PAPER

FREEZE DRYING OF KIWI (*ACTINIDIA DELICIOSA*) PUREE AND THE POWDER PROPERTIES

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ABSTRACT

In this study, it was intended to investigate the production of freeze dried kiwi (*Actinidia deliciosa*) puree in the form of powder that can be used as a natural alternative to synthetic additives used in food products such as pudding, instant tea, and sauces for improving their flavour. In order to obtain the powder product, kiwi puree as plain and with maltodextrin (Dextrose Equivalence of 10-12, as 10 % by weight) addition were freeze dried. Drying behaviour of plain kiwi puree and kiwi puree with MD were explained by Logarithmic model (R^2=0.994, RMSE=0.024, χ^2=0.0008) and Wang and Singh model (R^2=0.999, RMSE=0.012, χ^2=0.0002), respectively. The effective moisture diffusivity (D_{eff}) value was calculated as 7.3×10^{-10} m^2/s and it was observed that it was not affected by the addition of MD. The vitamin C content of fresh kiwi fruit was evaluated as 66.3 mg/100 g kiwi and there was a loss of 17.1% for plain and 19.8% for MD containing powders respectively after freeze drying. It was also observed that, the addition of maltodextrin decreased cohesiveness, on the other hand, increased bulk and tapped densities, average time values for wettability and solubility, and glass transition temperature of the powder products.

- Keywords: kiwi, kiwi puree powder, freeze drying, maltodextrin, vitamin C -

INTRODUCTION

Kiwi fruit contains high amounts of vitamins (vitamin C (100-400 mg vitamin C/100 g), A, B_2, and E), minerals (calcium, iron, copper, phosphorus, magnesium, and potassium), carotenoids (beta carotene, lutein, and xanthophyll), phenolic compounds (flavonoids and anthocyanins) and antioxidant compounds (CASSANO *et al.*, 2006). Kiwi fruit is being processed to obtain juice, frozen food, wine, jam, marmalade, and canned and dried slices. Drying might be a suitable technique to prolong the shelf life of kiwi, which is susceptible for microbial spoilage and softening due to its high moisture content. Fruit juices, purees and powders are being marketed due to an increased demand for ready-to-eat foods. In addition, powder products, with a long-term ambient shelf life and microbiological stability can reduce the transportation, and storage costs as well (JINAPONG *et al.*, 2008). Thus, alternatives to conventional processing technologies are being explored to produce better quality products. Due to high content of vitamin C, it is essential to protect vitamin C during drying of kiwi (KAYA *et al.*, 2010). Freeze drying is an important process for the protection of sensitive compounds such as vitamin C, phenolic compounds, biological activity, appearance, color, texture, aroma, and nutritional values of foods which compensates its high operating costs for drying of foods (ZEA *et al.*, 2013; WANG *et al.*, 2006). In addition, FERNANDES *et al.* (2011) reported that for producing whole fruit powder, drying fruits at low temperature and reduced pressure with low amounts of carrier is apparently the best alternate. Because, there exist some difficulties for drying of food extracts, juices, and purees because of the stickiness problems resulted by low glass transition temperatures of their components such as sugars and organic acids. In order to prevent problems in drying and obtaining powder products with acceptable properties, the drying aids that have high T_g is to be used. The use of drying agents such as gum arabic, maltodextrin, whey protein, sucrose etc. improves the drying process, and leads to an effective drying (NADEEM *et al.*, 2011).

Numerous studies were carried out with freeze drying of foods which contain sensitive compounds such as carrot (LIN *et al.*, 1998), pumpkin (QUE *et al.*, 2008), kiwi (ERGÜN, 2012) mango (SHOFIAN *et al.*, 2011) pineapple (MARQUES *et al.*, 2011), papaya (SHOFIAN *et al.*, 2011; MARQUES *et al.*, 2011) and guava (WANG *et al.*, 2006). Several researchers studied on drying of kiwi fruits such as convective, microwave, vacuum microwave, and freeze drying (KAYA *et al.*, 2010; ERGÜN, 2012; DOYMAZ *et al.*, 2009; KIRANOUDIS *et al.*, 1997) methods.

Describing dehydration kinetics is important in the design and optimisation of drying processes (SIMAL *et al.*, 2005). Thin layer drying models, generally means to dry as one layer of sample which provide uniform temperature assumption and suitable for lumped parameter models, are important in mathematical modelling of drying. Although, models depend on the process conditions, they are practical and provide sufficiently good results (ERBAY and ICIER, 2009). The properties of food powders such as bulk density, hygroscopicity, degree of caking, dispersibility, wettability, solubility, particle size, and size distribution are useful for design, and control of processing, handling, storage operations, and product quality control. Properties of powder products are usually studied in two groups such as particle properties (particle size, shape, distribution, density and morphological properties), and bulk properties (bulk density, wettability, solubility, porosity, cohesiveness, and flowability).

In this study it was intended to investigate the production of freeze dried kiwi (*Actinidia deliciosa*) puree in the form of powder that can be used as a natural alternative to synthetic additive used in food products such as pudding, instant tea, and sauces for improving their flavour. Also, an alternative product with the advantages of high nutritional value, long durability, easiness for usage in dry mixture formulations, being portable easily, and a healthier food additive for the consumers consumption will be obtained. In addition to the mentioned purposes: it was also aimed to determine the drying behaviour of kiwi puree (pure and with 10% MD) during freeze drying and the effect of maltodextrin addition and the properties of the powder product.

MATERIAL AND METHODS

The fresh kiwi fruits were obtained from a local supermarket in Izmir, Turkey. They were peeled and grounded into puree by using a home type blender (Tefal Smart, MB450141, Turkey). In order to obtain the puree with maltodextrin addition, maltodextrin (MD) with Dextrose Equivalence (DE) value of 10-12 (AS Chemical Industry and Commerce Limited Company, Turkey) was added directly to puree in suitable amounts (10% by weight).

Freeze drying

The freeze drying experiments were performed in a pilot scale freeze dryer (Armfield, FT 33 Vacuum Freeze Drier, England). Prior to drying kiwi puree was frozen in a layer of 3 mm in the petri dishes at - 40°C in an air blast freezer (Frigoscandia, Helsinborg, Sweden) for two hours, then freeze dried under vacuum (13.33 Pa absolute pressure), at - 48°C condenser temperature. The temperature of the heating plate was set to 30°C, which was constant during the drying process. The powder was obtained by grinding the dried material, obtained as pellets of diameter of petri size, in a blender (Tefal Smart, MB450141, Turkey), and powder was stored in glass jars in the dark at 20±1°C until further tests were carried out.

Physical and chemical analyses

The moisture content of kiwi puree and freeze dried kiwi puree powders (KPP) were determined according to AOAC (2000). For this process, each experiment for increasing time periods was carried out with new samples of equal mass, and moisture loss was determined gravimetrically by using a digital balance with 0.01 precision (Ohaus AR2140, USA). Moisture ratio was calculated according to equation (1).

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (1)$$

Where the M_t, M_0 and M_e are the moisture content at any time, initial, and equilibrium moisture content (kg water/ kg dry matter), respectively. Drying data was fitted to ten well-known thin layer drying models (Lewis, Page, Modified Page I, Henderson and Pabis, Logarithmic (Asymptotic), Midilli, Modified Midilli, Two-term, Two-term Exponential, and Wang and Singh) (ERBAY and ICIER, 2009). Nonlinear regression analysis was used to evaluate the parameters of the selected model by using statistical software SPSS 16.0 (SPSS Inc., USA). The goodness of fit was determined using the coefficient of determination (R^2), root mean square error (RMSE), and the reduced chi-square (χ^2) that can be described by the equations given by ERBAY and ICIER, 2009.

Where $MR_{exp,i}$ and $MR_{pre,i}$ is the experimental, and predicted moisture ratio at observation i; N is number of the experimental data points, and n is number of constants in model.

The effective moisture diffusivity (D_{eff}) of freeze dried kiwi slices were calculated by Fick's diffusion model (Eq. 2).

$$MR = \frac{M_t - M_e}{M_0 - M_e} = \frac{8}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{(2n-1)^2} exp\left[-(2n-1)^2\pi^2\frac{D_{eff}}{4L^2}t\right] \quad (2)$$

Where t is the time (s), D_{eff} is the effective diffusivity (m^2/s) and L is the thickness of samples (m). For long drying times, a limiting case of Eq. (3) is obtained, and expressed in a logarithmic form;

$$lnMR = ln\left(\frac{8}{\pi^2}\right) - \left(\frac{\pi^2 D_{eff}}{4L^2}\right)t \quad (3)$$

The effective diffusivity was calculated by plotting experimental moisture ratio in logarithmic form versus drying time. From Eq.(3), a plot of ln MR versus drying time gives a straight line with a slope of:

$$Slope = \frac{\pi^2 D_{eff}}{4L^2} \quad (4)$$

Water activity was measured by using Testo-AG 400, Germany, water activity measurement device. The pH values of kiwi puree and the powders were measured using a pH meter (Inolab WTW pH 720, Germany) directly and after dissolving the powder in deionised water (1 g/1 g) respectively.

The color values (L*, a*, and b* values) of fresh kiwi fruits, and the powders were measured with Minolta CR-400 Colorimeter, Japan, calibrated with white standard plate three times and results as the average of three measurements were expressed in accordance with the CIE Lab. System. The L* value, is a measure of lightness which ranges between 0 and 100. Increases in a* value in positive, and negative scales correspond to increases in red or green color, respectively. The b* value represents color ranging from yellow (+) to blue (-).

The vitamin C content of fresh kiwi fruits was determined according to HIŞIL (2007). Freeze dried powders were rehydrated to the initial moisture content prior to the analysis. The indication principle of vitamin C value is based on extraction with 10% oxalic acid afterwards adding of 2,6-dichlorophenolindophenol solution. The absorbance was measured at 518 nm by a Varian Cary 50 UV/Vis spectrophotometer.

Glass transition temperature

Glass transition temperature of the powder samples was determined by a Differential Scanning Calorimeter (TA Instruments, Q10, USA) equipped with a thermal analysis station. An empty sealed aluminum pan was used as a reference in each test. Nitrogen gas at a flow rate of 50 ml/min was used as the purge gas to avoid water condensation around the samples. About ten milligrams of kiwi sample was sealed in aluminum pans and cooled from room temperature to -40°C at 10°C/min for formation of glassy state in kiwi sample and equilibrated for 10 min. The heating rate was 10°C/min and the temperature range varied between -40 and 120°C, depending on sample moisture content. DSC thermograms, presenting the heat flow (W/g) and temperature relationship were used to analyze the thermal transitions in samples during heating and cooling. TA Instruments Universal analysis software was used to analyze the onset, mid and end points of the glass transition. The glass transition temperature (Tg) was calculated as the average of the onset and end point values.

Thermo gravimetric analysis

Thermo Gravimetric Analysis (TGA) was carried out by Perkin Elmer Diamond TG/DTA (Canada) under nitrogen flow. The assay conditions were as follows: isotherm at 30 °C and heating from 30.00°C to 1000.00°C at 10.00°C/min. Five milligrams of equilibrated samples was introduced into the apparatus and the measurements were plotted during the heating.

Scanning electron microscope (SEM)

The morphology of the powder samples, prepared by placing the powders on aluminium stubs using a double-sided adhesive tape and then coating with gold, were examined with a scanning electron microscope (SEM- Phillips XL-30S FEG, Eindhoven, Netherlands) operating at 5kV accelerating voltage.

Analysis of the powder properties

For the determination of bulk density, the method explained by JINAPONG *et al.* (2008) was used. The average wettability and solubility times of freeze dried kiwi puree powders were determined by using the method explained by GONG *et al.* (2008) and GOULA and ADAMOPOULOS (2008), respectively. Flowability and cohesiveness values of the powders were evaluated in terms of Carr index (CI) and Hausner ratio (HR), respectively. Both CI and HR were calculated from the bulk (ρ_{bulk}), and tapped (ρ_{tapped}) densities of the powder as shown below Eqs. (5) and (6), respectively.

$$CI = \frac{(\rho_{tapped} - \rho_{bulk})}{\rho_{tapped}} x\ 100 \quad (5)$$

$$HR = \frac{\rho_{tapped}}{\rho_{bulk}} \quad (6)$$

Statistical analysis

Data were analyzed by using statistical software SPSS 16.0 (SPSS Inc., USA). The data were subjected to analysis of variance (ANOVA), and Duncan's multiple range test (α=0.05) to determine the difference between means. The drying experiments were replicated twice and all the analyses were triplicated.

RESULTS AND DISCUSSION

Results of physical and chemical analyses

Kiwi is harvested through a long season. However, due to its high moisture content, storage period and its direct use in food compositions are limited and this makes necessary the drying to obtain pure, minimally processed, decreased in volume and easy to use form of the kiwi. The results of the experimental study showed that, it was possible to dry the fresh kiwi puree under the freeze drying condition. In order to improve the drying process, to see the effect of maltodextrin addition and to obtain a more stable powder, maltodextrin was used as a drying aid. The amount of MD to be used to prevent quality losses during drying and to obtain powder which has almost the same properties with fresh kiwi was determined by the preliminary tests. For this purpose, MD with amounts of 5, 10, 15, and 20% of the puree weight were added to the fresh kiwi puree. The addition of MD as 5% of the puree weight was not suitable since there was no decrease in the drying time of kiwi puree. For the MD amounts being more than 10 %, the powders lost their quality characteristics such as specific color, vitamin C content etc. Similar results were observed by QUEK *et al.* (2007). It was reported that after addition of the 10% MD watermelon powders lost their red-orange color. Therefore, as a result of the preliminary tests, the concentration of MD in the puree necessary for successful drying and powder production was determined as %10 of the puree weight. ZEA *et al.* (2013) reported that powder obtained by freeze drying of guava and pitaya pulp was found to be very hygroscopic and difficult to compact. In order to minimize this problem the researchers added 10% maltodextrin to guava and pitaya mash.

The drying behaviour of the freeze drying process was determined from the mass loss in samples of known initial moisture content. For the drying process, the total drying time was determined to be nine and ten hours respectively for the samples of kiwi puree, and kiwi puree with maltodextrin until getting constant weight of the samples. Similar results were obtained by MARQUES and FREIRE (2005) in their freeze drying study on pulps of tropical fruits as ten to thirteen hours.

The average values of the experimental results of the analysis applied on fresh kiwi puree and freeze dried powders are given in Table 1. The initial moisture content of kiwi puree was found to be as 81.19 % (wet basis, wb), and this result was consistent with KAYA *et al.* (2010) (81% wb). The final moisture content of kiwi powder is 9.55 % (wb) after removal of 88.24% of water. For the sample with MD, 94.31% of water was removed where the initial dry matter content of the sample was higher than the plain sample due to maltodextrin addition and the amount of water to be removed at the same drying time decreased. The residual moisture in the powder decreased, and the moisture content of the sample with MD was found to be 56% lower than the plain sample, and this differences between samples was found to be statistically significant ($P<0.05$).

The moisture ratio were calculated by using the determined moisture content values and the data were fitted to ten thin layer drying models (Lewis, Page, Modified Page I, Henderson and Pabis, Logarithmic, Midilli, Modified Midilli, Two-term, Two-term Exponential, and Wang and Singh). The coefficient of correlation

Table 1 - The physical and chemical properties of kiwi puree and freeze dried kiwi puree powders.

Properties	Fresh kiwi puree	Freeze dried kiwi puree powder	Kiwi puree with MD	The freeze dried kiwi puree powder with MD
Moisture content (% wb)	81.19 ±0.02[b]	9.55±0.64[r]	73.82±0.04[a]	4.20±0.05[p]
Water Activity	0.98 ±0.01[b]	0.28±0.03[r]	0.96±0.01[a]	0.22±0.01[p]
pH	3.16±0.01[a]	3.37±0.01[p]	3.38±0.01[a]	3.60±0.02[r]
Color				
L*	47.37±0.35[a]	77.93±0.53[p]	48.84±0.34[a]	78.12±0.44[p]
a*	-0.67±0.24[b]	1.16±0.09[r]	-0.74±0.08[a]	-6.53±0.12[p]
b*	17.5±0.29[a]	21.77±0.17[p]	17.85±0.18[a]	22.08±0.11[p]
Vitamin C (mg/100g, wb)	66.3±0.28[b]	54.97±0.13[r]	51.07±0.09[a]	40.95±0.51[p]

[a-b] Different letters in the same row indicate significant difference between averages of puree and puree with MD at P<0.05.
[p-r] Different letters in the same row indicate significant difference between averages of powder and powder with MD at P<0.05.

(R^2) was accepted one of the primary criterion for selecting the best model to define the freeze drying curves of kiwi puree powders. For freeze drying process of kiwi puree the highest R^2 value (0.994), and the lowest RMSE (0.02459), and $\chi 2$ (0.00083) values were obtained from logarithmic model (Fig. 1). However, for freeze drying of kiwi puree with MD the best fit was obtained from Wang and Singh model (R^2=0.999, RMSE=0.012, χ^2=0.0002) (Fig. 2). In the literature, the convective drying characteristics of kiwi slices were explained with two term exponential (KAYA *et al.*, 2010), Page (CEYLAN *et al.*, 2007; SIMAL *et al.*, 2005), and Henderson and Pabis (DOYMAZ, 2009) models.

The effective moisture diffusivity (D_{eff}) of freeze dried kiwi puree and pure with MD were evaluated as 7.3x10^{-10} m^2/s. The difference between calculated values was 0.002x10^{-10} m^2/s and this was not considered to be effective. KAYA *et al.* (2010) reported that the effective moisture diffusivity values of kiwi slices which were dried under different drying conditions (air velocity, temperature, and relative humidity) varied between 0.589 and 6.574 x10^{-10} m^2/s. SIMAL *et al.* (2005) reported that the effective moisture diffusivity of hot air dried kiwi slices (30-90°C) ranged between 3.00 and 17.21 x10^{-10} m^2/s. The D_{eff} value of kiwi powder was found to be similar to the D_{eff} value (7.13x 10^{-10} m^2/s) of kiwi slices which were dried at 50 °C hot air temperature (SIMAL *et al.*, 2005). The effective moisture diffusivity values in foods are in the range of 10^{-12} to 10^{-6} m^2/s.

Water activity is considered as one of the most important quality factors especially for long term storage and also it is related to moisture content, and responsible for biochemical reactions. The values of water activity under 0.6 is generally considered as microbiological-

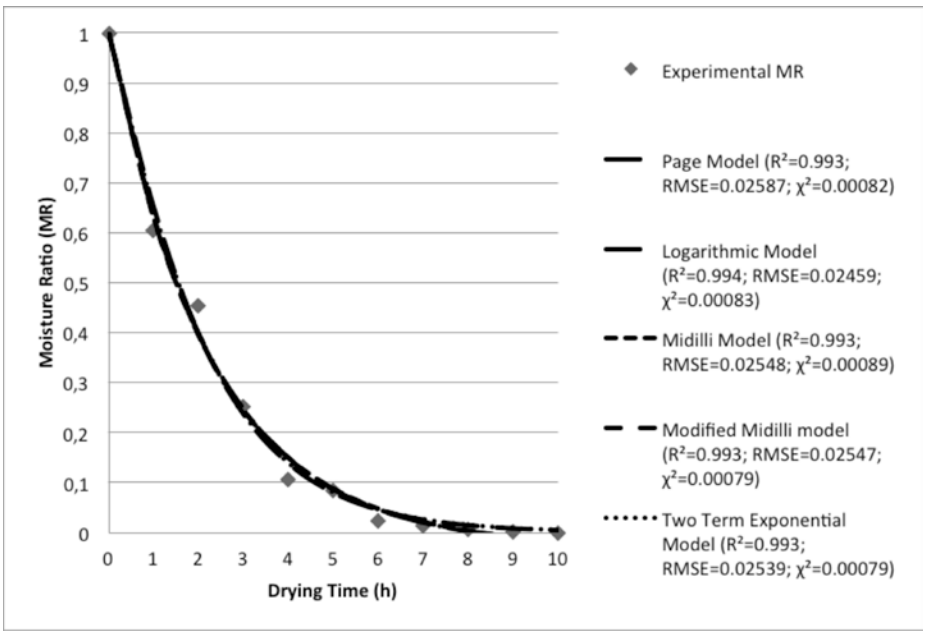

Fig. 1 - Experimental and computed moisture ratio values obtained by selected models for pure kiwi puree powder (R2≥0.993).

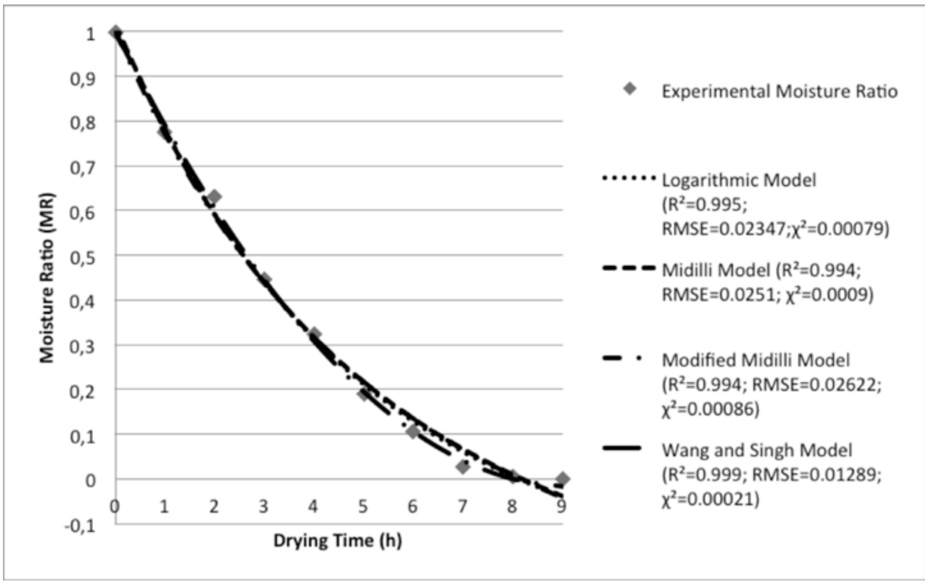

Fig. 2 - Experimental and computed moisture ratio values obtained by selected models for kiwi puree powder with MD ($R2 \geq 0.994$).

ly stable (QUEK, 2007) and between 0.20, and 0.40 ensure the stability of the product against browning, and hydrolitical reactions, lipid oxidation, auto-oxidation, and enzymatic activity (AMRQUES *et al.*, 2007). The water activity values of freeze dried kiwi puree powders (plain powder and powder with MD) were found to be as 0.287, and 0.225, respectively. In literature water activity values around 0.28 was also expressed for freeze dried guava and pitaya powders with 10% MD (ZEA et al., 2013). Drying process and addition of MD showed the significant effects on the water activity of freeze dried kiwi puree powders ($P<0.05$).

The pH value of kiwi puree was measured as 3.16. SOUFLEROSA *et al.* (2001) reported that the pH value of kiwi ranges between 3 and 4, due to the content of including the acids such as gluconic, galacturonic, oxalic, succinic, fumaric, oxcaloacetic, and p-coumaric acids. HARDER *et al.* (2009) and ARROQUI *et al.* (2004) measured the pH value of kiwi nectar and puree as 3.50 and 3.41, respectively. The pH values of powders (kiwi puree powder and powder with MD) were found to be as 3.37 and 3.60, respectively. Results showed that the drying process and addition of MD caused a significant increase in the pH value of powders ($P<0.05$). The increase in the pH values was found as 6.65% and 6.51% for plain and MD containing powders, respectively. This increase was comparable with the increase in 3.64% in freeze drying of guava concentrate MAHENDRAN (2010) and the reason for the increase can be explained with the loss of some acidic compounds during drying.

Color of the dried products is an important quality factor, which reflects the sensory attractiveness, and the quality of the powders (QUEK *et al.*, 2007). Thus, the color of the processed products should ideally remain unchanged after production. The color values (L*, a* and b*) of kiwi puree were measured as 47.37, -0.67, and 17.5 respectively. These values are quite different than the measurements of ANCOS (1999) reporting the color values (L*, a*, and b*) of kiwi puree 36.01, -12.35 and 23.03, respectively and this shows the differences between the cultivars and the storage time after harvest. The variation of color values for plain and MD containing samples depending on the drying time were shown in Figs. 3 and 4, respectively. As shown in Fig. 3, the L*, b* and a* values of freeze dried kiwi puree powder increased throughout the drying period and reached the final values as 77.93, 1.16, and 21.77, respectively. CHOPDA and BARRETT (2001) reported that the increase in L* (brightness), a* (redness) and b* (yellowness) values following production of guava puree powder was most likely a result of non-enzymatic browning during freeze drying which produced a darker product. The addition of MD in freeze drying, increased the L* (78.12), and b* (22.08) values, but decreased a* value (-6.53) (Table 1). Results showed that, drying process increased the brightness values of samples ($P<0.05$); addition of MD caused superior bright color but it was not found to be statistically significant ($P>0.05$). The same effect was also observed for yellow-blue (b*) value. Nevertheless, both drying process, and addition of MD showed a significant effect on the green-red (a*) value of the samples ($P<0.05$).

For the determination of vitamin C, freeze dried powders were rehydrated to the initial moisture content prior to the analysis to obtain comparable results. The vitamin C content of kiwi was found

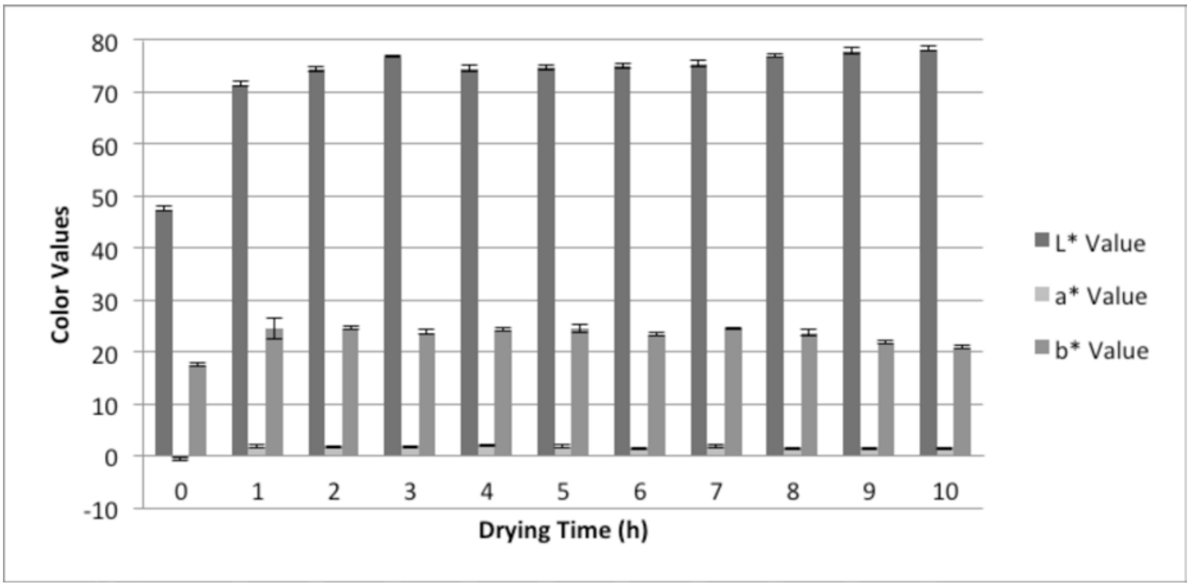

Fig. 3 - The variation of color values of plain samples depending on the drying time.

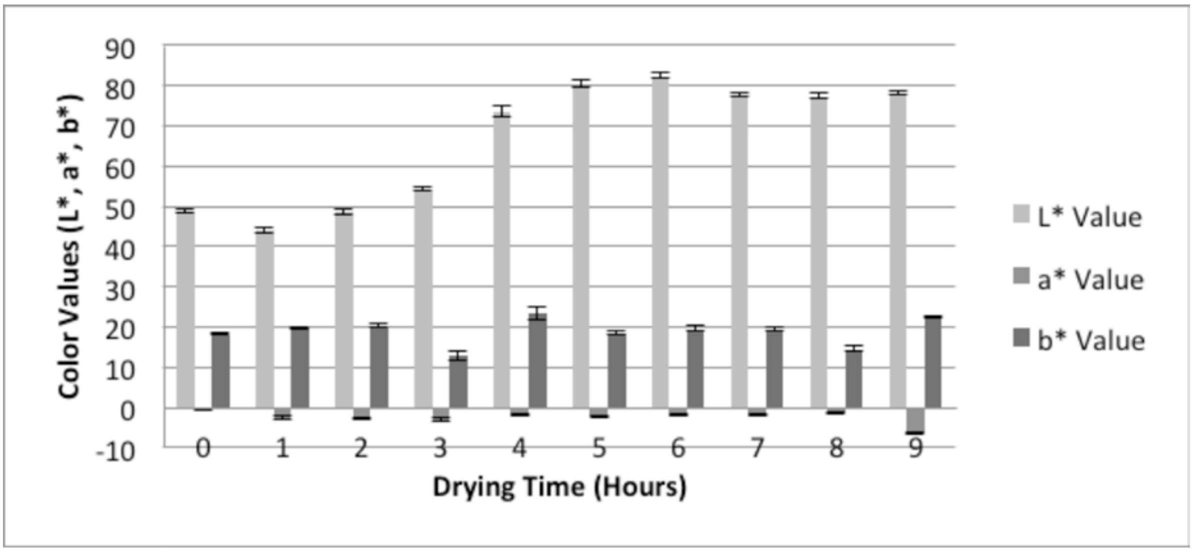

Fig. 4 - The variation of the color values of samples with MD depending on the drying time.

to be as 66.3±0.28 mg/ 100 g (wb) kiwi. The freeze drying process caused a significant (17.1%) decrease on the vitamin C content of kiwi powder ($P<0.05$). The vitamin C loss during drying is similar to losses of 18.8% (MAHENDRAN, 2010) and 16% (MARQUES *et al.* 2006) during freeze drying of some other fruit concentrate and pulps. Also, the addition of MD caused an insignificant loss in the vitamin C content (19.82%) ($P>0.05$). This decrease may occur due to the dilution effect. Exposure to heat, light, oxygen and metals may also lead to vitamin C losses. LIN *et al.* (1998) did not observed significant loss of Vitamin C in freeze-dried carrots. The vitamin C losses can be due to not only the freeze drying, but also by the operations before drying such as cutting, slicing and freezing. Therefore, grinding process, preparation of maltodextrin and kiwi puree blend may cause more vitamin C losses for the kiwi puree. MARQUES *et al.* (2011) reported that the vitamin C losses for freeze dried fruits are considerably smaller when compared the vitamin C losses caused to others drying methods due to the low temperatures, and to the use of vacuum in the process.

Glass transition temperature

In order to have safety storage, and stability of powders, the powders should be kept below glass transition temperature (T_g). So the T_g value of kiwi powders was determined. Kiwi powder exhibited well defined T_g (average -18°C) represented by an endothermic change in the base

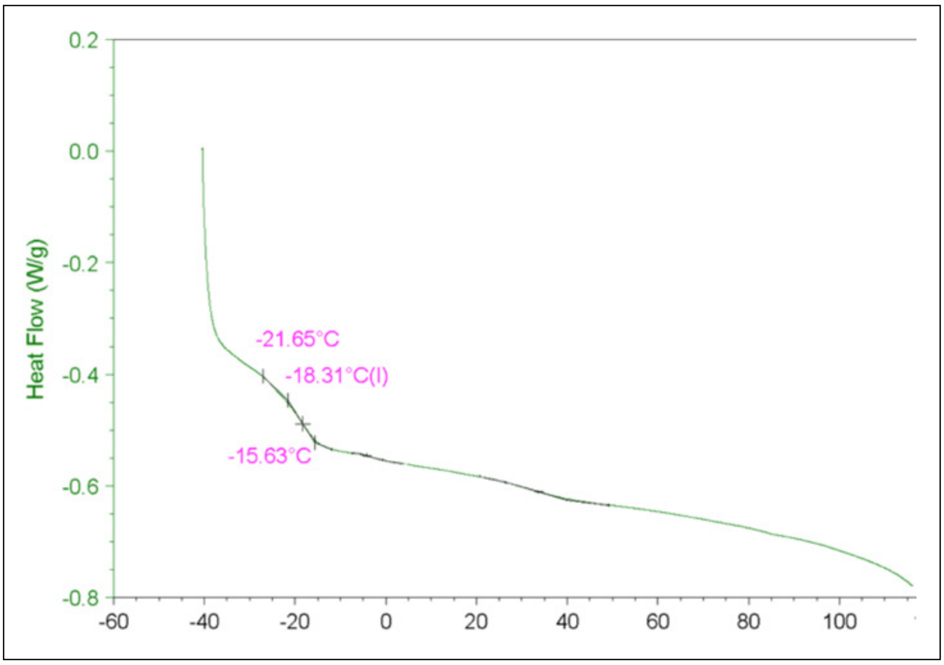

Fig. 5 - DSC thermogram for freeze dried kiwi puree powders.

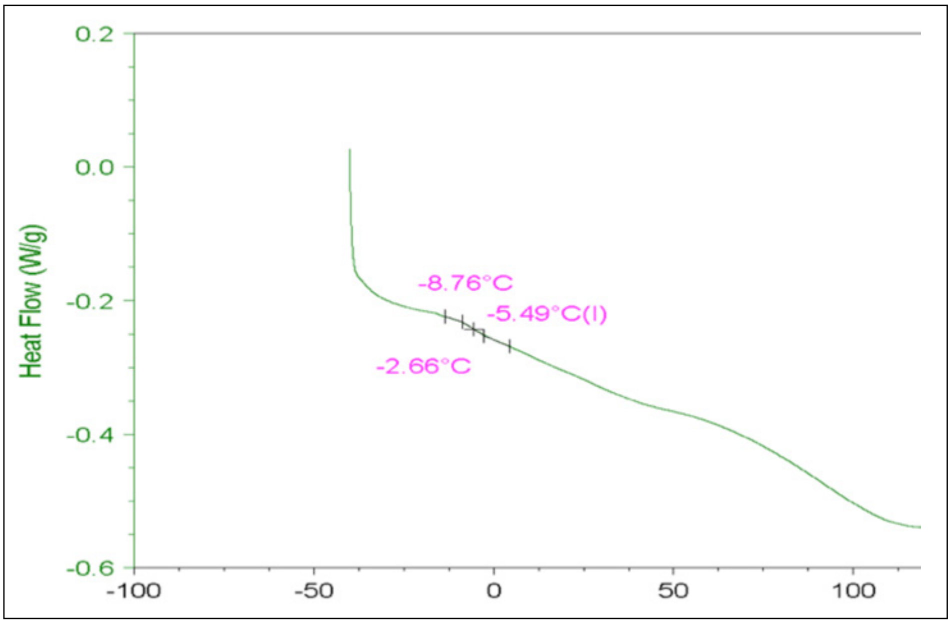

Fig. 6 - DSC thermogram for freeze dried kiwi puree powders with MD.

line (Fig. 5). Moisture content and water activity are the main factors affecting T_g of materials. However, in the consideration of food materials with similar moisture content and water activity values, the high acid and sugar content may decrease the T_g value. The increases in T_g values of kiwi puree powders with carriers possibly due to the addition of carriers, and the lower moisture content of carrier-incorporated powders. T_g of kiwi puree powders with MD (T_g average -5°C) was found to be higher (Fig. 6). SILVA *et al.* (2006) reported that, addition of 30% MD (w/w, DE20) increased Tg of freeze dried camu-camu pulp from -58.8°C to -40.1°C for the moisture content values between 0.2 to 0.5 (g dry solid/ g sample). After this value, T_g increased rapidly with decreasing moisture content. In their study, MOSQUERA *et al.* (2010) observed an increase in Tg with the addition of MD and this increase was slightly more where MD with low DE was used.

Thermo gravimetric analysis

The results of the analysis of the samples of kiwi puree powders by TGA are shown in

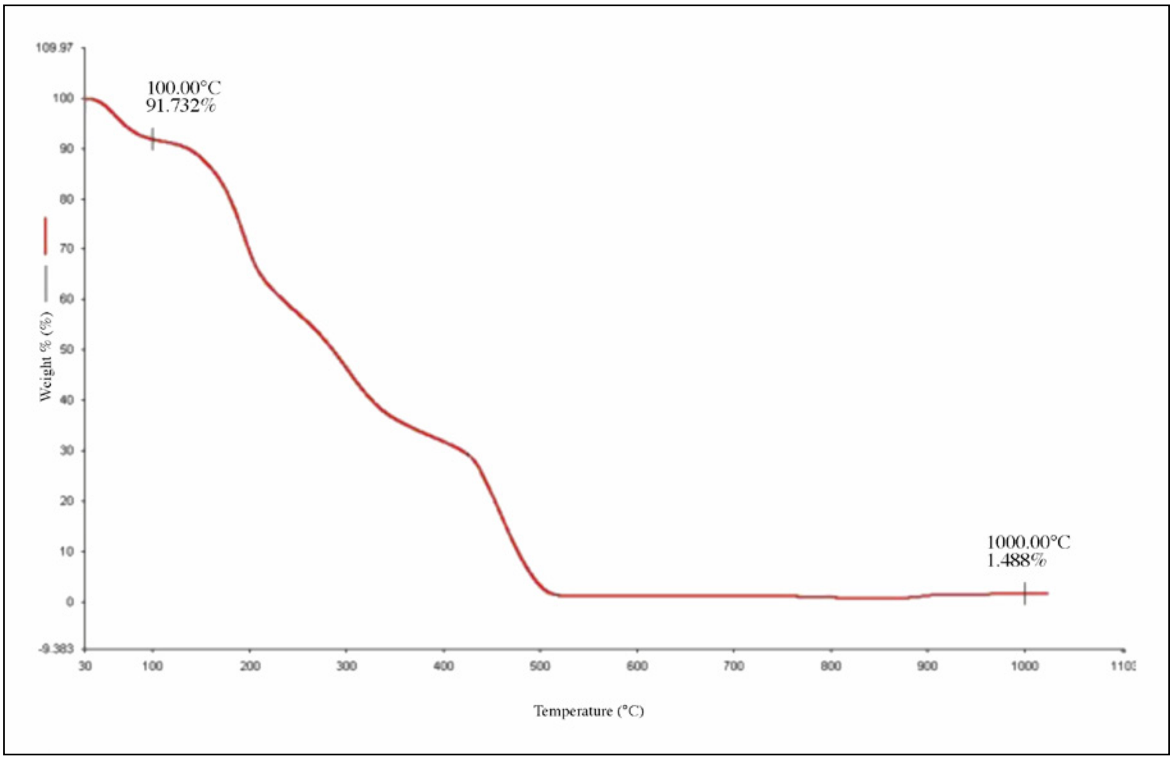

Fig. 7 - The variation of the weight of freeze dried kiwi puree powder with respect to time.

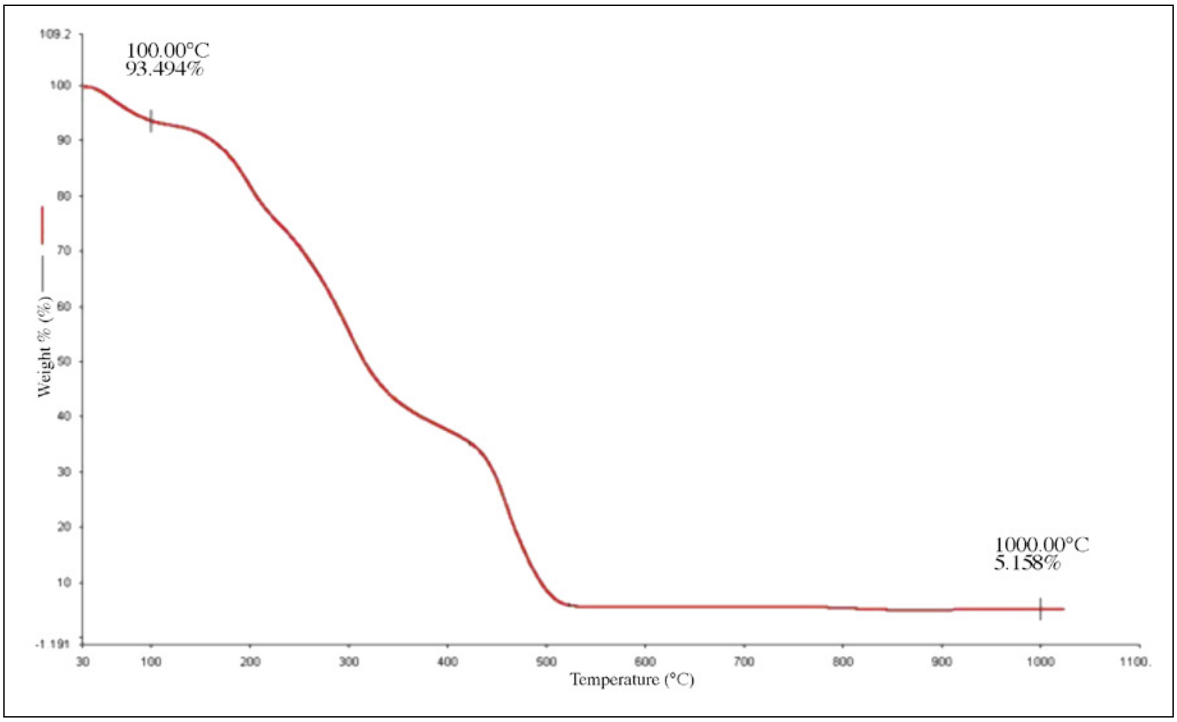

Fig. 8 - The variation of the weight of freeze dried kiwi puree powder with MD with respect to time.

the Figs. 7 and 8. These spectra determine the changes of weight in relation to change of temperature that the samples experiment when exposed to heating from room temperature to 1000°C. TGA spectra showed that the loss of matter began around 50°C for both samples but the kinetics of thermal decomposition is different for them. At 100°C, the sample with 10% MD lost around 6.5% of its own weight, but the sample that was dried without MD lost around 8.5% of its own weight. Their components were considerably stable until 150°C because the loss of matter is not significant. However, between 100 and 220°C, reactions such as Maillard's

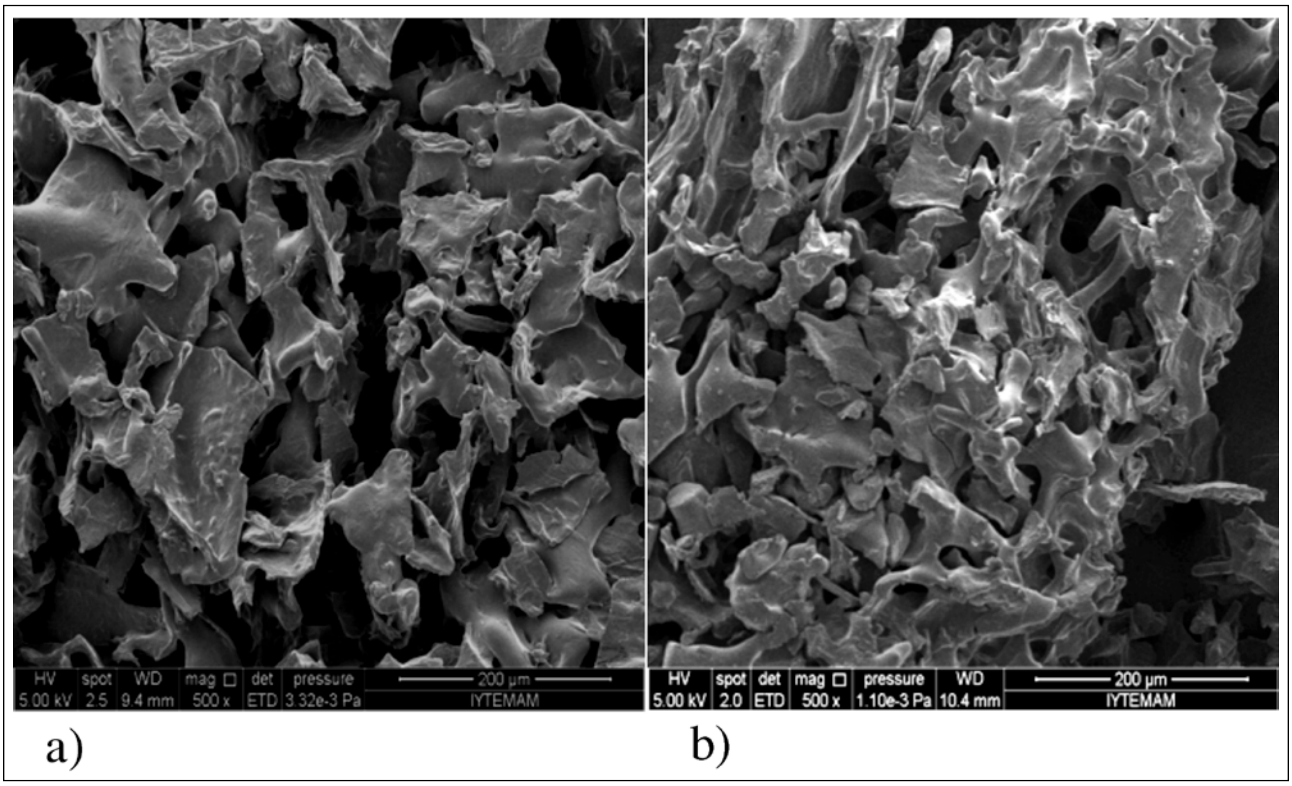

Fig. 9 - Scanning electron micrographs of freeze dried plain (a) and MD containing (b) kiwi puree powder at 500x magnification.

reaction or the condensation between phenolic acids and proteins may occur. As of 150°C, the loss of matter is significant, and the phenomena are exothermic for all samples.

Scanning Electron Microscope (SEM)

Selected images from the SEM microstructure analysis of the freeze dried kiwi puree powders were shown in Fig. 9 (a and b). The microstructures of freeze-dried kiwi powder had a skeletal-like structure with void spaces previously occupied by ice prior to freeze drying. This is because the absence of liquid phase in the material during freeze drying process suppressed the transfer of liquid water to the surface and the ice was converted to vapor without passing the liquid state (KROKIDA and MAROULIS, 1997). Micrographs revealed that powder particles of all powders were irregular in shape. Irregular shape of powder particles may due to the fibrous and porous nature of the kiwi fruit powders since powder was prepared from whole fruits (ZEA *et al.*, 2013).

Powder properties

The powder properties of freeze dried kiwi puree powders are given in Table 2. The tapped and bulk densities of freeze dried kiwi puree powder were found to be as 0.257 and 0.161 g/ml, and the addition of MD significantly increased the tapped and bulk densities of powder (0.416 and 0.316 g/ml) ($P<0.05$). MARQUES *et al.* (2006) reported that, apparent density of the studied pulps has presented a linear relationship with moisture content where the apparent densities of fruit pulps decreased linearly with moisture

Table 2 - The powder properties of freeze dried kiwi puree powders.

Powder Properties	Freeze dried kiwi puree powder	Freeze dried kiwi puree powder with MD
Tapped Density (g/mL)	0.26±0.01[a]	0.42±0.02[b]
Bulk Density (g/mL)	0.16±0.01[a]	0.32±0.01[b]
Solubility (s)	26±3[a]	290 ±48[b]
Wettability (s)	78.5±2[a]	186 ±0.71[b]
Flowability (CI)	38±3[b] (Bad)	24.04±2.87[a] (Fair)
Cohesiveness (HR)	1.60±0.08[b] (High)	1.32± 0.05[a] (Intermediate)

[a-b]Different letters in the same row indicate significant difference between averages at $P<0.05$.

content (dry basis) during freeze drying and the real density increased. The researchers reported that the remaining solids after moisture removal have higher densities than water and the overall solid density tends to increase as moisture is removed. MAHENDRAN (2010) dried the guava concentrate with different drying methods (freeze drying, tunnel drying and spray drying with the 30, 40, 50 and 60% concentrations of MD) and the bulk density of guava powders were measured as 0.63 g/mL; 0.69 g/mL and 0.61, 0.60, 0.57 and 0.54 g/mL, respectively. In this study, on the contrary of the results given by MAHENDRAN (2010) the bulk density increased with the addition of the MD. Lower density of the dried product is recommended to increase its attractiveness for consumers (DURANCE and WANG, 2002).

The average solubility time of the freeze dried kiwi puree powder was found to be as 26 seconds. The reason for the addition of MD was to improve the drying process and at the same time maltodextrin is highly soluble in the water to be used as a carrier. However, addition of maltodextrin caused a significant increase in the average solubility time of the powder (290s) ($P<0.05$). In a study by MAHENDRAN (2010) guava concentrate was dried with spray, tunnel, and freeze driers and the freeze dried guava powder was found highly soluble (96%) compared with the other drying methods. The solubility of the powder is related with moisture content, particle size, and chemical conversions in the material (GOULA and ADAMOPOULOS, 2008). Wettability is the ability of the powder particles to overcome the surface tension between themselves, and water. Wettability depends on particle size, density, porosity, surface tension, surface area, and surface activity of particle. Besides the effects of physical properties, the chemical composition of the powders also influences wettability depending on the content of fats, proteins, and carbohydrates on their surface (FANG *et al.*, 2008). Also, GOULA and ADAMAPOULOS (2008) reported that the residual moisture content of the powder affects the bulk density, wettability, flowability, and cohesiveness. The residual moisture content of powders is significantly affected the operational conditions, and carrier concentrations. The average wettability time of freeze dried kiwi powder was found to be as 78.5 seconds. Addition of MD caused a significant increase in the average wettability time as 186s ($P<0.05$).

Flow difficulties and caking are common problems in industries producing food powders. The flowability and cohesiveness properties of kiwi powders in terms of Carr Index and Hausner ratio were evaluated. The classification of powder flowability based on Carr index (CI) is very good (<15), good (15-20), fair (20-35), bad (35-45), and very bad (>45). The powder cohesiveness based on Hausner ratio (HR) is classified as low (<1.2), intermediate (1.2-1.4), and high (>1.4) (JINAPONG *et al.*, 2008). Kiwi powder with higher moisture content showed bad flowability (37.15±3.15) and high (1.59±0.08) cohesiveness. However, addition of MD caused a significant decrease in cohesiveness (1.29), and significant increase in flowability (22.36) behaviours of powder ($P<0.05$). The kiwi powder containing MD with low moisture content showed superior flow properties compared to kiwi powder.

CONCLUSIONS

The present work describes the possibility of producing kiwi puree powder by freeze drying, and the changes in some physicochemical and powder properties of powders which were affected by drying process and addition of MD. The results showed that freeze drying can satisfactorily be applied for drying of kiwi puree to obtain powders that can be used as an ingredient which have high vitamin C content for flavoring and improving nutritional value purposes. The possible uses of this dried product as a food supplement with valuable constituents of kiwi fruits and storage test might be studied in future projects.

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