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The effect of protein types and low molecular weight surfactants on spray drying of sugar-rich foods

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ABSTRACT

The effect of protein types and low molecular weight surfactants (LMS) on spray drying of sugar-rich foods has been studied using sucrose as a model sugar and sodium caseinate (NaCas) and pea protein isolate (PPI) as model proteins. Sodium stearoyl lactylate (SSL) and Polysorbate 80 (Tween-80) were chosen as model ionic and non-ionic LMS. The sucrose:NaCas and sucrose:PPI solid ratios were maintained at (99.5:0.5) and (99:1), respectively and spray-dried maintaining 25% solids in feed solutions. It was found that the proteins preferentially migrated to the air–water interface reasonably swiftly and the addition of LMS resulted into partial or complete displacement of the proteins from the air–water interface. More than 80% of amorphous sucrose powder was produced with the addition of 0.13% (w/w) of NaCas in feed solution. PPI was not as effective and produced less than 50% recovery even at 0.26% (w/w) in feed. Addition of 0.01–0.05% SSL displaced 2.0% and 29.3% of proteins from the surface of sucrose–NaCas–SSL droplet, respectively, resulting in a 6.5 ± 1.2% to 51.9 ± 1.9% reduction in powder recovery. The extent of protein displacement was higher when SSL was added into sucrose–PPI solution; however, the powder recovery was not much affected. The addition of 0.01% Tween-80 in sucrose–NaCas solution resulted in a 48.2 ± 1.5% reduction in powder recovery and at 0.05% concentration, it displaced a substantial amount or all the NaCas from the droplet surface and no powder was recovered. The addition of 0.01% and 0.05% Tween-80 into sucrose–PPI solution resulted into very low powder recoveries (24.9 ± 0.4% and 29.5 ± 1.8%, respectively). The glass transition temperature (T_g) results revealed that the amount of protein required for successful spray drying of sucrose–protein solutions depends on the amount of proteins present on the droplet surface but not on the bulk concentration. X-ray diffraction and scanning electron microscopy results showed that the powders of sucrose–NaCas/PPI and sucrose–NaCas/PPI with 0.01% SSL were mostly amorphous while those with sucrose–NaCas/PPI–Tween-80 (0.01%), sucrose–PPI–Tween-80 (0.05%) and sucrose–NaCas/PPI–SSL (0.05%) were crystalline.

1. Introduction

Spray drying is a well-established and widely used method for transforming a wide range of liquid food products into powder form. The process involves spraying finely atomized solutions into a chamber where hot and dry air rapidly evaporates the solution leaving the spray-dried particles. Spray-dried powders can be stored at ambient temperature for prolonged periods without compromising the powder stability. They are also cheaper to transport and easier to handle in manufacturing plants. Spray-dried powders are economical to produce compared to other processes such as freeze-drying (Knorr, 1998). Spray drying has many applications, particularly in the food, pharmaceutical and agrochemical industries (Adhikari, Howes, Shrestha, & Bhandari, 2007; Maa & Hsu, 1997; Maa, Nguyen, & Hsu, 1998; Vega, Goff, & Roos, 2005).

There are many food products that have very high sugar and organic acid contents and there is a growing interest to convert them into more useable and stable forms such as powders (Bhandari, Datta, & Howes, 1997). Conversion of high value food materials such as fruit and vegetable extracts and honey into particulate form is not easy due to the presence of a high proportion of low molecular weight sugars in their composition (Adhikari et al., 2007). This is because these constituents have a low glass temperature (T_g) which is the main reason for stickiness (Vega et al., 2005).

The stickiness problem causes considerable economic loss and limits the application of drying techniques, such as spray drying, for

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food and as well as pharmaceutical materials (Boonyai, Bhandari, & Howes, 2004; Maa & Hsu, 1997; Maa et al., 1998). To minimize the stickiness problem, process and material-science-based approaches are in place. Process-based approaches include: the mechanical scraping of the chamber wall; introduction of cold air at the bottom; and, the use of low temperature low humidity air. Changing the glass transition temperature of feed solution by the introduction of drying-aids is an example of the material-science-based approach (Downton, Flores-Luna, & King, 1982). Process-based modifications are not easy and can be economically non-viable. For example, stickiness could be avoided by keeping the outlet temperature of air below 50 °C or even at ambient temperature; however the production becomes economically non-viable. The material-science-based approach also has its own limitations. Large amounts of drying additives such as maltodextrins (>35%) are required to convert fruit juices such as blackcurrant, apricot and raspberry into powder form (Gabas, Telis, Sobral, & Telis-Romero, 2007; Righetto & Netto, 2005; Tonon et al., 2009). Addition of such large amounts of these carriers alters the resultant powder quality and risks consumer disapproval.

An alternative and novel way to minimize the stickiness problem is to modify the surface properties of the droplets/particles with small amounts of proteins (Adhikari, Howes, Bhandari, & Langrish, 2009). It was found that the preferential migration of proteins combined with their film-forming property upon drying, is responsible for overcoming the stickiness of sugar–protein solutions (Adhikari, Howes, Bhandari, et al., 2009). Proteins from legume seeds have been widely studied with regard to functional and bioactive properties and are considered important for novel food development and for human health (Pereira et al., 2009). The relationship between physicochemical characteristics and interfacial behaviour on oligomeric plant proteins (pea legumin) was investigated by Subirade, Gueguen, and Schwenke (1992). They found that the molecular properties of oligomeric seed proteins, particularly size, net charge and conformational characteristics are important in controlling the surface activity. Although there are a few studies reported on surface modification of sugar-rich foods with dairy proteins such as whey protein and sodium caseinate (Adhikari, Howes, Bhandari, et al., 2009), there is no comparative research on the efficacy of plant proteins in the modification of surface properties of droplets/particles of sugar-rich foods.

It is known that both protein and LMS compete for the air–water interface of a droplet (Mackie, Gunning, Wilde, & Morris, 2000; Pugnaloni, Dickinson, Ettelaie, Mackie, & Wilde, 2004; Rouimi, Schorsch, Valentini, & Vaslin, 2005; van Aken, 2003). Since LMS are smaller in size compared to proteins, the LMS are kinetically advantaged to occupy the surface of a droplet (van Aken, 2003). The effect of two low molecular weight surfactants (LMS) namely, sodium dodecyl sulphate and Polysorbate 80 along with proteins (whey protein and sodium caseinate) on spray drying of sugar-rich foods was studied (Adhikari, Howes, Wood, & Bhandari, 2009). However, no studies have been reported on plant proteins such as PPI along with LMS in the surface modification of sugar-rich foods.

Therefore, this study was aimed to investigate the effect of protein types (NaCas and PPI) and low molecular weight surfactants (LMS) on spray drying of sugar-rich foods.

2. Materials and methods

2.1. Materials

Sucrose with 99.5% purity (Sigma–Aldrich, Australia) was used as a model sugar-rich food. A dairy protein (NaCas) with a protein content of 92.9% (MG 2972, MG Nutritionals, Australia) and a plant protein (PPI) with a protein content of 90% (MyoPure, Australia) were used as received. Two food grade surfactants, sodium stearoyl lactylate (SSL) and Polysorbate 80 (Tween-80) were used as model surfactants. The former (Grindsted® SSL P 60 Veg) was purchased from Danisco, Denmark, while the latter was purchased from Sigma–Aldrich, Australia. SSL is an ionic surfactant which has a lower molecular weight (451.6 g/mol) and a comparatively higher hydrophile–lipophile balance (HLB) value of 22 while Tween-80 is a non-ionic surfactant with comparatively larger molecular weight (1310 g/mol) and a lower HLB (15) value. Both the surfactants are suitable for oil-in-water emulsions (McClements, 2005).

2.2. Methods

2.2.1. Solution preparation

The sugar–protein solutions were prepared by heating the solution at 45 ± 5 °C and gently agitating it with a magnetic stirrer. The sucrose:NaCas solid ratio was maintained at 99.5:0.5 while it was 99:1 in the case of sucrose:PPI solution on a dry solid basis. Since our preliminary experiments showed that no powder was recovered from sucrose:PPI (99.5:0.5) solution, hence the ratio of 99:1 was chosen. The total solid content was fixed at 25% w/w. The initial bulk protein concentration in sucrose–NaCas was 0.13% while it was 0.26% in the case of sucrose–PPI solution. Both pre-weighed sucrose and protein were dry mixed thoroughly before addition of water. Three hundred gram solution batches were prepared. The inherent moisture content of crystalline sucrose was taken as zero while it was determined and compensated for both NaCas and PPI. Solutions of sucrose–protein–SSL and sucrose–protein–Tween-80 were prepared by adding 0.01% and 0.05% of each surfactant to the sucrose–protein solutions. The solutions were heated to 45 ± 5 °C to ensure that all solids were completely dissolved. The solutions so prepared were tested for dynamic surface tension and subsequently spray dried.

2.2.2. Powder production

Spray drying of solutions was carried out on a bench-top spray-dryer (Buchi B-290, Buchi, Switzerland) with a water evaporating capacity of 1 l/h. The inlet and outlet temperatures were maintained at 165 °C and 65 °C, respectively. The air flow rate was maintained at 36 m^3/h while the aspiration was of 100%. The powders were collected from cyclone and the cylindrical part of the dryer chamber by lightly sweeping the chamber wall as proposed by Bhandari et al. (1997). The yield was calculated as the ratio of the mass of solids collected to the mass in feed solution on a dry basis.

2.2.3. Moisture

The moisture content was determined by drying the powder samples in a vacuum oven (Thermoline Scientific, Australia) at 70 °C for 24 h (Adhikari, Howes, Wood, et al., 2009). Samples were allowed to cool to room temperature in desiccators containing silica gel.

2.2.4. Water activity

Water activity of powder samples was determined using a pre-calibrated water activity meter (Novasina, Switzerland). The temperature was maintained at 24.5 ± 0.5 °C.

2.2.5. Glass transition temperature (T_g)

Glass transition temperature of all powders was measured using thermo-mechanical compression test (TMCT). Differential scanning calorimeter (DSC) was used in representative samples to compare the results obtained through the TMCT method.

TMCT measures the changes in particle bed compressibility at a constant stress (30.6 kPa) due to softening of the powder particles, which can be linked to the glass transition temperature of bulk