Research Article

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Product characteristics and quality of bovine blood-enriched dried vegetable paste

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Abstract

BACKGROUND: The aim of this study was to evaluate a preparation of vegetable paste with bovine blood in order to maximize the protein content using linear programming, and to analyze the product characteristics and quality of bovine blood-enriched vegetable paste dried in a spouted bed. The drying experiments were performed by evaluating the effects of inlet air temperature, paste flow rate and paste solids concentration on the dried product characteristics and quality (functional and nutritional properties).

RESULTS: The vegetable paste enriched with bovine blood was a good source of protein (~0.20 g g^{-1}, dry basis), and the linear programming was adequate to select the constituents (carrot, onion, potato, kale, tomato, soybean oil and bovine blood) and optimize their quantities. The drying conditions of bovine blood-enriched vegetable paste in the spouted bed that gave the best product characteristics were an air temperature of 110 °C and a paste flow rate of 600 mL h^{-1} with 0.07 g g^{-1} solids concentration.

CONCLUSION: The addition of bovine blood to vegetable paste by linear programming increased the protein content of the paste and improved its functional properties and digestibility. The powder obtained from the spouted bed drier showed suitable functional and nutritional properties and was also a good source of antioxidant compounds.

Keywords: bovine blood; functional properties; spouted bed; vegetable paste

INTRODUCTION

Vegetables are an important source of nutrients for human health owing to their content of vitamins, fibers, minerals and phytochemicals that may lower the risk of chronic diseases.[1] This protective effect has been attributed to the presence of antioxidants such as phenolic compounds and vitamins.[2] However, vegetables are very perishable and need to be processed to increase their shelf life, so drying them becomes a good option. The increasing demand for dried vegetables with high-quality shelf stability requires the optimization of the drying process with the purpose of evaluating not only the efficiency of the process but also the final quality of the dried product.[3]

Animal slaughterhouses produce a considerable amount of by-products of high biological value, with blood being prominent.[4] In order to avoid the generation of high pollutant loads in wastewater, research has shown that bovine blood is a potential source of low-cost proteins with good functional properties and is suitable for use in processed food.[5] Studies performed using blood have included drying in a spouted bed drier for protein improvement of defatted rice bran[6,7] and spray drying to evaluate functional properties in canned pet food.[8]

Fruits and vegetables have been dried by convective drying,[9] sun drying,[10] microwave oven drying,[11] osmotic dehydration[12] and spray drying.[13] Spouted bed drying of pastes and suspensions is a potential alternative to conventional spray drying owing to its low cost, and the product quality is comparable to that of materials obtained by spray drying.[14] The spouted bed technique promotes high rates of heat and mass transfer via the gas–solid contact achieved by the cyclic movements of particles. Although the industrial utilization of spouted bed drying presents a few challenges, e.g. difficulty of scale-up, this technique have been widely studied and found to be viable in the drying of starch suspension,[14] pulp fruits,[15,16] herbal extracts,[17] chitosan paste[18] and *Spirulina*.[19]

Since many vegetables are protein-deficient, blood incorporation could be an option to improve the functional and nutritional properties of vegetable proteins so as to obtain products that are a source of high-quality amino acids. However, there is little information on the evaluation of these properties for products dried in a spouted bed. Therefore the aim of this study was to use linear programming for the enrichment of a vegetable paste with bovine blood in order to maximize the protein content, and to evaluate the drying of the enriched paste in a spouted bed. Functional and nutritional properties of the dried products were determined, including protein solubility, protein digestibility, water-holding capacity, water solubility index, phenolic compounds, antioxidant activity and color parameters, and samples were also evaluated by scanning electron microscopy and Fourier transform infrared spectroscopy.

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MATERIALS AND METHODS

Reagents

Pepsin and pancreatin were acquired from Vetec Química Ltda (Rio de Janeiro, Brazil). Gallic acid, Folin–Ciocalteu reagent and 2,2-diphenylpicrylhydrazyl (DPPH) were purchased from Sigma-Aldrich (St Louis, MO, USA). All other chemical reagents were acquired from Merck (Darmstadt, Germany).

Formulation of vegetable paste enriched with bovine blood

The vegetable paste was constituted by carrot (*Daucus carota* L.), onion (*Allium cepa* L.), potato (*Solanum tuberosum*), kale (*Brassica oleracea*), tomato (*Lycopersicum esculentum*) and commercial soybean oil. The vegetables were acquired from a local market (Rio Grande, Brazil) and stored at 5.0 ± 0.5 °C. The choice of constituents was based on their high phytochemical content and availability throughout the year. Table 1 shows the composition and caloric value of each vegetable. The soybean oil was used to provide the lipid content necessary in the paste formulation. The bovine blood was collected from a slaughterhouse under aseptic conditions, using sodium citrate solution as anticoagulant, according to Maciel *et al.*[6]

In order to improve the protein content of the vegetable paste with bovine blood and to optimize the quantity of each constituent, the formulation was carried out using the linear programming technique of Excel Solver (Microsoft, Redmond, WA, USA). This mathematical technique has been used successfully in food formulation.[20,21] The objective function was maximized for protein content according to restriction limits established. The restrictions used were on carbohydrate, protein and lipid contents and caloric value, which had minimum and maximum limits according to preliminary tests. The limits established for use as restrictions in the formulation were a carbohydrate content of 0.50–0.70 g g^{-1}, a protein content of 0.10–0.20 g g^{-1}, a lipid content of 0.04 g g^{-1} and a caloric value of 2.00–5.00 kcal g^{-1}. The lipid content found in preliminary tests (~0.04 g g^{-1}) led to good particle circulation in the spouted bed.

Equation (1) shows the objective function used for maximization of the protein content. P_T is the maximized protein content (g), m_i is the amount of constituent i (g), P_i is the protein content of constituent i (g g^{-1}) and n is the total number of constituents.

$$P_T = \sum_{i=1}^{n} m_i P_i \quad (1)$$

The restrictions functions are given in Equations (2)–(4). Equation (2) shows the total amount of constituents on a dry basis (C_{db}) (five vegetables, soybean oil and bovine blood). Equations (3) and (4) show the restrictions on nutrient contents x_i (g g^{-1}) (carbohydrates, proteins and lipids) and caloric value to reach the established minimum, X_1 (g), and maximum, X_2 (g), values respectively. Equations (5) and (6) restrict the possibility of negative values and values higher than the maximum pre-established quantity (m) respectively.

$$C_{db} = \sum_{i=1}^{7} m_i \quad (2)$$

$$\sum_{i=1}^{7} m_i x_i \geq X_1 \quad (3)$$

$$\sum_{i=1}^{7} m_i x_i \leq X_2 \quad (4)$$

$$m_i \geq 0 \quad (5)$$

$$m_i \leq m \quad (6)$$

After the optimization by linear programming, each vegetable was washed in water, peeled (except kale), cut, weighed and crushed in a juice centrifuge (CF-01, Mondial, Barueri, Brazil) to achieve better extraction. The remaining solids and the extracted juice were mixed in a food processor (DLC-2A, Cuisinart, Kuki, China). Finally, the vegetable paste was homogenized with the commercial soybean oil and bovine blood in a blender and then sieved (1.4 mm mesh).

Drying experiments

The drying experiments were carried out in a conventional spouted bed drier, consisting of a cylindrical column with a conical base, which was developed in previous work.[20] A schematic diagram of the spouted bed equipment is shown in Fig. 1. The cell diameter was 0.175 m, the air inlet diameter was 0.029 m and the glass base had a taper angle of 60° and a height of 0.15 m. The cylindrical column had a diameter of 0.175 m and a height of 0.75 m. Thus the drier had a column diameter/air inlet diameter ratio of 1:6.

The equipment consisted of a 6 kW radial blower (CR0850, Ibram, São Paulo, Brazil), three resistors of 800 W each to heat the drying air, a thermostatic control (IDO2B, Contemp, São Caetano do Sul, Brazil), valves to regulate the air flow, an orifice plate connected to a U-tube manometer to measure the air flow, and copper/constantan thermocouples (CSC99, Contemp) to measure the temperature. Polyethylene particles (2 kg) of mean diameter 0.0032 m, sphericity 0.7 and density 960 kg m^{-3} were used as inert support in the spouted bed.

The minimum spouting air drying velocity was established as 0.61 m s^{-1} by plotting pressure drop/velocity curves (figure not shown). The air circulation rate used was 100% higher than the minimum spouting velocity, as recommended for drying pastes and suspensions.[22] The vegetable paste was introduced into the cell (center of column) through atomization by peristaltic pump and compressed air at 200 kPa absolute. The product obtained was transported pneumatically by air drying and collected in a Lapple cyclone.

Statistical analysis

According to preliminary drying experiments, three variables were defined for analyzing the drying process of vegetable paste with bovine blood. A factorial experimental design (type 2^3) was used to study the effects of inlet air temperature (90 and 110 °C), paste flow rate (400 and 600 mL h^{-1}) and paste solids content (0.07 and 0.10 g g^{-1}) on the characteristics of the final product (protein solubility and digestibility, water-holding capacity, water solubility index, phenolic compounds, antioxidant activity, color difference and hue angle).

In order to identify the variables that showed significant effects at 95% level ($P < 0.05$) on the drying of vegetable paste enriched with bovine blood, a variance analysis of the experimental data was performed and pareto graphics were generated using Statistica 6.0 software (StatSoft Inc., Tulsa, OK, USA).

Table 1. Composition and caloric value of vegetables and bovine blood

Constituent	Protein content, p_i (g g^{-1})	Lipid content, l_i (g g^{-1})	Carbohydrate content, c_i (g g^{-1})	Ash content, a_i (g g^{-1})	Caloric value, vc_i (kcal g^{-1})
Potato	0.11 ± 0.02	≤0.01	0.86 ± 0.03	0.03 ± 0.01	3.74 ± 0.15
Carrot	0.13 ± 0.07	0.02 ± 0.01	0.76 ± 0.03	0.09 ± 0.02	3.43 ± 0.12
Kale	0.29 ± 0.01	0.06 ± 0.02	0.52 ± 0.02	0.11 ± 0.02	2.97 ± 0.23
Onion	0.15 ± 0.06	0.01 ± 0.00	0.80 ± 0.04	0.04 ± 0.01	3.51 ± 0.10
Tomato	0.22 ± 0.08	0.04 ± 0.01	0.63 ± 0.03	0.10 ± 0.02	3.06 ± 0.33
Bovine blood	0.77 ± 0.04	0.03 ± 0.01	0.16 ± 0.02	0.02 ± 0.01	3.96 ± 0.11

Values are mean ± standard deviation of two measurements.

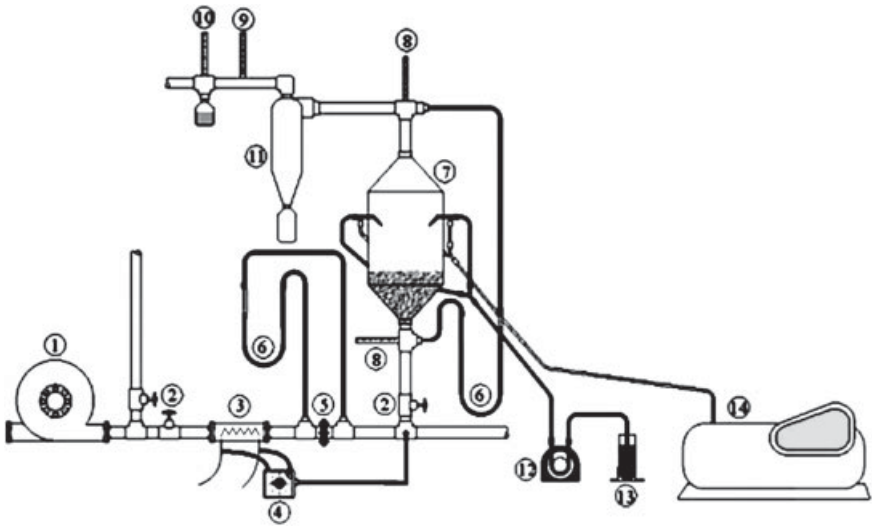

Figure 1. Schematic diagram of spouted bed equipment: 1, blower; 2, valves; 3, heating system; 4, temperature controller; 5, orifice meter; 6, manometer; 7, spouted cell; 8 and 9, thermocouples; 10, wet bulb thermocouple; 11, cyclone; 12, peristaltic pump; 13, suspension tank; 14, air compressor.[20]

Chemical composition of vegetable paste

Samples were analyzed for moisture (gravimetric method 925.09), ash (furnace method 923.03) and protein (micro-Kjeldahl method 979.09) contents by AOAC[23] methods and for lipid content according to Bligh and Dyer.[24] Carbohydrate content was calculated by difference.

Protein solubility

Protein solubility was determined according to Morr *et al.*[25] A 2.5 g sample was added to 50 mL of distilled water, shaken for 15 min and then centrifuged (Baby I 206BL, Fanem, São Paulo, Brazil) at 3500 × *g* for 15 min. The tube contents were filtered and the protein in solution was determined by the micro-Kjeldahl method.[23] Protein solubility was calculated as the percentage of soluble protein content relative to the total protein content in the sample.

In vitro protein digestibility

In vitro protein digestibility was determined as described by Khalil *et al.*,[26] with some modifications. A 100 mg sample was incubated with pepsin in HCl solution (0.1 mol L^{-1}) under constant shaking for 3 h. Then pancreatin in phosphate buffer solution (pH 8) was added. The flask was incubated again at 37 °C on an orbital-horizontal shaker at 130 rpm for 24 h. The reaction was terminated by adding 100 g L^{-1} trichloroacetic acid solution. After centrifugation at 1500 × *g* for 30min, soluble nitrogen in the supernatant was determined by the micro-Kjeldahl method. Protein digestibility was calculated as the percentage of soluble protein content relative to the total protein content.

Water-holding capacity and water solubility index

The water-holding capacity (WHC) and water solubility index (WSI) were determined according to Anderson *et al.*[27] A 2.5 g sample was added to 30 mL of distilled water, incubated in a water bath at 25 °C for 30 min and then centrifuged at 3500 × *g* for 15 min. The supernatant was poured into a weighed bottle and dried at 105 °C overnight to determine the soluble solids weight. WHC (g g^{-1}) and WSI (% w/w) were calculated according to Equations (7) and (8) respectively.

$$\mathrm{WHC} = W_c / \left(W_s - W_e\right) \tag{7}$$

$$\mathrm{WSI} = \left(W_e / W_s\right) \times 100 \tag{8}$$

Here W_c is the weight of centrifuged solids (g), W_s is the weight of the sample (g) and W_e is the weight of soluble solids (g).

Total phenolic compounds

Total phenolic compounds were determined by a spectrophotometric method (SP-220, Bioespectro, São Paulo, Brazil) using Folin–Ciocalteau reagent[28] and absorbance measurement at 750 nm with gallic acid as standard. Results were expressed as mg gallic acid equivalent (GAE) g^{-1} dry matter.

Table 2. Optimized amount of constituents used in vegetable paste formulation

Constituent	Amount (g, wet basis)
Soybean oil	2.1
Potato	37.5
Carrot	237.5
Kale	115.8
Onion	265.9
Tomato	205.9
Bovine blood	35.3

Antioxidant activity

Antioxidant activity was determined by the DPPH assay according to Brand-Williams *et al.*,[29] with modifications for simplicity and reproduction. The DPPH radical-scavenging capacity of extracts was measured as the absorbance maximum at 515 nm. Results were expressed as percentage inhibition of DPPH radical.

Color parameters

Color parameters were evaluated by the Minolta system (CR-300, Minolta Corporation, Ramsey, NJ, USA). Values of lightness (L), greenness/redness ($-a/+a$) and blueness/yellowness ($-b/+b$) were determined. Hue angle and color difference (ΔE) were calculated by Equations (9) and (10).

$$\text{Hue angle} = \tan^{-1}(b/a) \tag{9}$$

$$\Delta E = \left[(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2\right]^{1/2} \tag{10}$$

Here $\Delta L = L - L_0$, $\Delta a = a - a_0$ and $\Delta b = b - b_0$, where L_0, a_0 and b_0 are the color parameters of the vegetable paste before drying.

Fourier transform infrared spectroscopy

Attenuated total reflectance Fourier transform infrared (ATR-FTIR) spectroscopy (Prestige 21, Shimadzu, Kyoto, Japan) was performed on methanolic extracts to identify possible alterations in phenolic functional groups.

Scanning electron microscopy

The paste and powder obtained under the optimal conditions defined by statistical analysis were characterized by scanning electron microscopy (SEM) (JSM-6610LV, Jeol, Tokyo, Japan). A small quantity of each sample was mounted on a specimen stub with double-sided adhesive carbon tape and coated with gold.

RESULTS AND DISCUSSION

Formulation of vegetable paste enriched with bovine blood

All constituents were selected and optimized as shown in Table 2. The major amounts optimized were for onion, carrot and tomato, probably owing to their high carbohydrate content. Although the formulation objective was to maximize the protein content, the optimized amount was based on restrictions according to dried soups, which are composed basically of carbohydrates. Beyond that, the optimized amount of each constituent is a result of its composition, i.e. lipid, protein and carbohydrate contents and caloric value, which must be between the minimum and maximum limits used. The composition of the optimized formulation obtained by linear programming in order to produce 1 g of dried product with 0.04 g of lipid was 0.20 g g^{-1} protein content, 0.60 g g^{-1} carbohydrate content, 0.04 g g^{-1} lipid content and 3.27 kcal g^{-1} caloric value. Thus the linear programming technique was a suitable tool to optimize the amount of each constituent and to maximize the protein content of vegetable paste with bovine blood.

The chemical composition of the vegetable paste was analyzed to compare with the optimized data from linear programming. The experimental results for the vegetable paste composition (dry basis) showed 0.229 ± 0.020 g g^{-1} protein content, 0.664 ± 0.009 g g^{-1} carbohydrate content, 0.039 ± 0.001 g g^{-1} lipid content and 0.068 ± 0.001 g g^{-1} ash content.

Evaluation of vegetable paste drying in spouted bed

Table 3 shows the results for protein solubility, *in vitro* protein digestibility, WHC, WSI, phenolic compounds, antioxidant activity and color difference. A variance analysis of the experimental data was performed (table not shown) and pareto graphics were generated (Figure 2). Analyzing the pareto graphics, it can be observed

Table 3. Results of drying experiments according to factorial design matrix (2^3)

	Variables[a]			Results[b]						
Run	W (mL h^{-1})	T (°C)	C_s (g g^{-1})	Sol. (%)	Digest.(%)	WHC (g g^{-1})	WSI (%)	Phen.(mg GAE g^{-1})	AA (%)	ΔE
1	400	90	0.07	60.5 ± 3.0	59.0 ± 0.5	4.4 ± 0.3	38.9 ± 1.5	12.2 ± 0.9	9.6 ± 0.1	22.4 ± 0.1
2	600	90	0.07	72.2 ± 6.3	70.8 ± 0.5	4.3 ± 0.3	30.3 ± 1.9	8.3 ± 0.6	41.2 ± 0.6	20.9 ± 0.1
3	400	110	0.07	68.0 ± 0.3	73.0 ± 0.5	4.3 ± 0.2	41.7 ± 2.4	11.4 ± 1.2	21.9 ± 0.8	21.1 ± 0.2
4	600	110	0.07	63.3 ± 4.6	79.7 ± 0.8	3.9 ± 0.3	38.5 ± 0.4	12.7 ± 0.7	37.7 ± 0.3	22.6 ± 0.1
5	400	90	0.10	66.0 ± 0.4	69.6 ± 0.5	4.5 ± 0.1	33.0 ± 1.5	10.5 ± 1.3	12.4 ± 0.8	20.0 ± 0.6
6	600	90	0.10	56.7 ± 3.0	67.9 ± 0.6	4.2 ± 0.1	41.0 ± 0.7	11.9 ± 0.2	18.9 ± 0.1	23.3 ± 0.6
7	400	110	0.10	64.0 ± 0.4	77.5 ± 0.7	4.0 ± 0.1	33.3 ± 0.7	12.5 ± 0.1	9.2 ± 0.8	14.3 ± 0.2
8	600	110	0.10	84.5 ± 2.6	78.9 ± 0.7	3.7 ± 0.1	35.2 ± 1.8	16.3 ± 3.4	22.7 ± 0.7	19.9 ± 0.7

Values are mean ± standard deviation of two measurements.
[a] W, paste flow rate; T, inlet air temperature; C_s, solids concentration in paste.
[b] Sol., protein solubility; Digest., protein digestibility; WHC, water-holding capacity; WSI, water solubility index; Phen., phenolic compounds; AA, antioxidant activity; ΔE, color difference.

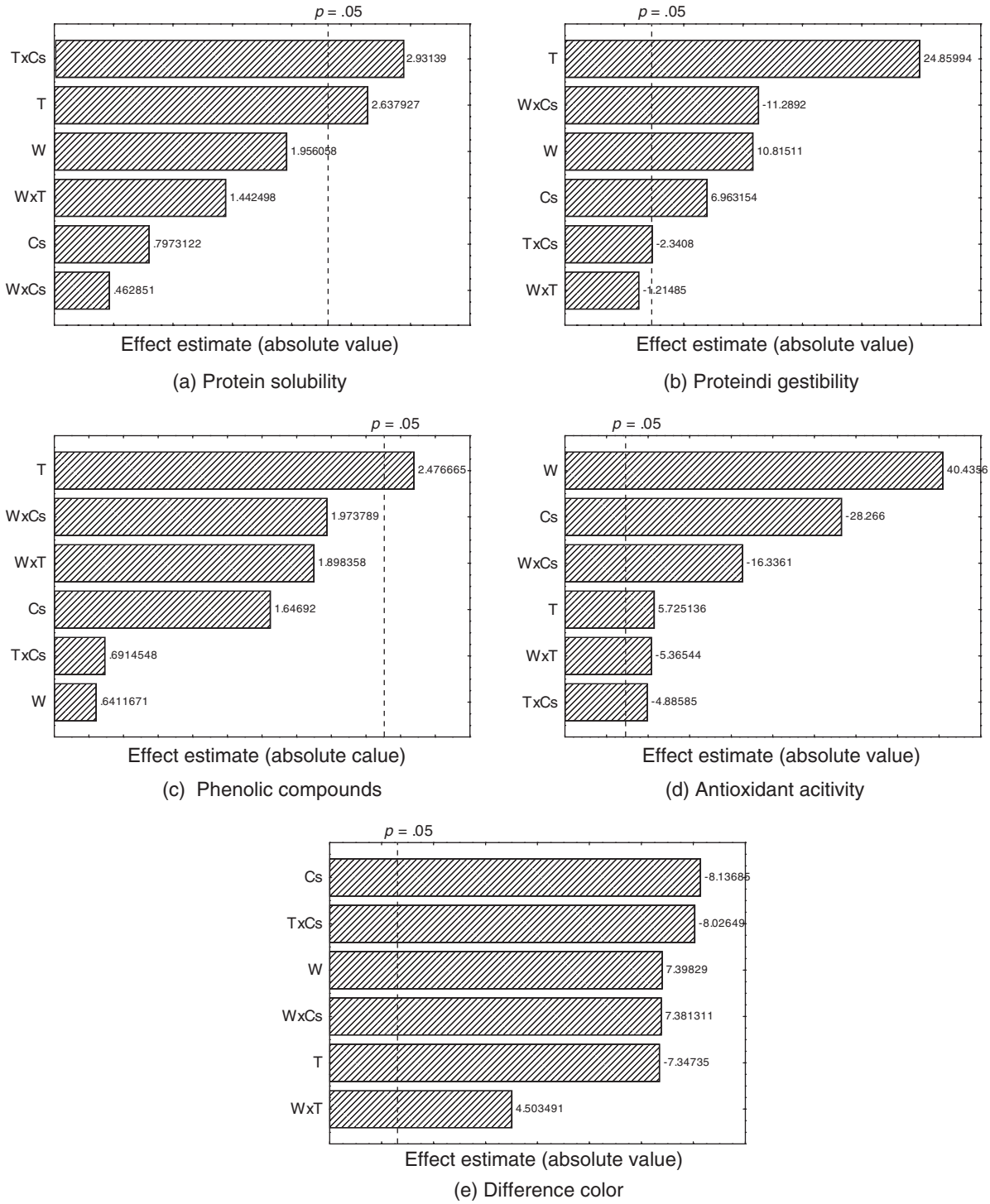

Figure 2. Pareto graphics of (a) protein solubility, (b) protein digestibility, (c) phenolic compounds, (d) antioxidant activity and (e) color difference.

that the inlet air temperature was the variable that showed highest significance for characteristics of the final product such as protein solubility, protein digestibility, phenolic compounds and WHC (figure not shown). However, the paste flow rate and solids concentration showed highest significance at 95% level ($P < 0.05$) for antioxidant activity and color difference respectively.

The air temperature and paste flow rate showed positive effects on the major responses: upon increasing the temperature from 90 to 110 °C and the flow rate from 400 to 600 mL h^{-1}, the dried product presented best characteristics (protein solubility, protein digestibility, phenolic compounds and antioxidant activity). In relation to paste solids concentration, using the lower concentration (0.07 g g^{-1}) also gave a product with suitable functional characteristics. The WSI showed statistical significance at 95% level ($P < 0.05$) only for interactions of solids concentration with paste flow rate and air temperature (figure not shown). In the statistical analysis of WHC, it was found that only the air temperature was significant ($P < 0.05$). In relation to color difference, all main effects

Table 4. Color parameters of dried products and vegetable paste

Experiment	*L*	*a*	*b*	Hue angle (°)
1	44.8 ± 0.2a	0.9 ± 0.1a	25.0 ± 0.7ace	87.8 ± 0.5a
2	44.5 ± 0.2a	0.6 ± 0.2a	23.3 ± 0.4b	88.5 ± 0.3a
3	41.3 ± 0.2b	3.7 ± 0.2b	25.4 ± 0.3a	81.8 ± 0.3b
4	44.7 ± 0.1a	3.2 ± 0.3b	24.8 ± 0.3 ac	82.6 ± 0.6b
5	41.6 ± 0.7b	0.8 ± 0.2a	24.6 ± 0.6ace	88.3 ± 0.6a
6	44.9 ± 0.8a	0.9 ± 0.3a	24.3 ± 0.3ace	88.0 ± 0.6a
7	31.5 ± 0.3c	4.9 ± 0.6c	21.2 ± 0.1d	76.9 ± 0.9c
8	41.6 ± 0.8b	2.0 ± 0.3d	24.1 ± 0.2e	85.2 ± 0.8d
Vegetable paste	29.8 ± 0.3d	−1.8 ± 0.1e	8.7 ± 0.3f	102 ± 1.3e

Values are mean ± standard deviation of two measurements. Different letters in the same column indicate significant differences ($P < 0.05$).

and their interactions were significant ($P < 0.05$), but the air temperature showed a negative effect on this characteristic. Therefore the increase in air temperature led to a decrease in color difference, with the occurrence of some pigment degradation, under the condition with higher paste flow rate (600 mL h^{-1}) and lower paste solids concentration (0.07 g g^{-1}).

The protein solubility, WHC and WSI values obtained in this study (Table 3) were superior to those reported by Larrosa *et al.*[20] for a vegetable paste without added bovine blood. This can be attributed to proteins such as globulins in bovine blood having greater interaction with water owing to their high solubility. According to Polo *et al.*,[30] heat-induced gelling capacity is of potential interest for food applications, since gels give texture and consistency, improve WHC and retain flavors and nutrients.

In relation to protein digestibility, the dried products had higher values owing to the addition of an animal protein source (Table 3). When a fresh sample without bovine blood was analyzed, a protein digestibility of 19.5 ± 0.3% (dry basis) was obtained. The addition of bovine blood to the vegetable paste resulted in a 3.8-fold increase in protein digestibility to 74.6 ± 0.6% (dry basis). The dried samples obtained in experiments 4, 7 and 8 showed higher values than the vegetable paste. These experiments were run at the higher inlet air temperature. Protein digestibility can increase with thermal processing, improving the bioavailability of amino acids.

The WSI (Table 3) is related to the degradation of starch. The samples dried in the spouted bed did not show severe starch decomposition, since the powders contained soluble materials such as pectin (tomato), starch (potato) and blood proteins. The WSI values were in accordance with those reported for sweet potatoes.[31]

Although phenolic compounds are heat-sensitive, they did not show degradation relative to those in the vegetable paste (9.9 ± 0.6 mg GAE g^{-1}); instead, an increase in these compounds was observed in the dried products (Table 3). A higher temperature can increase the phenolic content, through the availability of precursors of phenolic molecules, by non-enzymatic interconversion between phenolic molecules.[32] Another point to consider is that some components of blood might protect or interact with phytochemical compounds in vegetables, which could prevent oxidation from occurring under the drying conditions used.

The antioxidant activity of the dried products (Table 3) was lower than that of the vegetable paste (43.5% inhibition of DPPH). This is because blood hemoglobin can compete with phenolic compounds for DPPH and thus reduce its inhibition. It is probable that the separation and use of plasma from whole blood could increase

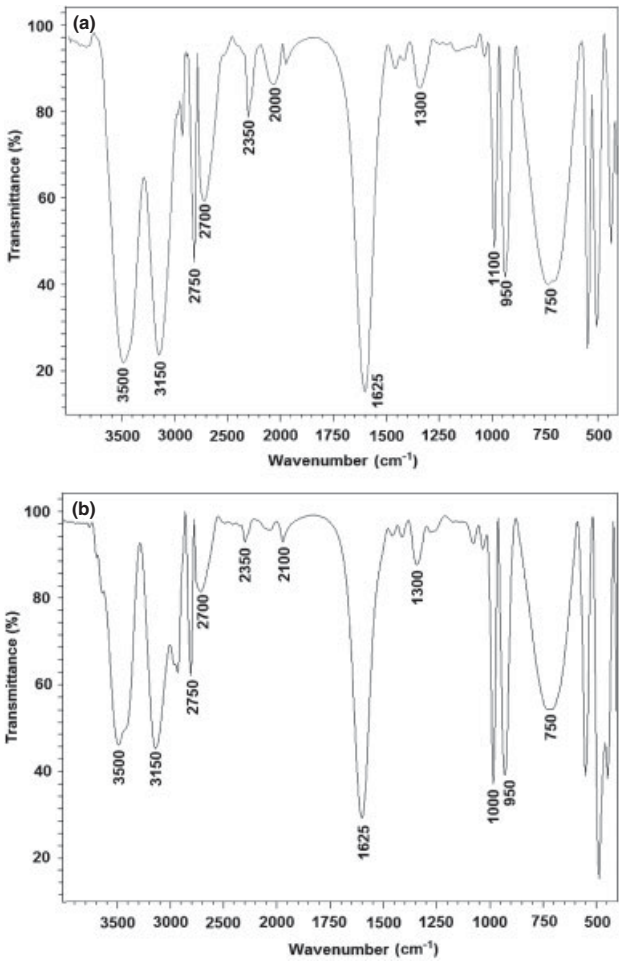

Figure 3. FTIR spectra of (a) vegetable paste and (b) dried product from spouted bed (600 mL h^{-1} with 0.07 g g^{-1} solids at 110 °C).

the antioxidant activity. Salgado *et al.*[33] showed that the incorporation of bovine plasma hydrolysate improved the antioxidant properties of vegetable protein-based films by increasing the amount of bioactive peptide antioxidants.

Studies on spouted bed drying need to consider not only the characteristics of the dried product but also the performance of the bed when a food paste is used. Experiment 4, carried out at 600 mL h^{-1} paste flow rate with 0.07 g g^{-1} solids concentration at 110 °C, resulted in the lowest mass accumulated in the

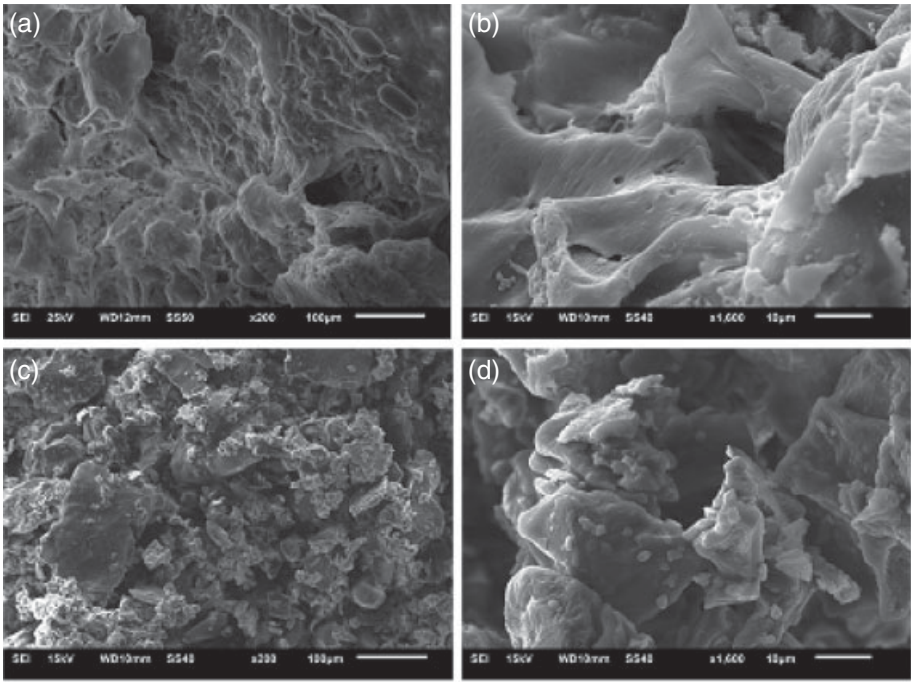

Figure 4. SEM images of (a) vegetable paste (×200), (b) vegetable paste (×1600), (c) dried product from spouted bed (×200) and (d) dried product from spouted bed (×1600).

bed (8.3 ± 2.0%). The experiments performed at 110 °C using vegetable paste with 0.10 g g^{-1} solids concentration showed poor behavior of the particles in the bed. Experiment 3 showed the highest mass accumulated owing to the outlet air temperature (92.1 °C). Furthermore, the higher temperature affected the carbohydrates in the paste and promoted more agglomeration of material via caramelization and glass transition. In all experiments the product showed a moisture content of around 0.08 g g^{-1}.

Color parameters

The color parameters of the dried products showed significance differences at 95% level ($P < 0.05$) relative to those of the vegetable paste (Table 4). Lightness (L) values ranged from 31.5 to 44.9 compared with 29.8 for the vegetable paste, resulting in lighter samples. Experiment 7 showed the lowest lightness, which could be explained by the lower paste flow rate and higher inlet air temperature. The a parameter of dried samples showed positive values, the experiments with the lowest values being those performed at the lower air temperature (experiments 1, 2, 5 and 6). The b parameter showed positive values in the range from 21.2 to 25.4, indicating a yellow color. The vegetable paste had the lowest b value. Hue angle values of the dried samples showed a higher intensity of color (red/yellow) compared with the fresh vegetable paste, which had a green/yellow color.

Fourier transform infrared spectroscopy

Figure 3 shows the FTIR spectra of methanolic extracts of the vegetable paste enriched with bovine blood and the dried product obtained under optimal conditions of the experimental design. It can be observed that the functional groups of phenolic compounds in the two spectra were not changed by drying in the spouted bed. The characteristic bands of phenolic compounds were found at 3500–3150 cm^{-1} (O—H stretching), 2750–2700 cm^{-1} (aldehyde groups), 2350–2100 cm^{-1} (CO_2 gas), 1625 cm^{-1} (C═O stretching vibrations), 1300 cm^{-1}, 1000 cm^{-1} (C—O stretching) and 950–750 cm^{-1} (substituted aromatic rings).[34]

Scanning electron microscopy

Figure 4 shows SEM images of the vegetable paste and the powder obtained under optimal conditions in the spouted bed. It can be seen in Figures 4(a) and 4(b) that the paste was compact and rigid, probably owing to the presence of fibers. Some spherical particles from the oil used in the paste were also observed. In Figures 4(c) and 4(d) the dried powder shows a different morphology from the vegetable paste. One can observe a homogeneous powder with irregular surface particles. Small particles were also seen that could be attributed to characteristic particles of blood. The powder particle size was around 100 μm, as illustrated by Figure 4(c).

CONCLUSIONS

Linear programming to optimize the quantity of each constituent of a vegetable paste, by maximization of the protein content, proved adequate to formulate a bovine blood-enriched paste with a protein content of around 0.20 g g^{-1} (dry basis). The addition of bovine blood improved the functional properties of proteins, protein digestibility and the content of antioxidant compounds with suitable antioxidant activity.

The drying conditions of bovine blood-enriched vegetable paste in the spouted bed that gave the best product characteristics were an inlet air temperature of 110 °C and a paste flow rate of 600 mL h^{-1} with a solids concentration of 0.07 g g^{-1}. These conditions resulted in suitable functional and nutritional properties (protein solubility and digestibility, WHC, WSI, phenolic compounds and antioxidant activity), a color difference of 22.6 ± 0.1 and a hue angle of 82.7°. The vegetable paste dried in the spouted bed showed good FTIR and morphological characteristics. Even at

the higher drying temperature, the technique preserved the functional groups of phenolic compounds. Furthermore, this powder could be an alternative product to instant soups, with suitable functional properties and high protein digestibility.

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REFERENCES

1 Roy MK, Takenaka M, Isobe S and Tsushida T, Antioxidant potential, anti-proliferative activities, and phenolic content in water-soluble fractions of some commonly consumed vegetables: effects of thermal treatment. *Food Chem* **103**:106–114 (2007).
2 Pereira MC, Steffens RS, Jablonski A, Hertz PF, Rios AO, Vizzotto M, *et al.*, Characterization and antioxidant potential of Brazilian fruits from the Myrtaceae family. *J Agric Food Chem* **60**:3061–3067 (2012).
3 Arslan D and Özcan MM, Dehydration of red bell-pepper (*Capsicum annuum* L.): change in drying behavior, color and antioxidant activity. *Food Bioprod Process* **89**:504–513 (2011).
4 Silva JG, Morais HA, Oliveira AL and Silvestre MPC, Addition effects of bovine blood globin and sodium caseinate on the quality characteristics of raw and cooked ham pâté. *Meat Sci* **63**:177–184 (2003).
5 Silva VDM and Silvestre MPC, Functional properties of bovine blood plasma intended for use as a functional ingredient in human food. *LWT – Food Sci Technol* **36**:709–718 (2003).
6 Maciel LR, Miyasaki E, Feisther VA and Pinto LAA, Statistical evaluation of the proteins enrichment of rice bran using spouted bed. *Dry Technol* **30**:733–738 (2012).
7 Massaro AF and Pinto LAA, Proteinic improvement of defatted rice bran, with bovine blood, using the spouted bed technique. *Adolfo Lutz* **61**:77–84 (2002).
8 Polo J, Rodríguez C, Ródenas J, Morera S and Saborido N, The use of spray-dried animal plasma in comparison with other binders in canned pet food recipes. *Anim Feed Sci Technol* **154**:241–247 (2009).
9 Frias J, Peñas E, Ullate M and Vidal-Valverde C, Influence of drying by convective air dryer or power ultrasound on the vitamin C and β-carotene content of carrots. *J Agric Food Chem* **58**:10539–10544 (2010).
10 Slatnar A, Klancar U, Stampar F and Veberic R, Effect of drying of figs (*Ficus carica* L.) on the contents of sugars, organic acids, and phenolic compounds. *J Agric Food Chem* **59**:11696–11702 (2011).
11 Wojdyło A, Figiel A and Oszmiański J, Effect of drying methods with the application of vacuum microwaves on the bioactive compounds, color, and antioxidant activity of strawberry fruits. *J Agric Food Chem* **57**:1337–1343 (2009).
12 Devic E, Guyot S, Daudin JD and Bonazzi C, Effect of temperature and cultivar on polyphenol retention and mass transfer during osmotic dehydration of apples. *J Agric Food Chem* **58**:606–614 (2010).
13 Moreira GEG, Azeredo HMC, Medeiros MFD, Brito ES and Souza ACR, Ascorbic acid and anthocyanin retention during spray drying of acerola pomace extract. *J Food Process Preserv* **34**:915–925 (2010).
14 Pereira NR, Godoi FC and Rocha SCS, Drying of starch suspension in spouted bed with inert particles: physical and thermal analysis of product. *Dry Technol* **28**:1288–1296 (2013).
15 Bezerra CV, Amante ER, Oliveira DC, Rodrigues AMC and Silva LHM, Green banana (*Musa cavendishii*) flour obtained in spouted bed – effect of drying on physico-chemical, functional and morphological characteristics of the starch. *Ind Crops Prod* **41**:241–249 (2013).
16 Rocha SCS, Souza JS, Alsina OLS and Medeiros MFD, Drying of tropical fruit pulps: spouted bed process optimization as a function of pulp composition. *Dry Technol* **29**:1587–1599 (2011).
17 Cortés-Rojas DF and Oliveira WP, Physicochemical properties of phytopharmaceutical preparations as affected by drying methods and carriers. *Dry Technol* **30**:921–934 (2012).
18 Dotto GL, Souza VC and Pinto LAA, Drying of chitosan in a spouted bed: the influences of temperature and equipment geometry in powder quality. *LWT – Food Sci Technol* **44**:1786–1792 (2011).
19 Oliveira EG, Rosa GS, Moraes MA and Pinto LAA, Phycocyanin content of *Spirulina platensis* dried in spouted bed and thin layer. *J Food Process Eng* **31**:34–50 (2008).
20 Larrosa APQ, Muszinski P and Pinto LAA, Linear programming for formulation of vegetable paste and drying operation in spouted bed. *Ciência Rural* **41**:2032–2038 (2011).
21 Doganis P and Sarimveis H, Optimal scheduling in a yogurt production line based on mixed integer linear programming. *J Food Eng* **80**:445–453 (2007).
22 Epstein N and Grace JR, *Spouted and Spout-fluid Beds: Fundamentals and Applications*. Cambridge University Press, New York, NY (2011).
23 AOAC, *Official Methods of Analysis* (16th edn). Association of Official Analytical Chemists, Washington, DC (1995).
24 Bligh EG and Dyer WJ, A rapid method for total lipid extraction and purification. *Can J Biochem Physiol* **37**:911–917 (1959).
25 Morr CVB, German J, Kinsela JM, Regenstein JP, Van Buren A and Kilara BA, A collaborative study to develop a standardized food protein solubility procedure. *J Food Sci* **50**:1715–1718 (1985).
26 Khalil AW, Zeb A, Mahood F, Tariq S, Khattak AB and Shah H, Comparative sprout quality characteristics of desi and kabuli type chickpea cultivars (*Cicer arietinum* L.). *LWT – Food Sci Technol* **40**:937–945 (2007).
27 Anderson RA, Conway HF, Pfeifer UF and Griffin Jr EL, Gelatinization of corn grits by roll and extrusion cooking. *Cereal Sci Today* **14**:4–7 (1969).
28 Nuutila AM, Puupponen-Pimia R, Aarni M and Oksman-Caldentey KM, Comparison of antioxidant activities of onion and garlic extracts by inhibition of lipid peroxidation and radical scavenging activity. *Food Chem* **81**:485–493 (2003).
29 Brand-Williams W, Cuvelier ME and Berset C, Use of free radical method to evaluate antioxidant activity. *LWT – Food Sci Technol* **28**:25–30 (1995).
30 Polo J, Rodríguez C, Saborido N and Ródenas J, Functional properties of spray-dried animal plasma in canned petfood. *Anim Feed Sci Technol* **122**:331–343 (2005).
31 Shih MC, Kuo CC and Chiang W, Effects of drying and extrusion on colour, chemical composition, antioxidant activities and mitogenic response of spleen lymphocytes of sweet potatoes. *Food Chem* **117**:114–121 (2009).
32 Que F, Mao L, Fang X and Wu T, Comparison of hot air-drying and freeze-drying on the physicochemical properties and antioxidant activities of pumpkin (*Cucurbita moschata* Duch.) flours. *Int J Food Sci Technol* **43**:1195–1201 (2008).
33 Salgado PR, Fernández GB, Drago SR and Mauri AN, Addition of bovine plasma hydrolysates improves the antioxidant properties of soybean and sunflower protein-based films. *Food Hydrocolloids* **25**:1433–1440 (2011).
34 Silverstein RM, Webster FX and Kiemle DJ, *Spectrometric Identification of Organic Compounds* (7th edn). Wiley, New York, NY (2005).

