface area of the packaging material through which water vapour permeates, p^* (Pa) is the saturation vapour pressure of water at storage temperature $T^\circ\text{C}$, Rh is the relative humidity of the storage environment and a_w is the water activity of the powder at $T^\circ\text{C}$. The integration of Eq. (7) with initial and critical moisture content value is used to predict the shelf-life of the honey powder.

On integration of Eq. (7) from initial moisture content X_i to critical moisture content X_c , the storage-life can be expressed as:

$$\theta = \frac{X_s(X_c - X_i)}{K A_p (Rh p^* - a_w p^*)} \quad (8)$$

Colour kinetics during storage

From the values of overall colour difference (ΔE) of vacuum puffed honey powder during storage under accelerated storage conditions, the rate constant k (1/day) and the order of reaction n (Lau et al. 2000) were estimated from Eq. (6):

$$\frac{d(\Delta E^* - \Delta E)}{d\theta} = -k_c(\Delta E^* - \Delta E)^n \quad (9)$$

where ΔE^* is the maximum possible overall color difference of stored honey powder till the end. The value of ΔE^* was obtained from a graphical plot of the experimental values of ΔE and θ . Solving Eq. (6) for $n = 0$ (zero order), $n = 1$ (first order) and $n = 2$ (second order), and considering that $\Delta E = 0$ at $\theta = 0$, the following equations (Eqs. 10, 11, and 12 respectively) are derived:

$$\Delta E^* - \Delta E = \Delta E^* + k_0\theta \quad (10)$$

$$\ln(\Delta E^* - \Delta E) = \ln(\Delta E^* + k_1\theta) \quad (11)$$

$$\frac{1}{(\Delta E^* - \Delta E)} = \frac{1}{\Delta E^*} - k_2\theta \quad (12)$$

Where, k_0 , k_1 and k_2 are reaction rate constants for the zero-order, first-order and second-order reactions, respectively. Value of these constants can be obtained from the slope of the linear plot between (1) $(\Delta E^* - \Delta E)$ and θ ; (2) $\ln(\Delta E^* - \Delta E)$ and θ and (3) $1/(\Delta E^* - \Delta E)$ and θ of Eqs. (10), (11) and (12) respectively. The kinetic order of the reaction responsible for the change in overall color difference of the honey powder will be the kinetic order corresponding to the maximum correlation coefficient between the observed and the predicted values of $(\Delta E^* - \Delta E)$ obtained from Eqs. (10), (11) and (12).

Statistical analysis

All the experiments were carried out in triplicate. Tests of significant differences between means were determined by Duncan's multiple range test at a significance level of 0.05. All the analysis and curve fitting etc. are carried out by using SPSS 11.5 (SPSS Inc., USA) and Design Expert-8 software.

Results and discussion

Physicochemical and quality analysis of liquid and powder honey

Physicochemical and quality attributes of fresh and vacuum puffed honey powder is presented in Table 1. Average values

Table 1 Physicochemical and quality attributes of liquid honey and vacuum puffed honey powder

Parameters	Fresh liquid honey	Honey powder
Moisture content (wb) (kg/kg)	0.182 ± 0.005	0.02 ± 0.004
Total solids (kg/kg)	0.812 ± 0.011	0.978 ± 0.009
Sucrose (kg/kg)	0.035 ± 0.007	0.014 ± 0.001
Fructose (kg/kg)	0.382 ± 0.001	0.155 ± 0.004
Glucose (kg/kg)	0.314 ± 0.005	0.126 ± 0.003
Total acid (as gluconic acid) (kg/kg)	0.0055 ± 0.0012	0.0042 ± 0.0002
Ash content (kg/kg)	0.0072 ± 0.0031	0.0086 ± 0.0036
Bulk density (kg.m ⁻³)	1462	-
Viscosity (Poise)	1841	-
Hygroscopicity (%)	-	8.40 ± 0.32
Degree of caking (%)	-	12.95 ± 0.41
Flowability (s)	-	23.83 ± 0.65
Sticky point temperature (°C) (at 5 % db)	-	48.56 ± 0.71
Overall color difference (ΔE)	-	8.12 ± 0.43

(Mean ± SD, $n = 3$)

of total solids, sucrose, fructose, glucose, total acid (as gluconic acid) and ash content of liquid honey indicates that around 85 % of total solid is contributed by different sugar components. Sticky nature of dried honey powder can be attributed to the higher sugar concentration, as it occurred in various fruit juice powder (Roos and Karel 1991; Jaya and Das 2005). To reduce the stickiness, the incorporation of maltodextrin was desirable for the production of dry powder products (Bhandari et al. 1997). Physicochemical characteristics of liquid honey suggest a very high sugar to acid ratio and hence higher tendency towards crystallization was observed in liquid honey during shelf storage. Result of total solid and ash content of this honey sample (0.812 ± 0.011 kg/kg and 0.0072 ± 0.0031 kg/kg respectively) was found to be similar with the findings for honey from various floral sources from western ghats region of India (Ahmed et al. 2007). Similar results were also reported for different types of Indian honey collected from various floral sources (Singh and Bath 1997). Singh and Bath (1998) further reported the significance of floral sources for various chemical properties of honey including pH, acidity and mineral content. Moisture and sucrose (0.182 ± 0.005 kg/kg and 0.035 ± 0.007 kg/kg respectively) content of our honey was observed to be in line with various commercial honey of Portuguese. Whereas, this honey sample possess comparatively higher ash content than Portuguese honey (Gomes et al. 2010). Present work further confirmed that various physicochemical characteristics of our honey was similar with the fresh honey of Luso region of Portugal except ash content (Silva et al. 2009). Saxena et al. (2010) compared different Indian commercial honey and their result brought a picture that our experimental honey is

comparatively less viscous and contains more ash. More ash content indicates that this honey sample may be a good source of essential minerals for supplementation and value addition in different food products.

Vacuum puffed honey powder was produced by incorporating optimum amount of maltodextrin, glycerol monostearate and tricalcium phosphate to achieve desirable quality attributes of the final product. The values of quality parameters of the vacuum puffed honey powder were: hygroscopicity 8.40 %, degree of caking, 12.95 %, flowability, 23.83 s, sticky point temperature at 5 % db, 48.56 °C and overall color difference $\Delta E_c = 8.12$. This indicated that honey powder exhibited similar quality attributes as reported for tomato soup powder, coffee powder and vacuum dried mango pulp powder (Jaya and Das 2005).

Permeability of the packaging material

The cumulative moisture uptake with respect to storage time by the silica gel sealed in the aluminium foil-laminated polyethylene pouches at 36 °C and 90 % relative humidity is shown in Fig. 1. The slope $dw/d\theta_p$ of the best fitted straight line is $0.000009 \text{ kg} \cdot \text{day}^{-1}$. The surface area of the pouch A_p is 0.002 m^2 and the saturation vapor pressure p^* at 36 °C is 5.923 kPa. Substituting the above values in Eq. (1), the permeability value K of the aluminium foil-laminated polyethylene pouch is $7.597 \times 10^{-8} \text{ kg/m}^2/\text{day/Pa}$.

Relationship between moisture content and sticky point temperature of honey powder and fitting GAB model to sorption data

The variation in sticky-point moisture content of the honey powder with respect to corresponding sticky-point temperature is shown in Fig. 2. The sticky-point temperature of the honey powder decreased with increase in moisture content. At

Fig. 1 Cumulative moisture gain by the silica gel (in kg) packed in aluminium foil-laminated polyethylene pouch with storage period (day)

Fig. 2 Changes in sticky-point moisture content (kg/kg dry solids) with respect to sticky-point temperature (°C) of vacuum puffed honey powder

0 % moisture, the sticky-point temperature was 72 °C. At 40 °C, the extrapolated sticky-point moisture content was 0.078 kg water/kg dry solids.

The moisture sorption data of vacuum puffed honey powder at 36 °C were fitted to the GAB model by using least square method. The values of model constants C_g and k_g as calculated with experimental water activities and corresponding moisture content were 17.60 and 0.343, respectively, whereas the value of monolayer moisture content X_0 was 0.081 kg water/kg dry solids. The value of the correlation coefficient R^2 of the fitted model was 0.976 with RMS and R_d values of 5.12 and 6.89, respectively. The actual and predicted equilibrium moisture content of the honey powder is shown in Fig. 3.

Determination of shelf-life of honey powder during accelerated storage

The initial moisture content X_i of the honey powder was 0.022 kg water/kg dry solids and the critical moisture content

Fig. 3 Fitting of moisture sorption data (i.e. variation of equilibrium moisture content of honey powder with water activity) to GAB model

X_c of the powder when stickiness started was 0.089 kg/kg dry solids. Substituting saturation vapor pressure of water at 40 °C from steam table as 6.9805 kPa, the relative humidity (Rh) of the storage environment as 0.9, the surface area of the pouch as 0.002 m² and water vapor permeability of the pouch material as 7.597×10^{-8} kg/m²/day/Pa and the amount of dry solids in 20 g of powder as 0.0192 kg in Eq. (10), the numerical solution of Eq. (4) resulted in the graphical relationship between the time of storage and the moisture content of the honey powder (Fig. 4). From Fig. 4, the predicted time required for the moisture content of the powder to increase from an initial value of $X_i = 0.022$ kg/kg dry solids to the critical value of $X_c = 0.078$ kg/kg dry solids is 222 days, where the actual shelf-life of honey powder was observed as 189 days. The value of R^2 obtained between the experimental and the predicted moisture content was 0.98 and the value of R_d between the actual and the predicted moisture contents was 8.23 %. Because R_d value is less than 10 %, we conclude that the prediction is adequate for indirect determination of moisture content and the shelf life of vacuum puffed honey powder. These findings are in similar line with various previous research outcomes. It was observed that mango and watermelon juice powder showed stickiness and significant caking at 8.9 % (db) and 5 % (db) moisture content respectively (Jaya and Das 2005; Arya et al. 1986). Experiments also revealed higher storage life of vacuum puffed honey powder in compared to 3 months and 105 days experimental shelf life of watermelon and mango juice powder respectively (Jaya and Das 2005; Arya et al. 1986). This may be attributed to the comparatively higher sugar content in honey and also variations in packaging and experimental conditions.

Fig. 4 Variation of moisture content (kg/kg dry solids) of dried honey powder with respect to storage period (day) ($n = 3$) (Δ Experimental values and — Predicted values)

Fig. 5 Changes in overall colour difference (ΔE) with storage period (day) ($n = 3$)

Colour kinetics of vacuum puffed honey powder during storage

Figure 5 indicates that the typical yellowish white colour of vacuum puffed honey powder is changed with increase in storage period. The rate of change was quite rapid during initial storage days but after getting faded up the rate of change of ΔE tend towards steadiness. From the experimental data ΔE^* was determined as 18.1. Using ΔE^* and various ΔE values during storage, linear plots between $(\Delta E^* - \Delta E)$ and storage time, $\ln(\Delta E^* - \Delta E)$ and storage time, and $1/(\Delta E^* - \Delta E)$ and storage time were drawn to identify the best fit equation comparing correlation coefficient. Analysis of the data revealed that the plot between $\ln(\Delta E^* - \Delta E)$ and storage time showed maximum correlation (0.998) with rate constant (k_1) as 0.037 day^{-1} . Hence, the result is in agreement with previous findings for sterilised milk (Kesseler and Fink 1986), tomato concentrate (Barreiro et al. 1997) and vacuum dried mango powder (Jaya and Das 2005) that the colour change reaction kinetics of vacuum puffed honey powder also follow first order reaction.

Conclusion

The present study was carried out to analyze the sorption phenomena, storage life and change in optical properties of vacuum puffed honey powder during accelerated storage. The shelf-life of the powder estimated from this consideration and GAB model was 222 days where the actual shelf-life of honey powder was observed as 189 days. Accuracy analysis by R_d and RMS revealed that the technique of determining shelf life of honey powder by considering sticky-point moisture content as the critical parameter is acceptable. Additionally, this technique can also be helpful to predict maximum storage

temperature of honey powder. Analysis of this research brought certain scope of improvement for the extension of shelf life and reduction of optical deviation kinetics. Reduction in moisture absorption and biochemical reaction rate by applying vacuum packaging and modified atmospheric packaging technique with suitable material may be one of the appropriate options of further research.

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