Effects Of Spray Drying On Physical Properties, Total Phenolic Content And Antioxidant Activity Of Carob Molasses

Züleyha Akkaya, *Ege University, Izmir*
Jewe Schröder, *Karlsruhe Institute of Technology (KIT)*
Sebnem Tavman, *Ege University, Izmir*
Seher Kumcuoglu, *Ege University, Izmir*
Heike Petra Schuchmann, *Karlsruhe Institute of Technology (KIT)*
Volker Gaukel, *Karlsruhe Institute of Technology (KIT)*

Effects Of Spray Drying On Physical Properties, Total Phenolic Content And Antioxidant Activity Of Carob Molasses

Züleyha Akkaya, Jewe Schröder, Sebnem Tavman, Seher Kumcuoglu, Heike Petra Schuchmann, and Volker Gaukel

Abstract

In the present study carob molasses (pekmez) was spray dried to obtain a powder with desired improved handling properties. Maltodextrin with dextrose equivalent (DE) values of 8.6, 15.3 and 18.6 was used as a drying agent. Different molasses to maltodextrin ratios (25:75, 50:50), and dryer air inlet temperatures (160 °C, 210 °C) were additional parameters. The spray dried powders were analyzed for glass transition temperature, moisture content, water activity, wetting behavior, particle size, color, total phenolic content and antioxidant activity. The expected increasing effect of decreasing DE value on the glass transition temperature was obscured by different moisture contents. The glass transition temperature was mainly lowered by increasing the pekmez to maltodextrin ratio but also by increasing the air inlet temperature resulting in increasing moisture content. Wetting behavior was strongly influenced by the DE value. Total phenolic content was reduced in general by about 10 % and antioxidant activity changed by about 20 % independent from the investigated parameters. It can be concluded that spray drying of pekmez with addition of maltodextrin is a suitable method to improve and adjust handling properties of pekmez without loss of its nutritional value.

KEYWORDS: spray drying, carob molasses, glass transition, antioxidant activity, phenolic content

Introduction

Molasses (pekmez) is a traditional food product in Turkey. It is produced from sugar rich fruits such as grape, mulberry, apricot and carob. The juice of these fruits is concentrated up to 70-80 % soluble dry matter content. Molasses contains carbohydrates, minerals, organic acids, proteins, flavonoids and phenolic compounds which make it a very beneficial product for human nutrition (Sengül et al., 2007; Karababa and Isikli, 2005). Carob fruit (*Ceratonia Siligua*) is also known as locust bean and has a high content of carbohydrates 45 % (sucrose 30 % or more), protein 3 % and low levels of fat 0.6 % (Sengül et al., 2007; Santos et al., 2005). Carob molasses is a thick syrup and is used as an alternative to jam, sugar or honey. Due to the high natural sugar content, carob molasses can be used also as a natural sweetener, colorant and flavoring agent in ice-cream toppings or cakes (Biner et al., 2007). It is also considered as a natural laxative (Bilia et al., 2007). From the technical point of view, it is a sticky and high viscous liquid which causes difficulties during usage in food processing (Papadakis et al., 2006; Sabanis et al., 2007). The production of a dry powder containing pekmez is a very promising method to achieve easier handling. This reduces also the volume and weight and prolongs shelf life.

Drying is one of the oldest techniques used for increasing the shelf life of food products (Brennan et al., 1971). Spray drying is a commonly used method for the transformation of liquid foods into a powder form (Shrestha et al., 2007; Roustapour et al., 2006). During the spray drying process the moisture is quickly removed which results in a mostly amorphous powder (Bhandari et al., 1997). Amorphous materials change from a glass state to rubber state over the glass transition temperature range (Shresta et al., 2007). Nevertheless, only a single temperature is usually given as the glass transition temperature T_g. Below the glass transition temperature molecular mobility is limited while above this temperature a rapidly increasing mobility is observed which results in various physical and chemical changes in the material (Karatas and Esin, 1990). The temperature at which amorphous materials show stickiness is approximately 10 to 20 °C above their T_g (Bhandari et al., 1997; Bhandari and Howes, 1999).

Stickiness is the main problem for spray dried, sugar rich products if T_g is in the range of product outlet or storage temperature. This is due to the high content of low molecular weight carbohydrates such as glucose, fructose, and sucrose. They depict T_g between 5 and 65 °C (Bhandari et al., 1993; Bhandari and Howes, 1999; Goula and Adamopoulos, 2008). The stickiness problem of such products is commonly reduced and stability increased by the addition of high molecular weight compounds of high T_g (Roustapour et al., 2006). A commonly used drying aid for this purpose is maltodextrin with T_g above 145 °C depending on its composition (Goula and Adamopoulos, 2008; Shrestha et al., 2007).

Maltodextrins are hydrolyzates of starches and characterized by their DE value (Kearsley and Dziedzic, 1995). A lower DE value indicates higher molecular weight carbohydrates due to less hydrolysis of the starch. Their T_g increases with decreasing DE value (Roos and Karel, 1991). Roos and Karel determined also that T_g of sucrose maltodextrin binary systems decreased as the maltodextrin content decreased.

Bhandari et al. (1993) found that best results regarding juice content, drying yield and material costs were obtained with a juice to maltodextrin dry matter ratio of 65:35 for blackcurrant, 60:40 for apricot, and 55:45 for raspberry at air inlet temperatures between 90 and 160 °C. Quek et al. (2007) concluded that the addition of maltodextrins reduced the stickiness of spray dried watermelon powders and that the air inlet temperature had an important effect on the physico-chemical properties of the produced powders. Roustapour et al. (2006) studied on the spray drying of lime juice using maltodextrin with a DE value of 5 as a drying aid and concluded that the optimal addition to reduce stickiness was 20 %. Chegini and Ghobadian (2005) studied spray drying of orange juice. They found that operating parameters such as feed flow rate, centrifugal atomizer speed and air inlet temperature have important effects on the physical properties of powders such as bulk density, particle size, residual moisture content, insoluble solids and average time of wettability.

The majority of the cited investigations have been conducted with lab or pilot scale spray dryers. For scale-up of spray drying processes to industrial scale, the spray drop size distribution and the combined impact of the air (temperature and humidity, especially the outlet conditions) and the residence time on the residual moisture content, the drying rate and the heat exposure have to be kept constant (Masters, 1994). These parameters influence strongly the physical and nutritional particle properties.

The present study was carried out to investigate effects of spray drying conditions of carob pekmez on total phenolic content, antioxidant activity and the physical properties of the resulting powder. Based on these results, it will be possible to define optimal process parameters depending on the desired product properties.

Materials and Methods

Materials and Experimental Setup

Carob pekmez was supplied by Atışeri Co. (Antalya, TR). According to the manufacturer it has a total carbohydrate content of 44.41 % (14.67 % glucose, 14.20 % fructose, 15.54 % sucrose). Maltodextrin powders (Cargill Deutschland

GmbH, Krefeld, DE) with three different DE values (8.6, 15.3, 18.6) were used for spray drying trials.

The feed solutions were prepared with pekmez to maltodextrin dry matter ratios of 25:75 and 50:50 under consideration of the dry matter content of pekmez and maltodextrin. The dry matter content of the pekmez was determined by measurement of °Brix. The overall carbohydrate concentration of the feed solution was adjusted to 20 °Brix. Therefore, maltodextrin was dissolved completely in demineralized water and then the necessary amount of pekmez was added under agitation.

A pilot scale spray dryer (Industrie-Werke Karlsruhe, C 117, DE) equipped with an external mixing pneumatic atomizer was used for the spray drying trials. Drying air flow rate varied between 250 and 280 m³/h due to varying filter permeability. The spray dryer was operated in co-current mode. Atomization pressure was set to 3 bar. The air inlet temperature T_{inlet} was set to 160 or 210 °C. The air outlet temperature T_{outlet} was kept at 75 °C for all trials by adjusting the feed flow rate. The spray dried pekmez was separated from the air flow by a cyclone and collected for 10 to 20 min at the outlet of the cyclone. Afterwards, it was stored in glass bottles with sealed caps until analyzed. A schematic of the spray drying setup is displayed in figure 1.
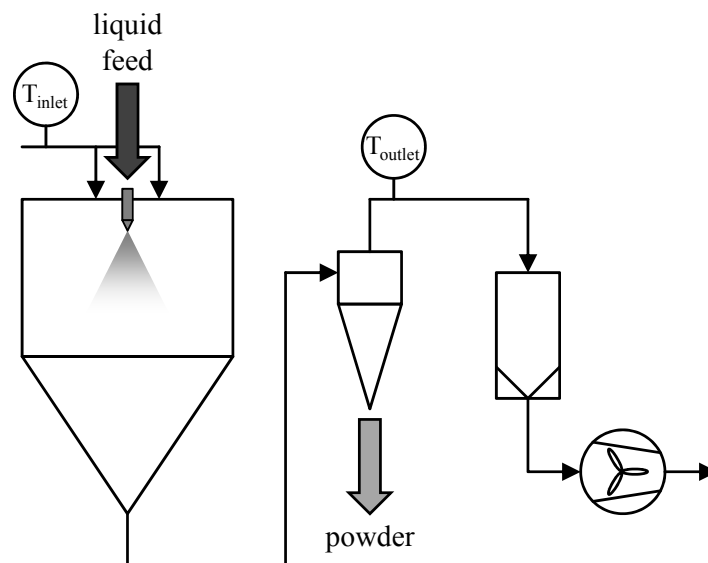

Figure 1: Schematic of spray dryer with atomizer (left), cyclone (middle) and fan with filter (right). All powder was separated from the air flow in the cyclone. The air temperatures T_{inlet} and T_{outlet} were measured prior entering the drying chamber and after exiting the cyclone.

Physical Properties

An infrared balance moisture analyzer (Mettler Toledo, LJ 16, CH) was used for the determination of the moisture content. The temperature was set to 105 °C and the stability criterion of no weight change during 1 min was selected. Considering the measurement temperature of 105 °C, caramelization may cause slightly higher moisture content values than actually present but the effect should be for all samples in the same magnitude. Each measurement was done in duplicate with a sample amount of 1.5 g and mean values were calculated.

Water activity (a_w) measurement of the powders was carried out using a water activity meter (Novasina, Aw Sprint TH-500, CH) at 25 °C. Each measurement was done in duplicate and mean values were calculated.

A differential scanning calorimeter (Thermal Analysis Instruments, DSC 2920 CE, US) was used to determine T_g of all produced powders. Nitrogen was used as the purge gas. A single point temperature calibration was carried out with Indium. All tests were performed in sealed aluminum pans with a sample weight of 7.5 mg (± 0.5 mg). From preliminary trials with heating rates between 5 and 20 °C/min, a heating rate of 10 °C/min was chosen for optimal indication of the glass transition temperature range. The measurement procedure was: isothermal for 3 min at -20 °C, heat scanning from -20 to 120 °C with 10 °C/min heating rate, isothermal for 3 min at 120 °C, cooling rapidly to -20 °C, isothermal for 3 min at -20 °C, heat scanning from -20 to 160 °C with 10 °C/min heating rate, isothermal for 3 min at 160 °C. The second scanning run of the sample was used in this method to avoid the enthalpy relaxation of the amorphous powder which appears in the first scan, thereby enhancing the accuracy of T_g measurement on DSC thermogram (Shrestha et al., 2007). T_g of the powders were determined with Universal Analysis V2.5H software. Although the onset, midpoint and offset temperatures of the glass transition range were determined only the onset temperatures are shown in the results. For each sample, a mean value was calculated from duplicate measurements. An example thermogram of a glass transition measurement is given in figure 2.

The wetting time method was used for determination of the wetting behavior of the powders. The method is also known as the immersion or slider method. By this method, the wetted height of a defined powder sample placed on top of a liquid surface is measured with respect to time. An unsteady state in the beginning is followed by a steady state (Schubert, 1990; Hogekamp and Schubert, 2003). The experimental setup consists of a container for the testing liquid and a powder section above the container. A slider separates the testing liquid and the powder prior to the measurement. An infrared distance sensor measures the changing position of the powder bulk once the slider is removed and the powder immerses (Pohl et al., 2004). Demineralized water was used in all cases as liquid.

For the samples with DE values 8.6 and 15.3, a measuring frequency of 60 Hz was selected because of their fast wetting. 10 Hz was chosen for the samples with DE value 18.6 because of its significantly slower wetting. For all samples, immersion speed in the steady state of the wetting was determined. Four measurements were done for each sample and mean values were calculated.
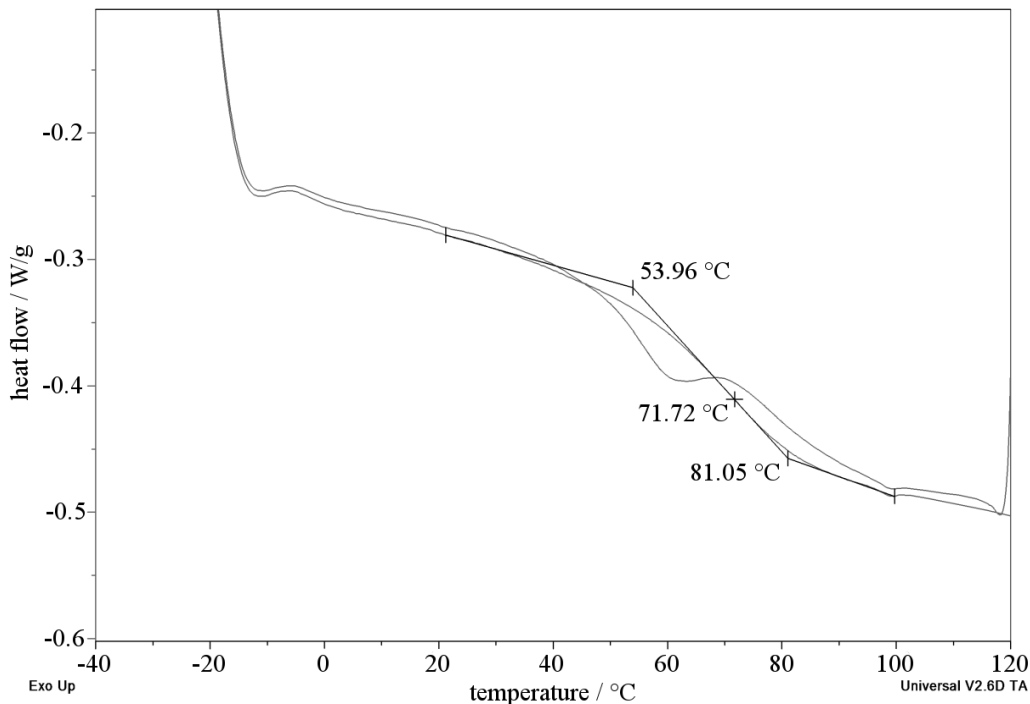

Figure 2: An example thermogram (DE 8.6, 25:75, T_{inlet} 160 °C) obtained during glass temperature measurements of the pekmez powders. Two scanning runs and the analysis of the second run are shown.

The particle size distribution of the spray dried powders was measured with a laser diffraction spectrometer (Malvern Instruments, 2600c, UK) using a dry dispersion unit. The measured scattering data were analyzed with the predefined optical model particle-in-air based on the anomalous diffraction model. The results were given in terms of Sauter mean diameter ($x_{1,2}$) of the particle collective. Measurements were done in triplicate and mean values were calculated.

The color of the powders was analyzed using a colorimeter (Minolta, CR-300, JP) which is based on the CIE (Commission Internationale de L'Eclairage) L*a*b* color space. White balance was performed with a calibration tile prior to every measurement. Five measurements were done for each sample and mean values were calculated.

Nutritional Properties

The Folin-Ciocalteau method was used for determination of the total phenolic content. Pekmez and spray dried powder samples were dissolved with demineralized water and diluted. 2.5 ml of Folin-Ciocalteau reagent (diluted 10 times with water) and 2 ml of Na_2CO_3 (75 g/l) were added to 0.5 ml diluted extract. The samples were kept for 2 h in the dark at room temperature. The absorbance values were measured with an UV-Vis spectrophotometer (Varian Inc., Carry 50 Scan, AU) at 760 nm. Three measurements were done for each sample. Total phenolic contents of the extracts were determined as gallic acid equivalent (mg gallic acid (GAE)/g dry matter) by using a calibration curve of gallic acid solutions of known concentration (Skerget et al., 2005). Three measurements were done for each sample and mean values were calculated.

The antioxidant activity of the pure pekmez and the produced powders was determined according to the modified method of Sanchez-Moreno (1998) using DPPH with a concentration of 0.025 g/l. Pekmez and spray dried powder samples were dissolved with demineralized water and diluted. The diluted extracts were added into 3.9 ml of DPPH solution. After 40 min, the absorbance of the DPPH solution was measured at 515 nm with an UV-Vis spectrophotometer (Varian Inc., Carry 50 Scan, AU) (Rodriguez et al., 2005; Sanchez-Moreno et al., 1998). The decrease in absorbance (expressed as percent of the initial absorbance) was plotted against the concentration of the antioxidant solution in the reaction mixture for each extract. The efficient concentration EC50 represents the amount of sample containing antioxidant necessary to decrease the initial DPPH concentration by 50 %. EC50 was calculated for each solution from a calibration curve by linear regression. EC50 is expressed in terms of g dry sample/g DPPH. Lower EC50 value indicates therefore higher antioxidant activity (Rodriguez et al., 2005).

Results and Discussion

Physical Properties

The spray drying trials with maltodextrin at a DE value of 18.6 and 50:50 pekmez to maltodextrin ratio were considered unsuccessful and not further analyzed as the feed solution sticked to the dryer wall and formed a toffee like layer. For that reason 50:50 pekmez to maltodextrin ratio was not used at a DE value of 18.6 for further trials. As expected the powders with higher maltodextrin content and dried at a lower drying air inlet temperatures showed less stickiness.

Mean values of moisture content and water activity of the powders are given in table 1. The moisture content ranged between 2.2 and 3.3 % and the water activity between 0.14 and 0.23. Both values are lower at lower air inlet

temperature of 160 °C. Water activity is an important indication for the shelf life of food products. The water activity values of all pekmez powder samples were below the critical water activity value for fat free food products and therefore microbiological, enzymatic and non-enzymatic degradation processes are reduced to a minimum (Kessler, 1996).

Table 1: Moisture content (MC) and water activity (a_w) of produced powders show at constant air outlet temperature (T_{outlet}) mostly a significant influence of air inlet temperature (T_{inlet}) and no systematic influence of pekmez to maltodextrin (P:M) ratio and dextrose equivalent (DE) value of maltodextrin.

T_{inlet} [°C]	T_{outlet} [°C]	DE	P:M ratio	MC [%]	a_w [-]
160	75	8.6	25:75	2.26 ± 0.10	0.156 ± 0.003
160	75	15.3	25:75	2.31 ± 0.03	0.141 ± 0.006
160	75	18.6	25:75	2.51 ± 0.01	0.134 ± 0.002
160	75	8.6	50:50	2.23 ± 0.06	0.145 ± 0.006
160	75	15.3	50:50	2.49 ± 0.01	0.159 ± 0.001
210	75	8.6	25:75	2.96 ± 0.08	0.188 ± 0.003
210	75	15.3	25:75	3.14 ± 0.06	0.177 ± 0.001
210	75	18.6	25:75	2.95 ± 0.08	0.158 ± 0.001
210	75	8.6	50:50	2.70 ± 0.00	0.211 ± 0.005
210	75	15.3	50:50	3.27 ± 0.06	0.224 ± 0.001

T_g of the pekmez powders in dependency of the DE value of maltodextrin, the pekmez to maltodextrin ratio and the air inlet temperature are given in figure 3. T_g was measured to verify a temperature difference of at least 10 to 20 °C to the potential storage temperate for avoidance of stickiness problems. A significant influence of the pekmez to maltodextrin ratio is observed. T_g of the produced powders were decreased with increasing DE value of the maltodextrin for both air inlet temperatures, however most pronounced for 160 °C. Except for the sample at 210 °C drying air inlet temperature, pekmez to maltodextrin ratio 25:75 and a DE value of 18.6, the moisture content is also decreasing with increasing DE value (see table 1) which also causes a lowering in T_g (see figure 3). Due to the cooccurrence of this two influencing factors, the expected lowering effect of the increasing DE value on the T_g could not clearly be shown in the present study. The pekmez to maltodextrin ratio has a significant influence on the T_g of the powders. As the pekmez to maltodextrin ratio increases, also the concentration of low molecular weight carbohydrates increases. Due to low T_g of these carbohydrates the glass transition of the produced powders was shifted to lower temperatures. Shrestha et al. (2007) obtained a similar result for spray dried orange juice. They also stated that the decrease in T_g with decreasing maltodextrin content was not linear.

An increase in the drying air inlet temperature caused a decrease in T_g of the spray dried powders and an increase in their moisture content as can be seen in table 1. Lower T_g for the powders produced at a higher air inlet temperature is expected to be the result of the higher moisture content of these powders. Chegini and Ghobadian (2005) reported that increasing the air inlet temperature causes reduced final moisture content of the product. The results of the present study have shown the opposite which is expected to be the result of crust formation on the drop surface. During spray drying the drying of a drop takes places in two stages. In the first stage most of the drying occurs as a result of free moisture vaporization from the surface of the droplet. In the second stage drying rate is lowered as a result of crust formation at the drop surface and concentration of unbound water to the inner part of the droplet (Masters, 2002). Especially for sugar rich products, evaporation is controlled by the moisture diffusion in the crust (Roustapour et al., 2006).
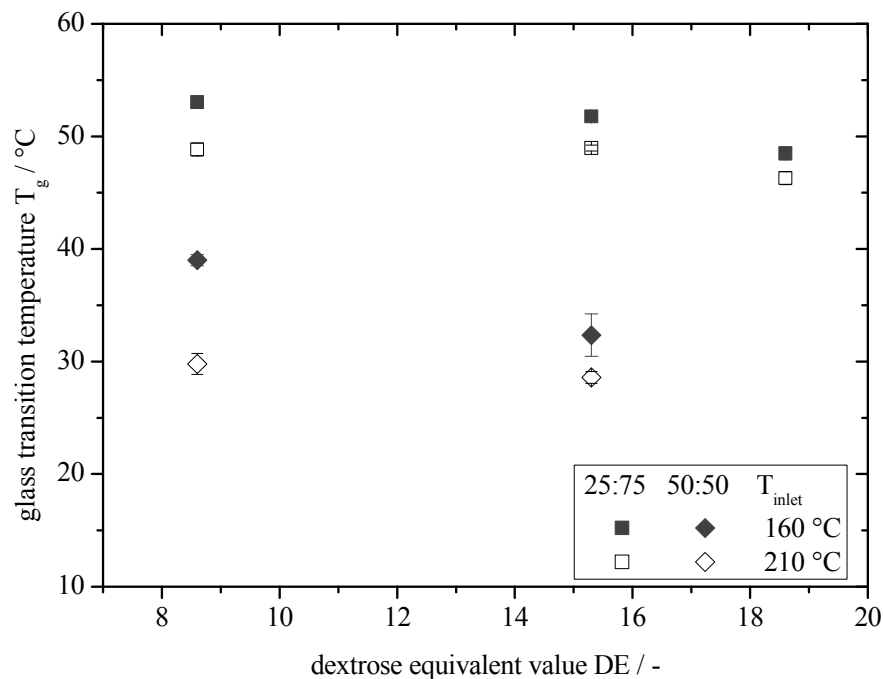

Figure 3: Glass transition temperature (T_g) of the pekmez powders in dependency of dextrose equivalent (DE) value of maltodextrin, pekmez to maltodextrin ratio and air inlet temperature (T_{inlet}). Significant influence of the pekmez to maltodextrin ratio is observed.

The immersion speed of the powders is given in figure 4. As the DE value increases the immersion speed of the powders decreases. Very slow immersion speed was found for powders at DE values of 18.4. The decrease of the immersion

speed due to increasing DE values and increasing pekmez to maltodextrin ratio can be related to the better solubility of lower molecular carbohydrates (Chronakis, 2010) causing a faster increase of the liquid viscosity during the measurement time. The increase in pekmez to maltodextrin ratio and air inlet temperature also causes a decrease in the immersion speed of the powders but less significant than the increasing DE value. The decrease due to higher air inlet temperature may be related to the formation of a thicker, less porous crust in the first drying stage at these drying conditions.
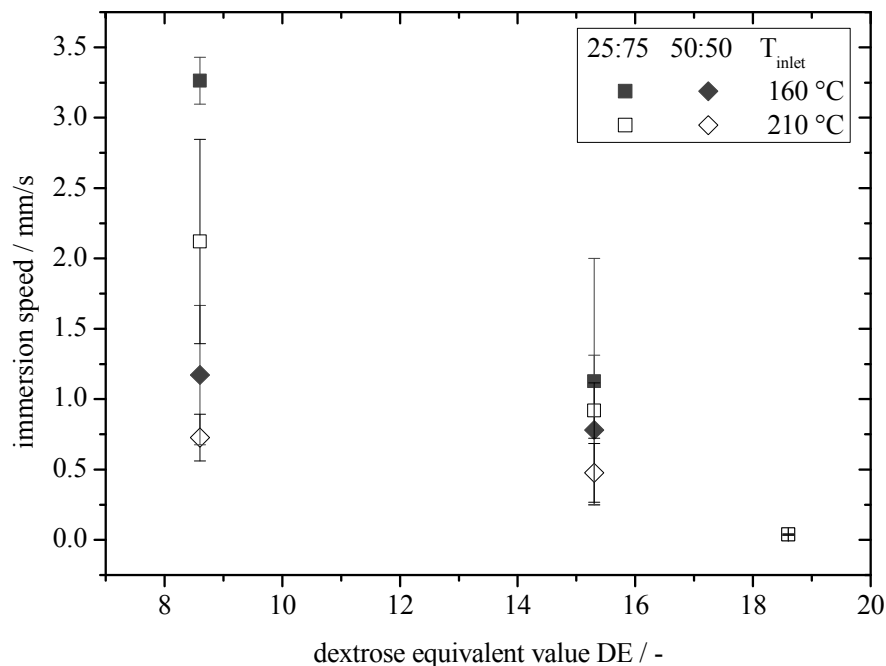

Figure 4: Immersion speeds of the pekmez powders in the steady state wetting in dependency of dextrose equivalent (DE) value of maltodextrin, pekmez to maltodextrin ratio and air inlet temperature (T_{inlet}). Most significant effect is caused by the change in DE values of used maltodextrin.

The Sauter mean diameter $x_{1,2}$ values of the spray dried powders are given in table 2. The Sauter mean diameters are in a quite narrow range. Increasing air inlet temperature leads to a slight increase which can be related to the faster crust formation and internal bubbles growth during the drying at higher temperatures.

The color measurement results for the spray dried powders are shown in table 2. As the pekmez to maltodextrin ratio increases the lightness of the powders decreases (decreasing L*) which is a result of the higher pekmez content. As

the pekmez to maltodextrin ratio increased both a* and b* were increased. The increase in the air inlet temperature also causes a decrease of L* as a result of caramelization of the carbohydrates in the pekmez and possibly Maillard reaction. The air inlet temperature increase caused an increase in a*, but b* was not affected significantly by this change. At constant pekmez to maltodextrin ratio are therefore both L* and a* a possible indicator for thermal exposure of the product.

Table 2: Sauter mean diameter ($x_{1,2}$) and color (lightness (L*), color indicators (a*, b*)) of produced powders show at constant air outlet temperature (T_{outlet}) mostly a significant influence of air inlet temperature (T_{inlet}) and pekmez to maltodextrin (P:M) ratio and low influence of dextrose equivalent (DE) value of maltodextrin.

T_{inlet} [°C]	T_{outlet} [°C]	DE	P:M ratio	$x_{1,2}$ [μm]	L* [-]	a* [-]	b* [-]
160	75	8.6	25:75	5.74 ± 0.20	90.63 ± 0.04	-0.72 ± 0.02	16.72 ± 0.17
160	75	15.3	25:75	7.43 ± 0.12	90.66 ± 0.23	-0.77 ± 0.01	16.23 ± 0.04
160	75	18.6	25:75	7.62 ± 0.04	91.16 ± 0.13	-0.80 ± 0.02	15.69 ± 0.20
160	75	8.6	50:50	7.61 ± 0.15	85.23 ± 0.18	-0.25 ± 0.04	22.61 ± 0.26
160	75	15.3	50:50	7.43 ± 0.26	85.11 ± 0.11	-0.28 ± 0.03	22.65 ± 0.28
210	75	8.6	25:75	8.89 ± 0.14	87.79 ± 0.17	-0.60 ± 0.04	17.71 ± 0.28
210	75	15.3	25:75	10.08 ± 0.40	87.81 ± 0.20	-0.58 ± 0.03	16.23 ± 0.18
210	75	18.6	25:75	10.19 ± 0.19	88.06 ± 0.10	-0.55 ± 0.02	17.22 ± 0.34
210	75	8.6	50:50	8.05 ± 0.16	83.61 ± 0.05	-0.16 ± 0.03	22.57 ± 0.20
210	75	15.3	50:50	8.70 ± 0.19	83.61 ± 0.17	-0.23 ± 0.05	22.87 ± 0.09

Nutritional Properties

The total phenolic content and antioxidant activity measurement results for the unprocessed carob pekmez and the spray dried powders are given in table 3. The pekmez to maltodextrin ratio needs to be taken into account when evaluating the results. Total phenolic content of pekmez powders ranged between 3.67 and 8.03 mg GAE/g dry matter while the total phenolic content of unprocessed carob pekmez was determined as 16.54 mg GAE/g dry matter. The antioxidant activity values of the carob pekmez and the powders were expressed in terms of EC50 value. Higher EC50 value indicates lower antioxidant activity. The EC50 value of unprocessed carob pekmez was determined to be 8.12 dry matter/g DPPH while the EC50 values of the powders ranged between 13.07 and 26.95 dry matter/g DPPH. Total phenolic content of the powders with 25:75 pekmez to maltodextrin ratio was approximately half of the powders with 50:50 pekmez to maltodextrin ratio and antioxidant activity was approximately twice, respectively. Taking into account the reduction of the pekmez content in the powders compared to the pure carob pekmez there was only a minor change in total phenolic content (approx. 10 %) and antioxidant activity (approx. 20 %) due to spray drying for all processing conditions. Due to the co-current operation mode of the spray drier the product itself will remain at the cooling limit temperature until the first drying

stage ends and rise afterwards to the constant air outlet temperature of 75 °C. Thus the product is not stressed significantly by high temperatures even with higher air inlet temperature and the nutritional properties are preserved.

Table 3: Total phenolic content (TFC) and antioxidant activity (represented by EC50) of carob pekmez and produced powders depending on air inlet/outlet temperature ($T_{inlet/outlet}$), dextrose equivalent (DE) value of maltodextrin and pekmez to maltodextrin (P:M) ratio. A change in TFC of about 10 % and in EC50 of about 20 % is observed taking the respective pekmez content into account.

T_{inlet} [°C]	T_{outlet} [°C]	DE	P:M Ratio	TFC [*mg GAE/g dry matter*]	TFC spray dried [%]	EC50 [*g dry matter/g DPPH*]	EC50 spray dried [%]
160	75	8.6	25:75	3.67 ± 0.07	88.8	26.13 ± 0.37	80.4
160	75	15.3	25:75	3.90 ± 0.07	94.3	25.48 ± 0.38	78.4
160	75	18.6	25:75	3.93 ± 0.08	95.0	25.33 ± 0.38	80.0
160	75	8.6	50:50	7.52 ± 0.12	90.9	13.88 ± 0.25	85.5
160	75	15.3	50:50	8.03 ± 0.12	97.1	13.88 ± 0.11	85.4
210	75	8.6	25:75	3.86 ± 0.04	93.3	25.79 ± 1.27	79.4
210	75	15.3	25:75	4.10 ± 0.05	99.1	26.20 ± 0.39	80.7
210	75	18.6	25:75	3.90 ± 0.16	94.3	26.95 ± 0.74	83.0
210	75	8.6	50:50	7.75 ± 0.32	93.7	13.07 ± 0.20	80.4
210	75	15.3	50:50	7.71 ± 0.00	93.2	13.29 ± 0.25	81.8
Carob pekmez				16.54 ± 0.24		8.12 ± 0.34	

Conclusion

The DE value of the maltodextrin and the air inlet temperature have only slight influence on T_g, Sauter mean diameter, water activity and moisture content. Therefore T_g can be adjusted by the pekmez to maltodextrin ratio and the immersion speed – representing the wetting behavior – by the DE value of the used maltodextrin with a minor impact of the air inlet temperature. Color change was significant and can be used at constant pekmez to maltodextrin ratio as a possible indicator for thermal exposure. Both total phenolic content and antioxidant activity were largely independent from all investigated drying conditions and depict a good preservation through the process. Therefore spray drying in co-current mode is a suitable method for drying of pekmez without significant loss of its beneficial nutritional properties and adjustable T_g and wetting behavior of the powder.

References

Bhandari BR, Senoussi A, Dumoulin ED, Lebert A. 1993. Spray drying of concentrated fruit juices. Drying Technology. 11:1081-1092.

Bhandari BR, Data N, Howes T. 1997. Problems associated with spray drying of sugar-rich foods. Drying Technology. 15:671-684.

Bhandari BR, Howes T. 1999. Implication of glass transition for the drying and stability of dried Foods. Journal of Food Engineering. 40:71-79.

Bilia AR, Bergonzi MC, Morgenni F, Mazzi G, Vincieri FF. 2001. Evaluation of chemical stability of St. John's wort commercial extract and some preparations. International Journal of Pharmaceutics. 213:199-208.

Biner B, Gubbuk H, Karhan M, Aksu M, Pekmezci M. 2007. Sugar profiles of the pods of cultivated and wild types of carob bean (Ceratonia siliqua L.) in Turkey. Food Chemistry. 100:1453-1455.

Brennan JG, Herrera J, Jowitt R. 1971. A study of some factors affecting the spray drying of concentrated orange juice on a laboratory scale. Journal of Food Technology. 6:295-307.

Chegini GR, Ghobadian B. 2005. Effect of spray drying conditions on the physical properties of orange juice powder. Drying Technology. 23:657-668.

Chronakis IS. 2010. On the molecular characteristics, compositional properties, and structural-functional mechanisms of maltodextrin: a review. Critical Reviews in Food Science and Nutrition. 38:599-637.

Goula AM, Adamopoulos KG. 2008. Effect of maltodextrin addition during spray drying of tomato pulp: I. drying kinetics and product recovery. Drying Technology. 26:714-725.

Hogekamp S, Schubert H. 2003. Rehydration of Food Powders. Food Science and Technology International. 9:223-235.

Karababa E, Isikli DN. 2005. Pekmez: A traditional concentrated fruit product. Food Reviews International. 21:357-366.

Karatas S, Esin AA. 1990. A Laboratory scraped surface drying chamber for spray drying of tomato paste. LWT - Food Science and Technology. 23:354-357.

Kearsley MW, Dziedzic SZ. 1995. Handbook of Starch Hydrolysis Products and their Derivatives. London: Blackie Academic.

Kessler HG. 1996. Lebensmittel- und Bioverfahrenstechnik – Molkereitechnologie. München: Verlag A. Kessler.

Masters K. 1994. Scale-up of spray dryers. Drying Technology. 12:235-257.

Masters K. 2002. Spray drying in practice. Charlottenlund: SprayDryConsult International ApS,.

Papadakis SE, Gardeli C, Tzia C. 2006. Spray drying of raisin juice concentrate. Drying Technology. 24:173-180.

Pohl M, Hogekamp S, Mandac A, Schubert H. 2004. Instant Properties of agglomerated food powders. International Congress on Engineering and Food.

Quek SN, Chok NK, Swedlund P. 2007. The physicochemical properties of spray dried watermelon powders. Chemical Engineering and Processing. 46:386-392.

Rodriguez R, Jaramillo S, Rodriäguez G, Espejo JA, Guilleän R, Fernandez-Bolanos J, Heredia A, Jimenez A. 2005. Antioxidant activity of ethanolic extracts from several Asparagus Cultivars. Journal of Agricultural and Food Chemistry. 53:5212-5217.

Roos Y, Karel M. 1991. Phase-transitions of mixtures of amorphous polysaccharides and sugars. Biotechnology Progress. 7:49-53.

Roustapour OR, Hosseinalipour M, Ghobadian B. 2006. An experimental investigation of lime juice drying in a pilot plant spray dryer. Drying Technology. 24:181-188.

Sabanis D, Tzia C, Papadakis E. 2007. Effect of different raisin juice preparations on selected properties of gluten-free bread. Food Bioprocess Technology. 1:374-383.

Sanchez-Moreno C, Larrauri JA, Saura-Calixto F. 1998. A procedure to measure the antiradical efficiency of polyphenols. Journal of the Science of Food and Agriculture. 76:270-276.

Santos M, Rodrigues A, Teixeira JA. 2005. Production of dextran and fructose from carob pod extract and cheese whey by leuconostoc mesenteroides NRRL B512(f). Biochemical Engineering Journal. 25:1-6.

Schubert H. 1990. Instantisieren pulverförmiger Lebensmittel. Chemie Ingenieur Technik. 62:892-906.

Sengül M, Ertugay MF, Sengül M, Yüksel Y. 2007. Rhelogical characteristics of carob pekmez. International Journal of Food Properties. 10:39-46.

Shrestha AK, Ua-arak T, Howes T, Adhikari BP, Bhandari BR. 2007. Glass transition behavior of spray dried orange juice powder measured by differential scanning calorimetry (DSC) and thermal mechanical compression test (TMCT). International Journal of Food Properties. 10:661-673.

Skerget M, Kotnik P, Hadolin M, Hras AR, Simoni M, Knez Z. 2005. Phenols, proanthocyanidins, flavones and flavonols in some plant materials and their antioxidant activities. Food Chemistry. 89:191-198.