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Characteristics of soy sauce powders spray-dried using dairy whey proteins and maltodextrins as drying aids

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ABSTRACT

This study investigated the effect of adding whey protein isolate (WPI) as a complementary drying aid of maltodextrin (MD) on spray drying of soy sauce powders. Soy sauce powders were prepared by spray drying soy sauce liquid adding 5%, 10% and 15% of WPI respectively together with MD as the drying aids. Tests were conducted to evaluate the powder properties relevant to the caking issue of the soy sauce powders. Results showed that addition of just 5% WPI could significantly increase the product yield for the spray drying process. At the same time, the caking strength of the spray dried soy sauce powders were significantly reduced during storage with WPI addition. XPS results indicated that WPI have preferential migration to the surface of the soy sauce powder. The over-expression of WPI on powder surface after spray drying might explain the improved stability for soy sauce powders during the caking test.

1. Introduction

Soy sauce is a traditional condiment in the East and Southeast Asian cuisines that contributes a salty and savoury flavour (Tanaka, 2000). While soy sauce is traditionally produced and applied in liquid form, nowadays powdered soy sauce is gaining more popularity in the food industry as an ingredient of soup mix, sauce mix and gravy mix for flavour enhancement (Okayasu and Hamano, 2003). Moreover, soy sauce in powdered form has the advantages in preservation of the naturally brewed soy sauce (Tamotsu, 1986). Therefore, the industry sees a great potential and motivation for producing soy sauce powder. However, during production and storage of soy sauce powder, the major problem occurred is the development of stickiness and caking, which results in lower product yield, operation shut-downs, equipment wear, difficulties in material storage and handling, etc., causing a considerable economic loss and consumers' discrimination (Tamotsu, 1986).

Caking is defined as an undesired phenomenon in which a free-flowing powder is transformed into lumps, agglomerates, or even hard cakes, resulting in loss of functionality and quality degradation. According to our previous study, spray dried soy sauce powder exists in amorphous form with presence of salt crystals (Wang and Zhou, 2012). In amorphous powders, stickiness and caking are associated with a number of intrinsic and extrinsic factors such as glass transition temperature and hygroscopicity of the food materials, and environmental temperature and relative humidity (Hamano and Sugimoto, 1978; Jaya et al., 2002). Glass transition temperature (T_g) is the temperature at which amorphous material undergoes phase transition from a rigid "glassy state" to a sticky "rubbery" state, resulting in viscosity change and structural deformation. Under an elevated temperature or due to water adsorption, T_g of the food could become lower than the ambient temperature, which causes the amorphous powder to undergo glass transition and thus results in stickiness and caking (Downton et al., 1982; Netto et al., 1998).

A common method to produce hygroscopic food powders is by dissolving maltodextrin, which has a high T_g, as an excipient (drying aid) into liquid food, and then subjecting the solution to spray drying. However, even with maltodextrin, the stickiness and caking problem of soy sauce powder cannot be completely solved (Wang and Zhou, 2012). Whey protein has been widely applied in the microencapsulation of flavours, oils, and micronutrients, where it functions as a wall material on the particle surface to prevent oxidative damage and release of the core materials (Jayasundera et al., 2009; Gharsallaoui et al., 2007). Recently, it was found that milk proteins could also be applied in spray dying sugars and sugar rich foods by reducing stickiness of the powders during spray drying (Adhikari et al., 2007, 2009a,b; Jayasundera et al., 2011). The researchers proposed that it was due the excellent surface activity and film-forming property of milk proteins that increased the T_g on the particle surface (Adhikari et al., 2007). However, in these

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studies the effect of milk proteins on powder storage stability after spray drying was not evaluated.

So far, there has been little published work on the spray drying of soy sauce powder using proteins as a drying aid. Moreover, the effects of milk proteins as a drying aid on the properties of spray-dried food powders were not characterised. Therefore, it is worthwhile to study the caking characteristics of spray dried soy sauce powders by adding whey protein as a drying aid. In this study, whey protein isolate (WPI) was used as a complementary drying aid with maltodextrin as the main drying aid to produce soy sauce powders. The effects of WPI dosage on product yield and powder characteristics relevant to caking were examined.

2. Materials and methods

2.1. Raw materials

The defatted soy sauce (Kikkoman, Singapore) was naturally brewed, which contained 10.3% proteins, 8.1% carbohydrates, and 16.5% NaCl on a wet basis, with total solid content of 35%. Drying carriers used were maltodextrin MALTRIN® M40 (Grain Processing, USA) with dextrose equivalent (DE) of 5 and whey protein isolate 895 (Fonterra, New Zealand). whey protein isolate (WPI) contained more than 92% protein (wet basis) according to the specification.

2.2. Sample preparation and spray drying

WPI and MD were dissolved into soy sauce liquid to prepare feed mixtures according to the formulations described in Table 1. Thus, the total solid content in the feed mixtures was uniformly 75%. For each formulation, three batches of powders were produced.

A pilot-scale spray dryer (Mobile MinorTM, GEA, China) was used in the study. The dimensions of the drying chamber included 0.62 m of cylindrical height, 0.80 m of diameter and a 60° conical base. The solutions were fed to a two-fluid nozzle at the top of the spray dryer using a peristaltic pump (Masterflex, USA). The spray dryer was operated in a co-current air flow mode. The inlet temperature of drying air was at 150 °C and its outlet temperature was maintained at 75 °C by adjusting the feed flow rate via the peristaltic pump. The compression air pressure for atomization was controlled at 2 bars, with an air flow rate of 4 m^3/h. Dried powders were collected from the base of a cyclone separator of the drier. Products were immediately packed in zip-log bags after cooling and kept in desiccators to prevent moisture adsorption.

2.3. Product yield

The product yield was calculated as the ratio of the amount of powders collected after every spray drying experiment to the initial amount of solids in the feed solution.

2.4. Moisture content analysis

About 1–2 g of each spray-dried sample were weighed and placed in an oven at 100 °C for 24 h. The moisture content was measured in triplicate and expressed as percentage wet basis (i.e. 100 × g water/g wet material).

Table 1
Formulations of soy sauce powder added with WPI and MD.

Sample formulation	Soy sauce (L)	WPI (g)	MD (g)
40% MD (control)	1	–	400
5% WPI + 35% MD	1	50	350
10% WPI + 30% MD	1	100	300
15% WPI + 25% MD	1	150	250

2.5. Particle size analysis

The particle size of soy sauce powder was measured with ethanol as a dispersion medium using a LA-950 V2 Laser Scattering Particle Size Analyzer (Horiba, Japan) at room temperature. The refractive index of ethanol and the stationary iteration number were set at 1.36 and 15, respectively. All samples were tested in triplicates. The particle size of powders was expressed as the median diameter measured by the instrument.

2.6. Cohesion index

Cohesiveness of powder was tested using a Powder Flow Analyzer (Stable Micro System, UK). A fixed powder volume of 140 mL was poured into the cylinder of the Analyzer prior to the testing. A rotating blade took a downward and then an upward movement for three cycles, corresponding to three compaction and decompaction phases. A force–displacement curve was thus generated by the system, exhibiting the force exerted on the cylinder bottom due to blade movement and powder displacement. A cohesion coefficient (g mm) was derived by Texture Exponent software (Stable Micro System, UK) through integrating the area underneath the curve during the decompaction cycle. The cohesion index (mm) was defined as the ratio of cohesion coefficient to sample weight. All samples were tested in triplicates.

2.7. Scanning Electron Microscopy (SEM)

Powder samples were mounted on aluminium stubs using a double-sided adhesive tape. The sample was then coated with platinum in a sputter coater for 50 s. SEM was performed using a JSM-5200 SEM system (JEOL, Tokyo, Japan), which was operated at an accelerating voltage of 15 kV. The samples were observed with a magnification of 1000×.

2.8. Glass transition temperature

Glass transition temperature (T_g) was measured by a Differential Scanning Calorimeter (Mettler-Toledo DSC822e, Switzerland) equipped with liquid nitrogen cooling accessories. Dry nitrogen was used to purge the surrounding and inside of the furnace chamber at 200 ml/min and 80 ml/min, respectively. Around 10 mg of soy sauce powder was weighed into a 40 μl aluminium standard crucible (ME-51119871, Mettler-Toledo, Switzerland) and hermetically sealed with an aluminium standard lid (ME-51119871, Mettler-Toledo, Switzerland). A sealed empty crucible was used as reference. Sample was cooled at a rate of 20 °C/min until it reached at −60 °C, held at −60 °C for 2 min, and then heated at a scan rate of 10 °C/min until 100 °C. T_g was analysed by STARe software (Version 8.01, Mettler-Toledo, Switzerland), and taken at the midpoint of phase transition.

Glass–rubber transition temperature (T_{g-r}) was tested by a Thermal Mechanical Compression Test (TMCT) system using the method described in Boonyai et al. (2007). A thin layer of powder (1–2 g) was dispersed in a sample holder which was attached to a Heater Controller (Cynebar, Australia) and a Texture Analyzer-XT2i (Stable Micro System, UK) with a 50 kg load cell. The Texture Analyzer used Texture Exponent software to monitor changes in the compressibility of the powder bed, which was expressed by the probe displacement under a temperature scan of 30 °C/min. A blank was also tested to subtract the probe displacement contributed by sample holder expansion during heating. All samples were tested in triplicates.