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Effects of Drying Methods on Physicochemical and Rheological Properties of Porcine Plasma Protein

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ABSTRACT

Porcine plasma is an important source of high protein content which can be used for food products. The objective of this study was to determine the effect of drying methods on the properties of porcine plasma protein powder (PPP). The effects of freeze drying, and spray drying at two levels of inlet air temperature (140 and 200 °C) were studied on the physicochemical and rheological properties of PPP. It was found that freeze-dried PPP showed significantly ($P < 0.05$) higher solubility and oil binding capacity (OBC) than spray-dried PPP. The higher inlet air temperature provided slightly higher OBC and water holding capacity of PPP. Moreover freeze-dried PPP had a red-yellow color as indicated by the lower values for lightness (L^*), higher redness (a^*) and higher yellowness (b^*), compared with spray-dried PPP which was green-yellow in color. As expected, the lower inlet temperature with spray drying exhibited higher values for L^*, a^* and b^* of PPP. All dried PPP showed a typical non-Newtonian flow behavior. Freeze-dried PPP exhibited Bingham plastic fluid behavior while spray-dried PPP exhibited pseudoplastic fluid behavior. Therefore, the drying method affected different PPP properties which can be tailored to food processing and application to improve food quality.

Keywords: porcine plasma protein, freeze drying, spray drying, physicochemical, rheological

INTRODUCTION

Pig production in Thailand has increased 1.90% from the previous year due to higher consumption (Office of Agricultural Economics, 2013). Therefore, porcine blood—a by-product from slaughterhouses—is available in a large volume though its utilization has been limited as in general terms, animal blood is 3–5% of the body weight (Mandal *et al*., 1999; Ofori and Hsieh, 2011) and generally consists of 60% plasma and 40% red blood cells (Ockerman and Hansen, 2000; Toldra *et al*., 2004). Blood is a good source of protein, containing essential and non-essential amino acids (Ockerman and Hansen, 2000; Ramos-Clamont *et al*., 2003). Porcine plasma protein consists of various proteins, mainly albumin and globulins, which have good emulsification properties (Jantawat *et al*., 1996; Cofrades *et al*., 2000; Ramos-Clamont *et al*., 2003; Ofori and Hsieh, 2011). The spray drying technique is a short dehydration process and is widely used in the food industry to produce food powder (Jittanit *et al*., 2010; Anandharamakrishnan *et al*.,

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2007). The drying air temperature and feed rate have been reported to be factors influencing the quality of spray- dried food powder (Jittanit *et al*., 2010). Freeze drying is a process involving low temperature and a long dehydration period which results in less damage than other dehydration methods. However, freeze drying may affect the functionality of protein because of partial protein denaturation. Chinprahast *et al*. (1995) studied the functional properties of freeze-dried and spray-dried porcine blood plasma and found that the functional properties decreased as the temperature of drying increased. Parés *et al*. (1998) found that spray drying affected the consistency of porcine blood plasma gels as the water holding capacity (WHC) and consistency of porcine blood plasma gels decreased when the pH decreased. Yu *et al*. (2007) reported that spray-dried peanut protein concentrate (PPC) exhibited better functional properties, particularly emulsifying capacity and foaming capacity, than PPC dried in a vacuum oven. However, no research has been reported on the rheological properties of porcine plasma protein powder (PPP). The objective of this study was to determine the effect of drying methods on the physicochemical and rheological properties of PPP.

MATERIALS AND METHODS

Preparation of porcine plasma protein

Porcine blood was obtained from a slaughterhouse in Nakhon Pathom province, Thailand. Sodium citrate solution (3.8% weight per volume) was used to prevent blood coagulation during collection (Nuthong *et al*., 2009). The porcine blood was kept in ice and transported to the Department of Food Engineering, Kasetsart University, Kamphaengsaen Campus. Porcine blood was centrifuged at 3,000×*g* for 30 min at 4 °C using a refrigerated centrifuge (Eppendorf centrifuge 5804R, Hamburg, Germany) to separate the plasma protein (supernatant) from blood cells by decantation.

Effect of drying methods on porcine plasma protein powder

Three drying methods (freeze drying, and spray drying at two levels of inlet air temperature, T_i) were studied to produce porcine plasma protein powder (PPP).

PPP was lyophilized using a freeze drier (Elcold DK-9500; Hobro/Scanvac Coolsafe 100-4 Pro; Lynge, Denmark). On the other hand, PPP was dried using a spray drier (Lab-Plant SD-04 spray dryer; West Yorkshire, England) at two levels of T_i (140 and 200 °C) with an outlet air temperature of 70 °C and a feed rate of 0.4 $L.hr^{-1}$. PPP samples were kept at -20 °C until used.

Characterization of porcine plasma protein powder

Chemical composition

The chemical composition (the moisture, protein and ash contents) of PPP were determined by the method of Association of Official Analytical Chemists (2000).

Color measurements

The PPP color values (L^*, a^* and b^*) in the CIE system (International Organization for Standardization, 2008) were measured using a Spectro-guide (BYK-Gardner GmbH; Geretsried, Germany). A white standard plate (L^*= 97.75, a^*= -0.49 and b^* = 1.96) was used.

Solubility

Solubility was determined according to the method of Suzuki and Shimizu (1982). Briefly, 0.5 g of PPP was dissolved in 20 mL of deionized water and shaken in a shaking water bath (WNB14; Memmert; Duesseldorf, Germany) for 1 hr at room temperature (25 °C). Insoluble matter was obtained by filtration and later dried at 105 °C for 3 hr until a constant weight was reached. The solubility (%) was calculated by a weight difference as follows: Solubility as a percentage = $[(W_1 - W_2)/W_1] \times 100$, where W_1 is the initial weight of the dry matter measured in grams and W_2 is the weight of the insoluble dry matter measured in grams.

Water holding capacity and oil binding capacity

The water holding capacity (WHC) was determined according to the method of Beuchat (1977). Each PPP sample of 0.5 g was suspended in 10 mL of deionized water, vortexed for 2 min, allowed to stand at room temperature (25 °C) for 1 hr and then centrifuged with a refrigerated centrifuge (5804R; Eppendorf; Hamburg, Germany) at 8,000×*g* for 20 min. The supernatant was decanted and the centrifuge tube containing the water-absorbed sample was weighed. The WHC (measured in grams of water per gram of PPP) was calculated as WHC = $(W_2-W_1)/W_0$, where W_0 is the weight of the dry sample measured in grams, W_1 is the weight of the tube plus the dry sample measured in grams and W_2 is the weight of the tube plus the water absorbed sample measured in grams. Triplicate samples were analyzed for each measurement. The oil binding capacity (OBC) was also determined for samples by dispersing 0.5 g of PPP in 10 mL of vegetable oil similar to the method used for determining the WHC (Beuchat, 1977). The OBC was expressed in grams of oil absorbed sample per gram of PPP.

Rheological measurements

Steady state flow and dynamic viscoelasticity measurements were carried out in a controlled stress rheometer (HAAKE RheoStress 600; Thermo Electron Ltd.; Karlsruhe, Germany) using cone-plate geometry (cone diameter = 60 mm, angle = 1°, gap = 0.052 mm).

Steady shear measurements

The PPP (2% weight per weight (w/w) of freeze dried or spray dried sample) was dissolved in deionized water, stirred using a magnetic stirrer and then heated at 70 °C for 30 min in the shaking water bath. The solutions were cooled to room temperature (25 °C).

The apparent viscosity and the shear stress were obtained by performing the shear rate (1 to 100 s^{-1}) when the shear stress was increased from 0 to 20 Pa at 25 °C.

The flow behavior of the PPP solutions was analyzed by fitting the experimental data with a power law model as $\eta = k.\dot{\gamma}^{n-1}$, where η is the apparent viscosity (measured in pascal.seconds), $\dot{\gamma}$ is the shear rate (per second), k is the consistency index (pascal.seconds^n) and n is the flow behavior index (dimensionless).

Dynamic measurements of viscoelastic properties

The PPP sample (2% w/w of spray dried sample) was dissolved in deionized water, stirred using a magnetic stirrer and then heated at 70 °C for 30 min in the shaking water bath. The solution was then cooled to room temperature (25 °C). An oscillatory stress sweep test was performed from 0.01 to 20 Pa. Based on the stress sweep results, a frequency of 1 Hz was selected to set the upper limit of the linear viscoelastic region (LVR) for frequency sweep measurements at a range in the angular frequency (ω) of 0.1–100 rad.s^{-1}. Dynamic viscoelastic parameters—the storage or elastic modulus (G') and the loss or viscous modulus (G")— were determined as a function of ω.

Statistical analysis

A completely randomized design was used to study the main factors (drying methods and inlet temperatures). Three replications were used to determine each property. Data were subjected to analysis of variance and Duncan's multiple range test was used to determine significant differences at the 95% confidence interval. Analysis was performed using the SPSS package (SPSS 11.0 for Windows; SPSS Inc.; Chicago, IL, USA).

RESULTS AND DISCUSSION

Physicochemical properties of porcine plasma protein powder

Freeze-dried PPP had a red-yellow color compared with spray-dried PPP which was green-yellow in color. Table 1 shows the chemical composition of PPP. None of the drying methods affected the protein and ash contents of PPP, which ranged from 79.63 to 82.16% and 11.73 to 12.41%, respectively. Variations in chemical composition came from the physical conditions of the pig and the time of slaughter (Pongkongkaew, 2006). As expected, spray-dried PPP at the higher T_i (200 °C) had a lower moisture content than at the lower T_i (140 °C). This was due to the higher temperature gradient on the surface of feed drops at the higher T_i resulting in a higher heat transfer rate (Jittanit *et al.*, 2010). This corresponded to a decrease in the moisture content of spray-dried black mulberry powder with increasing T_i (Fazaeli *et al.*, 2012). Freeze-dried and spray-dried PPP samples at the higher T_i had similar moisture contents. This indicated that the higher T_i of spray drying in this study did not affect the chemical composition of PPP when compared to using a low temperature and a longer time for freeze drying.

Color is an important sensory attribute for food acceptance. Thus, the different drying methods might reflect different color values of PPP. It was found that the drying method significantly affected the color values (L^*, a^* and b^*) of PPP. Freeze-dried PPP had the lowest L^* and the highest a^* and b^* values among all drying methods (Table 2) as shown by its red-yellow color. The higher L^* value of spray-dried PPP than that of freeze-dried PPP was similar to the findings of Espinto Santa *et al*. (2013) and Joshi *et al*. (2011). Spray drying at the higher T_i provided lower L^*, a^* and b^* values than those at the lower T_i. Such a difference was probably due to the higher degree of Maillard reaction or non-enzymatic browning at the higher T_i (Sarochwikasit and Tangduangdee, 2011).

Drying methods significantly affected the solubility of PPP. The higher solubility of freeze-dried PPP not only resulted from the porous structure but also possibly came from the lowered degree of protein denaturation or aggregation in the freeze-dried sample compared to in the spray-dried one, resulting in a higher solubility (Table 3). There was no effect of T_i on the solubility of spray-dried PPP. This result was contrary to another study that reported a higher T_i increased the solubility of spray-dried black mulberry powder (Fazaeli *et al*., 2012). The variation might have been due to the difference in the raw material and the drying conditions used.

Interactions of water and oil with proteins are important in food systems and can affect the flavor and texture of foods. Unfortunately, the

Table 1 Composition of porcine plasma protein powder.

Chemical component	Drying method		
	Freeze drying	Spray drying at 140 °C	Spray drying at 200 °C
Ash (%)	12.37±0.04^a	12.41±0.13^a	11.73±0.19^a
Protein (%)	80.80±0.35^a	79.63±0.42^a	82.16±1.06^a
Moisture content (%)	6.10±0.53^a	10.17±0.18^b	6.65±0.74^a

Table 2 Color values of porcine plasma protein powder.

Drying method	L^*	a^*	b^*
Freeze drying	59.32±0.80^a	4.04±0.53^b	15.27±0.36^c
Spray drying at 140 °C	77.58±1.89^c	0.62±0.05^a	12.14±0.17^b
Spray drying at 200 °C	64.83±0.49^b	0.05±0.06^a	9.24±0.22^a

Each value is the mean of three replications ± SD.

Means in the same row with different lowercase superscripts are significantly different ($P < 0.05$).

WHC of freeze-dried PPP could not be determined. This might have been due to the greater solubility of freeze-dried PPP. There was no significant difference in the WHC of spray-dried PPP at the different levels of T_i. However, the OBC of freeze-dried PPP was the highest followed by spray-dried PPP at a T_i of 200 °C and then 140 °C, respectively. It was hypothesized that the porous structure of freeze-dried PPP might bind and entrap a higher volume of oil—more than in the spray-dried PPP (Table 3). The OBC of spray-dried PPP increased with increase in T_i. Similarly, the WHC and OBC of peanut protein isolate increased as a high pressure was applied (He *et al*., 2014). Moreover, the T_i was more pronounced on the OBC of spray-dried PPP than with WHC.

Rheological properties of porcine plasma protein powder

Steady shear

The viscosity decreased with an increase in the shear rate for all dried PPP. The steady shear rheological properties of PPP are shown in Figure 1. All dried PPP showed a typical non-Newtonian flow behavior. Freeze-dried PPP exhibited Bingham plastic fluid behavior, which required a shear stress of a certain value (yield stress) to flow at which stage the viscosity of the freeze-dried PPP was independent of the shear rate. Clearly, the viscosity of freeze-dried PPP was very small, compared to spray-dried PPP. However, spray-dried PPP (140 °C and 200 °C) exhibited pseudoplastic fluid behavior. The high

Table 3 Solubility, water holding capacity (WHC) and oil binding capacity (OBC) of porcine plasma protein powder.

Drying method	Solubility (%)	WHC (g H_2O/g protein)	OBC (g oil/g protein)
Freeze drying	97.11±0.82^b	-	4.67±0.07^c
Spray drying at 140 °C	42.06±2.21^a	3.66±0.41^a	2.07±0.23^a
Spray drying at 200 °C	42.46±2.29^a	3.75±0.27^a	2.73±0.26^b

Each value is the mean of three replications ± SD.
Means in the same row with different lowercase superscripts are significantly different (P < 0.05).
- = No data available.

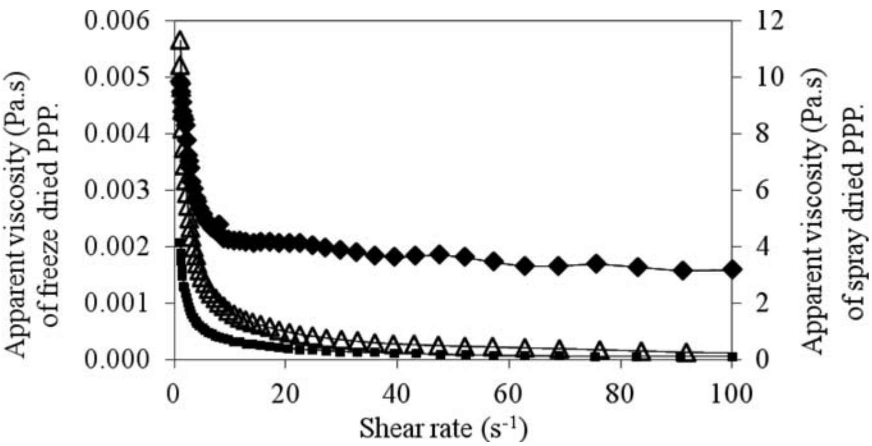

Figure 1 Flow curves of freeze-dried porcine plasma protein powder (PPP) (◆) and spray-dried PPP at different inlet temperatures: 140 °C (■) and 200 °C (△).

T_i affected the biopolymer state (glassy or rubbery state) and induced a thermal degradation of the molecular structure (Leon-Martinez *et al*., 2011). The spray-dried PPP at a T_i level of 200 °C had significantly greater consistency index (k) values (Table 4). The k value of freeze-dried PPP was the lowest, corresponding to the lowest viscosity. The flow behavior index (n) of spray-dried PPP was less than for freeze dried PPP, indicating that spray dried PPP exhibited more pseudoplastic fluid or shear-thinning behavior (n < 1) than did freeze-dried PPP. This was similar to the reported pseudoplastic fluid behavior of rice flour gels (Meng *et al*., 2014) and the pseudoplastic fluid behavior of bovine plasma proteins (Rodriguez Furlán *et al*., 2010).

Viscoelastic properties

Rheological properties are important in the quality control, storage and processing of foods as these properties can indicate the stability and predict texture (Leon-Martinez *et al*., 2011). The linear viscoelastic region (LVR) value was determined from oscillatory stress sweep tests at an angular frequency of 1 Hz. Shear stress at 1 Pa showed LVR in all samples for frequency sweep measurements. LVR could not be detected in the freeze-dried PPP (2% w/w); therefore, no data were determined in this study.

A predominantly elastic behavior (G' > G") was observed in the spray-dried PPP solutions throughout the frequency range studied. This indicated that the behavior of the spray-dried PPP was comparable to a gel-like material. Both the G' and G" values showed a slight dependency on frequency similar to the finding reported with rice flour-based batters (Matos *et al*., 2014). The G' and G" values of dried PPP increased with an increase in the angular frequency (Figure 2).

Table 4 Steady shear rheological properties of porcine plasma protein powder.

Drying method	Flow consistency index, k ($Pa.s^n$)	Flow behavior index, n	R^2
Freeze drying	0.004±0.001^c	0.792±0.035^a	0.947
Spray drying at 140 °C	4.327±0.119^b	0.128±0.038^b	0.995
Spray drying at 200 °C	10.483±0.578^a	0.131±0.048^b	0.998

Each value is the mean of three replications ± SD.
Means in the same row with different lowercase superscripts are significantly different (*P* < 0.05).
R^2 = Correlation coefficient.

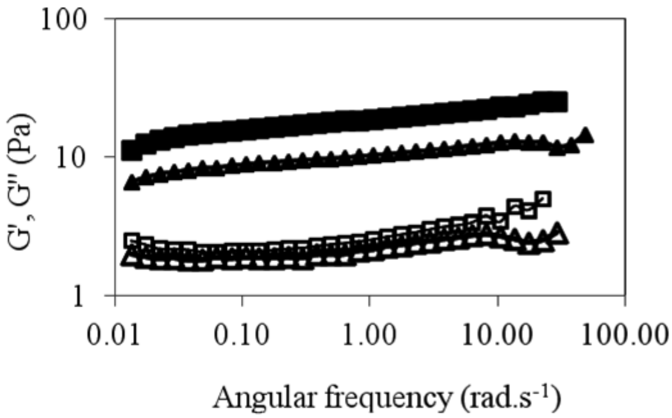

Figure 2 Mechanical spectra showing the angular frequency dependence of storage modulus (G', solid squares) and loss modulus (G", unfilled squares) of spray-dried PPP at 140 °C (■) and 200 °C (△).

CONCLUSION

Different drying methods affected the physicochemical and rheological properties of PPP. Freeze-dried PPP exhibited significantly higher solubility and OBC than spray-dried PPP. The higher inlet air temperature in spray drying provided a slightly higher OBC and WHC of PPP. Moreover, the drying methods produced different rheological properties of PPP. Freeze-dried PPP had a much lower viscosity than spray-dried PPP. The results showed that dried PPP might be used as a food additive to improve the food texture or as a biopolymer material for edible film and coating to maintain the quality of food products.

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