



Effect of vegetable proteins on physical characteristics of spray-dried tomato powders

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Abstract

In the present study, the effectiveness of different vegetable proteins (pea protein isolate, soy protein isolate and zein from maize) at two different ratios (1% and 5%) on product yield and physical properties of spray-dried pulpy tomato juice was investigated. Additionally, these proteins were compared with whey protein concentrate which has a superior effect on spray dried products at the same concentrations. Additionally, plain tomato juice was also spray dried for comparison with vegetable proteins. The product yield of the tomato powders dried with the vegetable proteins was lower than with the whey protein concentrate. Among vegetable proteins, the highest product yield was produced with 1% soy protein isolate. In all products, there was a slight colour difference between the reconstituted tomato powders and the raw tomato juice, which indicated that pulpy tomato juice can be spray dried with minor colour change. All powders had unique free-flowing properties estimated as Carr index and Hausner ratio due to their large particles.

Keywords

Tomato powder, physical properties, spray drying, vegetable proteins

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INTRODUCTION

Spray drying is a process that transforms liquids into powder form. In this process, atomised droplets are dried with the use of high temperatures. Despite the high temperatures, very rapid moisture evaporation from the surface of droplets keeps the droplets relatively cool until drying (Fang and Bhandari, 2012). Stickiness is a common problem in the spray drying process, due to the content of low-molecular-weight sugars in fruit juices. This stickiness problem mainly arises from low glass transition temperature and high hygroscopicity of the sugars (Fang and Bhandari, 2012). New approaches have been developed using excipient materials in the spray drying process to prevent stickiness of products. Mechanical scrapping of the drying equipment, introducing cold air from the bottom, and using

low-temperature dehumidified air are some examples of process-based approaches. The material-based approach is based on changing the glass transition of feed solution by addition of carrier materials (Jayasundera et al., 2011a). Generally, large amounts of carrier materials, mostly maltodextrin and gum Arabic, are added to fruit juices to increase the glass transition temperature (Ferrari et al., 2012b; Osorio et al., 2011; Roustapour et al., 2012; Tonon et al., 2010). However, addition of these materials increases the product's cost, causes off-flavour and reduces consumer approval of the fruit juice powders. A few recent studies have attempted to replace the large amount of maltodextrin with a small amount of proteins, due to film-forming properties of proteins. In these studies, a

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small amount (<5%) of protein used as carrier material increased product yield (PY) in comparison to maltodextrin at high concentration (up to 50%) (Fang and Bhandari, 2012; Jayasundera et al., 2011a, 2011b). Milk proteins such as whey protein and sodium caseinate are used as carrier materials in these studies.

Vegetables are a good and cheap source of proteins. Additionally, plant proteins are less allergenic to humans compared to animal-derived proteins. Thus, the application of these proteins in different products has increased in the food industry (Nesterenko et al., 2013). Vegetable proteins have many different functional advantages such as biocompatibility, biodegradability, emulsifying and foaming capacity, water and fat absorption, gelation and film-forming properties (Nesterenko et al., 2013). Although some studies have been carried out to determine effectiveness of these proteins in microencapsulation of different core materials (Karaca et al., 2015; Nesterenko et al., 2013), further research is needed to understand the effectiveness of vegetable proteins in spray dried fruit juice powders.

The world annual production of tomatoes is more than 160 million metric tonnes. Different products such as tomato paste, canned tomato and powdered tomato are produced for the preservation of tomatoes. Among these products, powdered tomato has some advantages, i.e., ease of packaging, transportation, mixing and stability. Sun drying, oven drying, drum drying and spray drying can be used to produce powdered tomato (Al-Asheh et al., 2003). However, spray drying of tomato juice was claimed to be very difficult because of stickiness and caking problems (Goula et al., 2004). Therefore, in the current study it is chosen as a model juice.

The present study was undertaken to investigate effects of the vegetable proteins on PY and some physical properties of tomato powder. For this purpose, three different vegetable proteins (pea protein isolate (PPI), soy protein isolate (SPI) and zein from maize (ZM)), commercially available and previously used in spray drying studies, were investigated as carriers instead of whey protein concentrate (WPC). The tomato powders were analysed for their moisture content, water activity, colour, density, particle size, porosity, flowability, cohesiveness, hygroscopicity and wettability.

MATERIAL AND METHODS

Materials

Tomato juice (100%) was purchased from a company (Tamek Şefim, İstanbul, Turkey) which regularly produces tomato juice. It was pulpy and at 5.5 °Bx. PPI (88% protein concentration, Pisane M9) was obtained from Cosucra (Warcoing, Belgium), WPC (77% protein concentration, Lactomin 80) was acquired from Rovita GmbH (Engelsberg, Germany) and SPI (90%

protein concentration) was purchased from Kemika (Zagreb, Croatia). ZM (92% protein concentration) was purchased from Sigma-Aldrich (Poole, Dorset, UK). Ethanol, 2-propanol, petroleum ether and potassium nitrate were all of reagent grade and obtained from Sigma-Aldrich (Poole, Dorset, UK).

Feed solution preparation

Feed solutions were prepared by addition of proteins (WPC, SPI, PPI and ZM) to 500 mL tomato juice without any filtration. Due to the insolubility of zein in water, it was dissolved in 20 mL aqueous ethanol (85%) before addition of tomato juice (Quispe-Condori et al., 2011). The protein concentrations were 1% (w/w) and 5% (w/w) in dry basis of the tomato juice. The solutions were stirred for 30 min before spray drying to dissolve the proteins completely.

Spray drying

A mini spray dryer (Büchi B-290, Büchi Laboratoriums-Technik, Flawil, Switzerland) was used for the spray drying processes. All drying processes were carried out at a feed rate of 35% (9.2 ± 0.4 mL/min), aspirator rate of 100% ($35 \text{ m}^3/\text{h}$), nozzle air flow of 30 mm (473 L/h) and inlet temperature of 150°C (Fang and Bhandari, 2012).

Product yield

PY is defined as the ratio of the amount of powder collected in the collection vessel to total dry matter of the emulsion (equation (1)).

$$PY \left(\frac{\text{g}}{100\text{g}} \right) = \frac{\left\{ \frac{\text{Weight of collected tomato powder (g dm)}}{\text{Weight of feed solution (g dm)}} \right\}}{\times 100} \quad (1)$$

Moisture content and water activity

Moisture content of samples was analysed using a KERN 60-3 infrared moisture analyser (drying at 120°C to constant weight). Water activity measurements were performed at 25°C using an AquaLab 4TE as described by the manufacturer (Decagon Devices, Inc, Pullman, WA).

Colour measurement

Colour analyses were carried out by using a tristimulus colourimeter (Konica Minolta Sensing, Inc., Japan)

equipped with a CR-400 measuring head (with the reference illuminant/observer D65/2°); colour was expressed in L (darkness/whiteness), a (greenness/redness) and b (blueness/yellowness). Hunter scale parameters; 1.1 g of tomato powder was dissolved in 20 mL water and placed above the light source in the sample holder of the instrument, and each colour value was recorded as the mean of three determinations. The instrument was standardised against a white tile where $L=95.24$, $a=-0.31$ and $b=3.01$. Different indicators were calculated from these experimental results: Browning index (equation (2)) (Youssefi et al., 2009), hue angle (equation (3)), chroma (equation (4)) and total colour differences (equation (5)) (Anekella and Orsat, 2013).

$$\text{Browning Index} = \frac{\left[100 \left(\frac{(a+1.75L)}{(5.645L+a-3.012b)} - 0.31 \right) \right]}{0.17} \quad (2)$$

$$\text{Hue Angle} = \frac{180}{\pi} \times \arctan \frac{b}{a} \quad (3)$$

$$\text{Chroma} = (\sqrt{a^2 + b^2}) \quad (4)$$

$$\begin{aligned} \text{Total colour difference } (\Delta E) \\ = \sqrt{(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2} \end{aligned} \quad (5)$$

where L_0 , a_0 and b_0 represent the colour parameters for the raw tomato juice, and L , a and b represent the colour parameters of the reconstituted product.

Particle size

The particle size was determined using a laser light-diffraction instrument (Mastersizer 2000, Malvern Instruments, Malvern, UK) equipped with wet dispersion unit (Hydro 2000S). 2-Propanol was used as dispersant, and the distribution of particle size was monitored during 10 successive measurements. The particle size was expressed as $D[4,3]$ (De Brouckere mean diameter, equation (6)) and $D[3,2]$ (Sauter mean diameter, equation (7)), which are common characterisation of particles (Ferrari et al., 2012b).

$$D[4,3] = \frac{\sum n_i d_i^4}{\sum n_i d_i^3} \quad (6)$$

$$D[3,2] = \frac{\sum n_i d_i^3}{\sum n_i d_i^2} \quad (7)$$

where n_i is the number of droplets of diameter d_i .

Bulk and tapped density

Bulk density was calculated from the occupied weight of the 10 mL of the tomato powder. The tapped density was calculated from the volume after tapping the cylinder 100 times by hand (Jinapong et al., 2008).

Particle density

Particle density of the powder sample was analysed according to Jinapong et al. (2008). One gram of tomato powder was transferred into a 10-mL measuring cylinder with a stopper. After addition of 5 mL of petroleum ether, the measuring cylinder was shaken to suspend all particles. Finally, all the powder particles on the wall of the cylinder were rinsed down with a further 1 mL of petroleum ether (6 mL in total), and the total volume of petroleum ether with suspended powder was read. The particle density was calculated from equation (8).

$$\rho_{\text{particle}} = \frac{\text{weight of powder (g)}}{\left\{ \begin{array}{l} \text{total volume of petroleum ether with} \\ \text{suspended powder (ml)} - 6 \end{array} \right\}} \quad (8)$$

Porosity, flowability and cohesiveness

Porosity (ε) was calculated using the relationship between the tapped (ρ_{tapped}) and particle (ρ_{particle}) densities of the powder (equation (9)). Flowability and cohesiveness were evaluated in terms of the Carr index (CI) and Hausner ratio (HR), as defined in equations (10) and (11), respectively.

$$\varepsilon = \frac{\rho_{\text{particle}} - \rho_{\text{tapped}}}{\rho_{\text{particle}}} \quad (9)$$

$$CI = \frac{\rho_{\text{tapped}} - \rho_{\text{bulk}}}{\rho_{\text{tapped}}} \quad (10)$$

$$HR = \frac{\rho_{\text{tapped}}}{\rho_{\text{bulk}}} \quad (11)$$

Hygroscopicity

One gram of each tomato powder was kept in wide-neck jars sealed inside a desiccator maintained at a relative humidity of 79.5%, using a saturated salt solution of potassium nitrate at room temperature (25°C). After equilibration of the relative humidity, the samples were

weighed, and the hygroscopicity of the powders was calculated using equation (12).

$$\text{Hygroscopicity (\%)} = \frac{\frac{x}{a_h} + W_i}{1 + \frac{x}{a_h}} \times 100 \quad (12)$$

where x is the increase in weight of tomato powder (g), a_h is the amount of powder used for measurement (g) and W_i (% wb) is the water content of the powder before exposure to humid environment (Syamaladevi et al., 2012).

Wettability

The average time of wettability was taken as the time required to wet 0.5 g powder when dropped onto the surface of 50 mL water at 25°C (El-Tinay and Ismail, 1985).

Statistical analysis

All drying experiments and analyses were carried out in duplicate. The data were subjected to variance analysis, and appropriate means separation was conducted using Duncan's Multiple Range Test in SAS System for Windows 7 (SAS Institute Inc., Cary, NC, USA).

RESULTS AND DISCUSSIONS

Product yield

The PYs of the tomato powder dried with tested proteins and without additive were ranged between 23.55 and 40.17 g product dm/100 g feed dm (Table 1). These estimated results were substantially lower than the ideal

parameters of at least 50%, informed by Bhandari et al. (1997). Goula and Adamopoulos (2005a) compared a standard and dehumidified air spray dryers in tomato juice drying. While similar PY to the present study was obtained by standard spray dryer (19.90–48.23%), dehumidified air spray dryer provided higher PY (36.62–65.86%) (Goula and Adamopoulos, 2005a).

The glass transition temperature of the sugars and organic acids present in fruit juices is low. Therefore, applied high drying temperature in spray drying results in the transformation into the viscoelastic rubbery state at the surface of the material and sticks to the drying chamber. Spray drying of such a material is not possible without using carrier materials that increase the glass transition temperature of the feed solution (Barbosa et al., 2015). Indeed, in a previous study, while no powder was recovered after spray drying of plain bayberry juice, addition of maltodextrin or whey protein to the feed solution resulted in high PY (Fang and Bhandari, 2012). In the current study, addition of 1% WPC increased the PY from 26.55% (spray dried plain tomato juice) to 36.89%. The differences between these studies could arise from the protein content of the whey protein. Indeed, the protein content of the WPC used in the current study was 77%, while the protein content of the whey protein isolate in the study of Fang and Bhandari (2012) was 94.56%.

Among the tested proteins, WPC provided the highest PY at 5%, followed by WPC at 1% and SPI at 1%. A similarly superior effect of milk protein (sodium caseinate) on PY over PPI was reported for spray drying of sucrose solution (Jayasundera et al., 2011b). The lower PY of the tomato juice powder dried with vegetable proteins could be related to their low solubility in water. Notably, 5% SPI and 1% ZM did not significantly ($p > 0.05$) change the PY when compared to plain tomato juice powder. As expected, increasing the WPC and ZM concentration in the feed solution resulted in higher PY. On the contrary, the PY was decreased by increasing the amount of PPI and SPI in the feed solution.

Table 1. Product yield, moisture content and water activity of tomato powder

Sample	Product yield (g/100 g)	Moisture content (g/100 g)	Water activity
Plain	26.55 ± 1.09d	4.19 ± 0.79a	0.178 ± 0.009b
1% WPC	36.89 ± 1.27ab	4.71 ± 0.56a	0.257 ± 0.008a
5% WPC	40.17 ± 1.39a	4.08 ± 0.04a	0.167 ± 0.017b
1% PPI	29.16 ± 3.24bcd	3.41 ± 0.23a	0.189 ± 0.014b
5% PPI	27.71 ± 3.46cd	3.95 ± 0.61a	0.201 ± 0.006b
1% SPI	34.74 ± 2.34abc	4.09 ± 0.22a	0.183 ± 0.018b
5% SPI	23.55 ± 2.42d	4.14 ± 0.25a	0.169 ± 0.005b
1% ZM	25.74 ± 3.06d	4.23 ± 0.17a	0.204 ± 0.005b
5% ZM	27.36 ± 1.04cd	4.55 ± 0.08a	0.204 ± 0.016b

Different letters in same column show significant ($P < 0.05$) differences. PPI: pea protein isolate; SPI: soy protein isolate; ZM: zein from maize; WPC: whey protein concentrate.

Moisture content and water activity

Moisture content and water activity play a chemically and microbiologically critical role in food-powder stability. Since it acts as a plasticiser, water in a very small amount depresses the glass transition temperature and causes stickiness and caking problems (Ferrari et al., 2012b).

The moisture content and water activity of the tomato powders were in the range of 3.41–4.71 g/100 g and 0.167–0.257, respectively (Table 1). The moisture content and water activity results were generally consistent with the findings of many previous studies

(1.5–10 g/100 g and 0.15–0.32, respectively) (Angel et al., 2009; Ferrari et al., 2012a; Goula et al., 2004; Rodriguez-Hernandez et al., 2005). Since the feed rate of the solution at different protein contents was constant, the moisture content and water activity of the products were almost the same. The moisture content of the tomato juice powder produced with different carriers was statistically similar. The slight but significant ($p < 0.05$) difference was determined in the water activity of tomato powder produced with 1% WPC. This difference could be related to the water-holding capacity of the WPC at low concentrations. Similar to the present study, Fang and Bhandari (2012) reported higher water activity at 1% whey protein content (0.293) than at 5% whey protein content (0.204) for bayberry juice powder.

Colour

The colour values of the tomato powders were evaluated for L , a , b , hue angle, chroma, browning index and total colour differences. The a value of all powders was determined as similar, statistically. Additionally, the hue angle, chroma and browning index values were statistically similar in all samples except the powder produced with 5% ZM (Table 2). This could be taken from the deeper yellow colour of zein. Indeed, the b value of tomato powder produced with 5% ZM was significantly higher than other samples.

The highest browning index value was calculated in the tomato powder produced with ZM. Additionally, the browning index increased with increasing protein content in the feed solution. The browning index of tomato powders (1.81–16.8%) was determined as lower than reported values (25.89–75.27%) for black mulberry juice (Fazaeli et al., 2012a). This indicates limited non-enzymatic browning reaction occurred in spray drying of the tomato juice.

Total colour difference (ΔE) of tomato powder from the raw tomato juice was also calculated and ranged between 0.65 and 1.98. The estimated results are lower than those obtained in several previous studies. ΔE of unclarified pomegranate and gac juice powders was reported between 8 and 13 (Horuz et al., 2012; Kha et al., 2010). ΔE of juçara (*Euterpe edulis* M.) pulp powder produced with different carrier agents (malto-dextrin, gelatin and gum Arabic) was determined between 4.45 and 15.84 (Bicudo et al., 2015). The ΔE differences can be related to naturally occurring pigment content of feed material which is sensitive to drying process. One possible reason for the low ΔE in present study can also be related to low amount of carrier agent. Indeed, Horuz et al. (2012) used 39.08–64.12% carrier agent for unclarified pomegranate juice powder, and Kha et al. (2010) used 10–30% carrier agent for gac fruit juice powder. Additionally, proteins could provide a greater protective effect than maltodextrin against colour change.

The hue angle and chroma values of tomato juice powder were 39.88–42.97 and 20.91–24.55, respectively. The hue angle and chroma of the tomato powder produced with 5% ZM were significantly higher than those of other powders. The main reason of higher hue angle and chroma values in the sample produced with 5% ZM is deeper yellow colour of the zein, since both of these values were calculated from b and a values. In a study on spray drying of watermelon juice at different inlet temperatures, the hue angle and chroma were reported as 47.39–53.96 and 22.02–31.09, respectively (Quek et al., 2007).

Particle size

The particle size of tomato powder is expressed as $D[4,3]$ (De Brouckere mean diameter), which is the mean diameter of a sphere with the same volume and

Table 2. Color values of tomato powders

Sample	L	a	b	Browning index (%)	Hue angle	Chroma	Total color difference
Plain	29.28 ± 0.42ab	16.77 ± 0.51a	14.16 ± 0.32ab	3.70 ± 1.18b	40.16 ± 0.23b	21.17 ± 0.18b	1.73 ± 0.26ab
1% WPC	28.99 ± 0.22ab	16.76 ± 0.23a	14.00 ± 0.22ab	2.62 ± 2.06b	39.88 ± 0.06b	21.17 ± 0.35b	1.73 ± 0.35ab
5% WPC	28.86 ± 0.30ab	16.05 ± 0.12a	13.68 ± 0.28b	6.19 ± 2.08b	40.22 ± 0.29b	21.72 ± 0.36b	0.96 ± 0.37bc
1% PPI	28.55 ± 0.07b	16.03 ± 0.07a	13.42 ± 0.04b	2.98 ± 1.36b	39.94 ± 0.11b	21.03 ± 0.20b	1.86 ± 0.17ab
5% PPI	28.75 ± 0.10ab	16.14 ± 0.17a	13.63 ± 0.04b	6.81 ± 0.58b	40.68 ± 0.11b	21.59 ± 0.57b	1.20 ± 0.56abc
1% SPI	29.02 ± 0.39ab	16.61 ± 0.17a	14.02 ± 0.33ab	1.81 ± 1.30b	39.94 ± 0.17b	21.33 ± 0.06b	1.58 ± 0.00abc
5% SPI	28.63 ± 0.14b	16.15 ± 0.13a	13.56 ± 0.13b	3.82 ± 0.33b	39.99 ± 0.00b	20.91 ± 0.01b	1.98 ± 0.06a
1% ZM	29.17 ± 0.49ab	16.56 ± 0.53a	14.13 ± 0.68ab	5.81 ± 1.15b	40.91 ± 0.00b	22.22 ± 0.40b	0.65 ± 0.27c
5% ZM	31.27 ± 2.00a	17.74 ± 1.25a	16.23 ± 1.94a	16.80 ± 2.41a	42.97 ± 0.74a	24.55 ± 1.74a	1.18 ± 0.04abc

Different letters in same column show significant ($P < 0.05$) differences. PPI: pea protein isolate; SPI: soy protein isolate; ZM: zein from maize; WPC: whey protein concentrate.

D[3,2] (Sauter mean diameter), which is the mean diameter of a sphere with the same surface area (Karlović et al., 2015). D[4,3] and D[3,2] of the tomato juice powder were 520.43–834.08 μm and 287.61–446.82 μm , respectively (Table 3). These results are much higher than particle size results reported for other fruit juices. For instance, Goula and Adamopoulos (2004) reported particles of tomato powder as 15–70 μm . Similarly, particles of black carrot and orange juice powder were found to be in the range of 3–70 μm (Mestry et al., 2011). However, Ferrari et al. (2012a) reported higher particle sizes of up to 477 μm . The main reason for the bigger particles obtained in this study could be related to the characteristics of the raw material: as pulpy tomato juice was spray dried without any pre-treatment (filtration, centrifugation, etc.), the pulps might have increased the size of the formed particles.

Table 3. Particle size of tomato powders

Sample	D[4,3] (μm)	D[3,2] (μm)
Plain	681.80 $\pm$ 49.30ab	400.61 $\pm$ 0.15abc
1% WPC	688.33 $\pm$ 137.8ab	446.82 $\pm$ 82.43a
5% WPC	826.38 $\pm$ 30.10a	325.70 $\pm$ 38.86bc
1% PPI	834.08 $\pm$ 60.31a	392.90 $\pm$ 0.15abc
5% PPI	709.34 $\pm$ 7.95ab	374.17 $\pm$ 3.25abc
1% SPI	782.26 $\pm$ 35.38a	395.27 $\pm$ 7.71abc
5% SPI	520.43 $\pm$ 100.8b	287.61 $\pm$ 27.65c
1% ZM	785.80 $\pm$ 59.66a	461.57 $\pm$ 36.29a
5% ZM	772.39 $\pm$ 49.87a	442.69 $\pm$ 3.14ab

Different letters in same column show significant ($P < 0.05$) differences. PPI: pea protein isolate; SPI: soy protein isolate; ZM: zein from maize; WPC: whey protein concentrate.

Tomato juice powder produced with 5% SPI had the smallest particles among the proteins. On the other hand, the biggest particles in the tomato powders were measured in the product produced with 1% ZM.

Generally, spray-dried powders have small particle size ($< 50 \mu\text{m}$), which diminishes their handling and reconstitution properties. To improve these properties, these powders must be subjected to an agglomeration process using a fluidised bed granulator and dryer (Gong et al., 2008). Given the large size of the particles obtained in this study, there is no need for further processing to improve the physical properties of the tomato powders.

Density, porosity, flowability and cohesiveness

The bulk density, tapped density, particle density, porosity, CI and HR of the tomato powders are presented in Table 4. While the bulk density of the powder ranged between 0.49 and 0.65 g/mL, tapped densities were in the range of 0.49–0.68 g/mL. Particle density of the tomato powder was found to be 1.64–2.31 g/mL. Tapped and particle density of the particles are statistically similar. On the other hand, 5% WPC provided significantly lower bulk density than other proteins. In other studies on spray drying of fruit juices, bulk density of powders has been found in the range of 0.09–0.47 (Fazaeli et al., 2012b; Goula and Adamopoulos, 2005b; Horuz et al., 2012). Relatively higher bulk density for orange juices has also been reported by Chegini and Ghobadian (2005). The obtained high bulk and tapped density in the present study could be related with the big particle size of the tomato powder. Although Goula and Adamopoulos (2010) and Ferrari et al. (2012a) report that bigger particle size resulted in lower bulk density because of the higher interstitial air content between the particles, in the

Table 4. Densities, porosity, cohesiveness and hygroscopicity of the tomato powders

Sample	Bulk density (g/mL)	Tapped density (g/mL)	Particle density (g/mL)	Porosity (%)	Hausner ratio	Carr index	Hygroscopicity (%)
Plain	0.61 $\pm$ 0.02a	0.63 $\pm$ 0.03a	1.94 $\pm$ 0.49a	65 $\pm$ 11a	1.03 $\pm$ 0.04a	2.76 $\pm$ 2.49	37.99 $\pm$ 0.44abc
1% WPC	0.65 $\pm$ 0.02a	0.68 $\pm$ 0.00a	2.31 $\pm$ 0.07a	73 $\pm$ 0a	0.97 $\pm$ 0.01ab	4.32 $\pm$ 3.87	37.28 $\pm$ 0.49bc
5% WPC	0.49 $\pm$ 0.02b	0.51 $\pm$ 0.01a	1.89 $\pm$ 0.19a	72 $\pm$ 3a	1.07 $\pm$ 0.04a	4.49 $\pm$ 2.99	36.99 $\pm$ 0.71c
1% PPI	0.62 $\pm$ 0.01a	0.61 $\pm$ 0.01a	1.69 $\pm$ 0.49a	60 $\pm$ 10a	1.00 $\pm$ 0.06a	0.65 $\pm$ 0.65	36.55 $\pm$ 0.54c
5% PPI	0.59 $\pm$ 0.02a	0.59 $\pm$ 0.00a	2.17 $\pm$ 0.06a	74 $\pm$ 0a	0.96 $\pm$ 0.01ab	1.68 $\pm$ 1.68	37.24 $\pm$ 1.14bc
1% SPI	0.61 $\pm$ 0.04a	0.58 $\pm$ 0.01a	1.79 $\pm$ 0.18a	76 $\pm$ 13a	0.97 $\pm$ 0.08ab	< 0	40.51 $\pm$ 0.48a
5% SPI	0.57 $\pm$ 0.00ab	0.55 $\pm$ 0.01a	1.38 $\pm$ 0.04a	61 $\pm$ 1a	0.94 $\pm$ 0.05ab	< 0	40.41 $\pm$ 1.40a
1% ZM	0.59 $\pm$ 0.02a	0.56 $\pm$ 0.04a	1.64 $\pm$ 0.08a	66 $\pm$ 0a	0.94 $\pm$ 0.02ab	< 0	39.80 $\pm$ 0.04ab
5% ZM	0.56 $\pm$ 0.04ab	0.49 $\pm$ 0.05a	2.01 $\pm$ 0.50a	74 $\pm$ 10a	0.84 $\pm$ 0.05b	< 0	40.10 $\pm$ 0.61a

Different letters in same column show significant ($P < 0.05$) differences. PPI: pea protein isolate; SPI: soy protein isolate; ZM: zein from maize; WPC: whey protein concentrate.

present study big particle size resulted in high bulk density. Indeed, the particle density results obtained in the present study were higher than the reported values for blackberry powder (1.487–1.512 g/mL) (Ferrari et al., 2012a) and red raspberry powder (1.200–1.300 g/mL) (Syamaladevi et al., 2012).

Porosity of the tomato powders was calculated as 61–76% and did not significantly change with different carrier agents. Similar porosity values were reported by Ferrari et al. (2012a) for blackberry powder. However, in a study on spray drying of red raspberry juice, lower porosity values were obtained (Syamaladevi et al., 2012). The differences between studies could arise from spray drying conditions and carrier materials. Addition of the vegetable proteins into tomato juice did not change the porosity of the tomato powder.

Flowability and cohesiveness are two important handling properties of dried particles. The combined effect of process parameters on flowability is usually expressed as the CI, and the cohesiveness property is expressed as the HR. Lower CI values are favourable for better flowability, which is desirable, and a higher HR indicates greater cohesiveness, an undesirable trait (Mestry et al., 2011).

In this study, the CI of the tomato powders was found below five, indicating free-flowing characteristics (Jinapong et al., 2008). Spray dried fruit juice powders generally have low flowability, and therefore a high CI. For instance, the CI of ginger extract was found to be between 28 and 37 (Jangam and Thorat, 2010). In another study, the CI of fermented mixed carrot and watermelon juice was determined in the range of 19–52 (Mestry et al., 2011). Thus, tomato powder produced in this study had superior flow properties. This may be related to the concentration and composition of the raw tomato juice used in this study and the particle size of the powders. Powders with HRs lower than 1.25 are classified as free flowing. As can be seen in Table 4, the HR of the products was estimated at below 1.25, which indicates a free-flowing powder. Tomato powders produced with 5% zein had the lowest HR, and therefore the most free-flowing behaviour.

Hygroscopicity and wettability

Hygroscopicity can be defined as the ability of a food to absorb the moisture from a high relative humidity environment, and has been related either to the porosity of the powder or the amorphous glassy state of the sugars present in the food (Angel et al., 2009). For different fruit powders hygroscopicity varies from 17.39 to 48.93% (Angel et al., 2009; Ferrari et al., 2012b; Horuz et al., 2012; Rodriguez-Hernandez et al., 2005). In the present study, hygroscopicity of the tomato powder

was in the range of 36.55–40.51% (Table 4), which is consistent with the literature (Angel et al., 2009; Ferrari et al., 2012b; Horuz et al., 2012; Rodriguez-Hernandez et al., 2005). The lowest hygroscopicity was achieved with both 5% WPC and 1% PPI. On the contrary, the highest hygroscopicity was determined in the samples produced with SPI and ZM. This can be related to the higher water absorption capacity of SPI and ZM. Indeed, Naczek et al. (1986) reported that SPI (445–584%) has higher water absorption capacity than PPI (278–293%).

Wettability is the ability of a powder bulk to be penetrated by a liquid because of the capillary forces. Wettability directly related to the particle size and larger particles can easily penetrate to the water (Ferrari et al., 2012a). In the present study, powders instantly sunk under the surface. This situation was expected because of the large particles obtained in this study. Gong et al. (2008) similarly reported that while the particle size of agglomerated bayberry powder increased from 74 to 200 µm, wettability reduced from 120 to 15 s.

CONCLUSIONS

In the present study, the effect of different vegetable proteins (PPI, SPI and ZM) on physical properties of spray dried pulpy tomato juice was investigated and compared with WPC, which has superior effects on PY. Among the vegetable proteins, the highest PY in tomato powder was obtained by addition of SPI (1%). Addition of the other proteins did not substantially increase the PY in comparison to plain tomato juice powder. Likewise, there was no clear colour change in the samples added by the vegetable proteins except ZM. All of the tomato powders had unique free-flowing properties due to their large particle sizes. From the results, we conclude that SPI (1%) is the best vegetable protein for use as a carrier agent for tomato juice.

DECLARATION OF CONFLICTING INTERESTS

The author(s) declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

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APPENDIX

Notation

a	greenness/redness
a_h	amount of powder used for measurement (g)
a_0	greenness/redness of the raw tomato juice
b	blueness/yellowness
b_0	blueness/yellowness of the raw tomato juice
d_i	diameter of droplets
$D[3,2]$	Sauter mean diameter
$D[4,3]$	De Brouckere mean diameter
L	darkness/whiteness
L_0	darkness/whiteness of the raw tomato juice
n_i	number of droplets
x	increase in weight of tomato powder (g)
Wi	water content of the powder (g/100 g)
ΔE	total colour differences
ε	porosity
ρ_{bulk}	bulk density (g/mL)
ρ_{particle}	particle density (g/mL)
ρ_{tapped}	tapped density (g/mL)