Journal of Food Engineering 190 (2016) 1–9

Contents lists available at ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

Physical and flow properties of rice protein powders

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ARTICLE INFO

Article history:
Received 11 March 2016
Received in revised form
22 May 2016
Accepted 24 May 2016
Available online 27 May 2016

Keywords:
Rice protein powders
Dairy protein powders
Food powders
Microstructure
Physical properties
Flow properties

ABSTRACT

In this study, the physical and flow properties of a range of rice protein powders, including three rice protein concentrates (RPC 1, RPC 2 and RPC 3), two rice endosperm protein hydrolysates (RPH 1 and RPH 2) and two rice bran protein hydrolysates (RBPH 1 and RBPH 2) were determined and compared with those of selected dairy protein powders, i.e., skim milk powder, whey protein isolate and whey protein hydrolysate. The physical properties analysed included particle size distribution, particle shape and surface characteristics. Differential scanning calorimetry analysis demonstrated that RBPH samples had lower thermal stability compared to RPC and RPH samples. Analysis of the moisture sorption properties showed a higher hygroscopicity at high relative humidity values of hydrolysed protein powders compared to their intact counterparts. All protein ingredients analysed displayed good flowability (i.e., easy-flowing or free-flowing behaviour), while the bulk density of intact rice protein ingredients was higher than that of their hydrolysed counterparts. The results obtained in this study enable enhanced control of the behaviour of rice protein powders during storage, handling and processing.

1. Introduction

Food security and environmental sustainability reasons are currently driving the need to increase the utilisation of plant proteins in food formulations, as a substitute to proteins derived from animal sources. Plant protein derived ingredients and food products are in great demand among health-conscious consumers. Soy proteins are the most widely utilised plant proteins for human food, although proteins derived from other plant sources, including but not limited to, wheat, rice, corn, pea, canola and potato are also commercially available (Day, 2013). Understanding, predicting and controlling physical and functional properties of these protein ingredients is required in order to evaluate their potential applications in food formulations.

Rice is the staple food of an estimated 3.5 billion people worldwide, with Asian countries accounting for most of its production and consumption. In Asia, rice provides up to 50% of the dietary caloric supply and a considerable proportion of the protein intake for millions of people (Muthayya et al., 2014). Although the protein content of rice is relatively low, its total food protein production per hectare is second only to that of wheat among cereals (Childs, 2004). Rice flour from milled rice or broken rice kernels and rice bran represent the two main sources of rice proteins, and various treatments have been evaluated for their extraction, including alkaline, enzymatic and physical methods (Fabian and Ju, 2011; Shih, 2003). Rice proteins are generally regarded as hypoallergenic (Helm and Burks, 1996) and rice has been estimated to have a higher protein digestibility and biological value compared to other cereals (i.e., wheat, corn, barley, millet and sorghum), the latter being due to the higher content of lysine (Eggum, 1979), i.e., the first limiting amino acid among cereal proteins (Young and Pellett, 1994). In a study in which the nutritional quality of rice, soy, casein and whey proteins was evaluated, rice bran and rice endosperm proteins showed true digestibility values (90.8–94.8%) comparable to those of the other protein ingredients analysed (91.7–94.8%), and biological values (66.7–72.6%) second only to that of whey protein (78.8%) (Han et al., 2015).

Protein ingredients are commonly produced industrially in powder form. The main advantages of the powder form over liquid form is the increased shelf-life through the reduction of its water content and thus preservation of the nutritional, organoleptic and physicochemical properties of the ingredient until it is required for utilisation (Fitzpatrick and Ahrné, 2005). The behaviour of food powder ingredients during storage, handling and processing depends on their physical and flow properties (Teunou et al., 1999). Therefore, the design, optimisation and performance of storage,

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http://dx.doi.org/10.1016/j.jfoodeng.2016.05.022
0260-8774/

handling and processing operations are influenced by these properties (Fitzpatrick, 2007).

The aim of this study was to characterise the physical and flow properties of a range of rice protein powders and to compare them with dairy protein powders to facilitate a greater understanding of their functionality.

2. Materials and methods

2.1. Materials

The ingredients analysed included seven rice protein ingredients, i.e., three rice protein concentrates (RPC 1, RPC 2 and RPC 3), two rice endosperm protein hydrolysates (RPH 1 and RPH 2) and two rice bran protein hydrolysates (RBPH 1 and RBPH 2), with protein contents ranging from 32.0 to 78.2%. Rice flour (RF) and rice bran (RB) obtained from Beneo (Tienen, Belgium) were analysed as commodity rice ingredients. The microstructure, physical and flow properties of three dairy protein ingredients, i.e., low heat skim milk powder (SMP) (33.7% protein) obtained from the Irish Dairy Board (Dublin, Ireland), whey protein isolate (WPI) (89.7% protein) obtained from Davisco Foods International (Le Sueur, MN, US) and whey protein hydrolysate (WPH) (78.3% protein, degree of hydrolysis 12.9%) obtained from Kerry Group (Tralee, Co. Kerry, Ireland) were also analysed. The compositional analysis of the ingredients was described by Amagliani et al. (2016).

2.2. Particle size distribution

The particle size distribution of the powders was determined by laser diffraction using a Malvern Mastersizer 3000 with Aero S dry dispersion unit (Malvern Instruments, Worcestershire, UK) with a measurement range of 0.01–3500 μm and particle refractive and absorption indices of 1.52 and 0.1, respectively. Samples were applied using the Aero S dry dispersion unit consisting of the use of the General Purpose Tray operating at a feed rate of 20–40% using a hopper gap of 2.5 mm, and a pressure of 1 bar on the standard venturi disperser. Results were calculated using the Mie theory and presented as: D[4,3] (volume-weighted mean particle diameter), D[3,2] (surface-weighted mean particle diameter), Dv(10) (particle size below which 10% of sample volume is found), Dv(50) (particle size below which 50% of sample volume is found), Dv(90) (particle size below which 90% of sample volume is found), span (measurement of the width of the distribution calculated as: ((Dv(90)–Dv(10))/Dv(50)), and SSA (specific surface area, i.e., total area of the particles divided by total weight).

2.3. Scanning electron microscopy

The powders were mounted on aluminium stubs using double-sided adhesive carbon tape and sputter coated with a 5 nm layer of gold/palladium (Au:Pd = 80:20) in a Q150R ES (Quorum Technologies, UK) coating system. Subsequently, the powders were imaged using a JSM-5510 scanning electron microscope (JEOL Ltd, Tokyo, Japan), operated at an accelerating voltage of 5 kV. Images were taken at a magnification of 500×.

2.4. Differential scanning calorimetry

Differential scanning calorimetry (DSC) was performed using a DSC823e (Mettler Toledo, Greifensee, Switzerland). Powders (30 mg) were weighed directly into 120 μL medium pressure crucibles. The samples were tempered at 5 °C for 5 min and heated to 100 °C at a heating rate of 5 °C min^{-1}. A pan containing 30 mg calcined aluminium oxide was used as a reference. Peak temperature (T_p) and enthalpy (ΔH) of protein denaturation, starch gelatinisation or glass transition were determined using the built-in software (STARe system, Mettler Toledo).

2.5. Colour

Colour of the powders was determined by measuring the CIELAB coordinates (L*, a* and b*) with a Chroma Meter CR-400 (Konica Minolta Sensing, Inc., Japan) equipped with a granular-materials attachment CR-A50. A white calibration tile was used to calibrate the instrument prior to colour measurements. In the CIELAB colour space system, L* value measures brightness, with values ranging from 0 (black) to 100 (white), a* value measures degree of redness (positive values) or greenness (negative values), and b* value measures degree of yellowness (positive values) or blueness (negative values).

2.6. Water activity

The water activity (a_w) of the powders was determined at 20 °C using an Aqualab Series 3TE water activity meter (Decagon Devices, Pullman, Washington, US) equipped with a thermoelectric system that allows the instrument to maintain a set chamber temperature throughout the measurement.

2.7. Water sorption isotherms

Water sorption isotherms of the powders were measured using an SPS11-10 μ Sorption Test System (Projekt Messtechnik, Ulm, Germany). The powders (1500 mg) were weighed into aluminium cups. Relative humidity (RH) was initially set at 40% and decreased stepwise to 10% and then increased stepwise up to 90% (in increments of 10% RH). Changes in moisture content of the powders were monitored throughout the analysis. Each step was equilibrated for ~24 h. Measurements were conducted at 20 °C.

2.8. Flow properties

Flowability, wall friction, bulk density (ρ_b) and compressibility index (CI) of the powders were analysed using a Brookfield Powder Flow Tester (PFT) (Brookfield Engineering Laboratories, Inc., Middleboro, MA, US) as described by Crowley et al. (2014).

2.9. Statistical data analysis

Differential scanning calorimetry analysis of the powders was performed in duplicate, with all other analyses performed in triplicate. Analysis of variance (ANOVA; Tukey's HSD test) was carried out using Minitab® 16 (Minitab Ltd, Coventry, UK) statistical analysis package. The level of statistical significance was determined at $P < 0.05$.

3. Results and discussion

3.1. Particle size distribution

Particle size distribution parameters of the powders are presented in Table 1. Volume-weighted mean particle diameter (D[4,3]) values were in the range 22.6–146 μm for rice protein ingredients, while the corresponding values for dairy protein ingredients were in the range 51.7–83.1 μm. RB displayed the highest D[4,3] value at 296 μm, this value being more than threefold higher compared to RF (95.1 μm); also, RBPH samples had significantly ($P < 0.05$) higher D[4,3] values compared to RPH samples, with RBPH 2 having the highest value among the protein ingredients