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High moisture extrusion for microparticulation of whey proteins –Influence of process parameters

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ABSTRACT

Defined functional properties of whey proteins can be achieved by controlling thermal unfolding and subsequent aggregation. To achieve a controlled formation of micro-particles, thermo-mechanical treatment by high moisture twin screw extrusion was used. The aim was to control the degree of denaturation as well as the particle size by variation of the process parameters. The temperature of the extruder has a strong impact on the maximum product temperature and increasing the extruder temperature increases the degree of denaturation. An increasing mass flow in contrast decreases the specific heat transfer to the product and leads to a decrease in denaturation. Increasing the screw speed has almost no effect on the degree of denaturation, but results in an exponential decrease in particle size due to increasing mechanical shear stress. Thus, the degree of irreversible protein denaturation as well as the particle size distribution can be controlled by these process parameters and aggregates with specific properties can be produced.

1. Introduction

Processing functions of extruders can include conveying, mixing, shearing, separation, heating or cooling, shaping, co-extrusion, venting volatiles and moisture, flavor generation, encapsulation and sterilization of biomaterials (Guy, 2001). Hence, extrusion processes can change the molecular structure of food ingredients, e.g. of proteins. Extrusion processes at low moisture levels are widely used in food industry for production of instant snack foods, cereals, pasta and pet foods (Guy, 2001; Harper, 1981; Kokini et al., 1992). In contrast, extrusion cooking at higher moisture contents (wet extrusion) has been studied much less frequently. Wet extrusion applications utilize twin screw extruders due to their efficient conveying capabilities. The rheological properties, torque, pressure build-up and energy requirements of high moisture extrusion systems are different from those of low moisture systems (Akdogan, 1999). Extrusion at high moisture levels is distinguished by lower friction and low viscous dissipation. Wet extrusion allows the production of innovative food products such as texturized proteins. Examples include extruded crab analog (Thiébaud et al., 1995), texturized soybean foods (Shen and Wang, 1992), fibrous structures for meat analog (Cheftel et al., 1992; Osen et al., 2014; Thiébaud et al., 1996) and sodium caseinate (Cheftel et al., 1992; Fichtali and Voort, 1995). Onwulata et al. (2010), Quéguiner et al. (1992) and Qi and Onwulata (2011) processed whey protein by high moisture extrusion and extrude it subsequently a second time together with a starch matrix in order to obtain improved textural properties. Furthermore, whey proteins can be used to produce aggregates with specific functional properties using a micro-particulation process at acidic pH (Onwulata et al., 2010; Quéguiner et al., 1992). For the extrusion process of Quéguiner et al. (1992), pH values of at least below 3.9 were necessary to achieve small aggregates. However, micro-particles with an acidic pH can limit their application in food products (Cheftel and Dumay, 1993).

Microparticulation is a controlled thermally induced aggregation process, during which shear forces are applied simultaneously or sequentially to limit the aggregate size. Whey proteins processed accordingly, used as additives, represent a possibility to impart specific structural and physical properties to food. These aggregates can be applied as fat replacer (Sandoval-Castilla et al., 2004) or functional ingredient to modify viscosity in various food products (Çakır-Fuller, 2015; Damodaran and Paraf, 1997; Lee et al., 2013). A specific variation of whey protein properties can be achieved by controlled unfolding and subsequent aggregation mainly mediated

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via disulfide bonds and hydrophobic interactions (Havea et al., 2001; Wijayanti et al., 2014; Zuniga et al., 2010). This targeted formation of particles with limited particle sizes to avoid a sensorially relevant impact, e.g. sandiness or mealiness induced by larger particles can be achieved by combination of thermal and mechanical treatment. The fundamental molecular mechanisms of unfolding and aggregation of whey proteins, which form the basis for particle formation, have been extensively studied (e.g. (Bon et al., 1999; Erabit et al., 2014; Hollar et al., 1995; Nicolai et al., 2011; Roefs and Kruif, 1994; Steventon, 1992; Wolz et al., 2016). To realize a combined heating and shearing process, different options are possible at industrial scale. Microparticulation of whey proteins can be realized in a scraped surface heat exchanger (Spiegel and Huss, 2002) or in a tubular heat exchanger followed by high pressure treatment (Iordache and Jelen, 2003; Paquin et al., 1992; Singer and Dunn, 1990). An alternative technique is extrusion cooking. Using extrusion for the thermomechanical modification of proteins allows the variation of different process parameters, such as e.g. temperature, screw speed and protein concentration, in a wide range. Another advantage is the possibility of coping with higher viscosities and therefore higher protein concentrations compared to other available techniques like scarped surface heat exchangers. Such high concentrations also allow a short residence time due to accelerated denaturation kinetics with increasing whey protein concentration (Wolz and Kulozik, 2015). Furthermore, a long run time can be expected as a result of negligible product caking which is due to the self-cleaning effect of the screws.

The aim of the present study is to control the degree of denaturation as well as the particle size distribution for microparticulation of whey protein concentrate by high moisture extrusion. In comparison to literature, a neutral instead of an acidic pH is used to enable possible applications in food products with neutral pH. Furthermore, a relatively low lactose concentration is chosen and no other additives are added to increase the reaction kinetics and to avoid a browning reaction during the thermal process. Depending on the future application the aim is to produce aggregates with different particle sizes and various degrees of protein denaturation. However, the most challenging task is to produce small aggregates (between 0.5 and 10 μm) and a narrow particle size distribution with a high degree of denaturation (high yield). Addition of such particles increase creaminess and heat stability of the product during further processing and which can otherwise cause coarse protein aggregation and grittiness. The resulting physical and chemical properties at macroscopic scale depend strongly on the processing conditions. The influence of temperature, mass flow and screw speed on the resulting aggregate properties are extensively investigated in this study.

2. Material and methods

2.1. Materials

Whey protein concentrate (WPC80, Germanprot Sachsenmilch, Leppersdorf, Germany) with a protein concentration of 80% was used as feed material. By addition of deionized water, the protein concentration was adjusted to 30% (w/w) during the extrusion process. This corresponds to a dry matter concentration of about 38% and a pH of 6.7. Analysis of the major components present in the used WPC80 yielded the following contents: protein 80.0%, lactose 4.4% and ash 3.2%.

2.2. Extrusion process

Extrusion experiments were carried out using a co-rotating intermeshing twin-screw extruder (ZSK25, Coperion, Stuttgart, Germany) with a screw diameter of 25 mm, a smooth barrel, and a total length of the screw of 38D. The barrel consisted of nine segments, each segment (except the first one) being equipped with an independent temperature control which is heated by an electric cartridge heating system and cooled with water (Fig. 1). The second and third heating segment were constantly set at 30 °C and 50 °C respectively, and the other heating segments at different extrusion temperatures between 90 °C and 120 °C ± 0.5 °C (in the following named extruder barrel temperature). For all process conditions, the maximum product temperature reached at the end of the heating zone as well as the product outlet temperature was measured by a thermocouple temperature sensor touching the product. Several pretests have been conducted to ensure that the actual product temperature was measured and not the barrel temperature. The die end plate has one hole of a 10 mm diameter.

The screw speed was set between 100 and 800 rpm. Whey protein powder was fed using a distinct weight feeder (K-Tron Soder, Niederlenz, Switzerland) and water was fed using a membrane pump (Grundfos, Erkrath, Germany). The total feed rate ranged from 5.3 to 21.1 kg/h. The screw profile was consisted of different screw elements that can be assembled on shafts. The screw profile is depicted in Fig. 2.

The screw profile comprised 3 zones (from feed to exit). Zone 1 (feeding zone) had a length of 366 mm and consisted of forwarding screws with a pitch of 36 mm intercepted by 2 kneading blocks (5 disks with an offset of 45° and a length of 12 mm). Zone 2 had a length of 336 mm and consisted of 4 alternating kneading blocks (5 disks with an offset of 45° and a length of 36 mm) and of 48 mm forwarding screw with a pitch of 24 mm. Zone 3 with a length of 256 mm was the cooling zone, which was comprised of a pure forwarding screw to avoid unnecessary energy input.

2.3. Sample collection and determination of process response

Samples were collected after the extruder system parameters (product temperature and motor torque) reached a steady state condition. Samples were filled in glass containers and immediately cooled in an ice bath. Maximum product temperature, product outlet temperature and motor torque were recorded. Samples were stored at 4 °C until analysis.

Specific mechanical energy (SME) was calculated from the maximum screw speed (n_{max} = 1200 rpm), the maximum engine power (P = 20 kW), the actual screw speed n_{act} [rpm], the torque τ [%] and the total mass flow rate m [kg/h] according to equation (1).

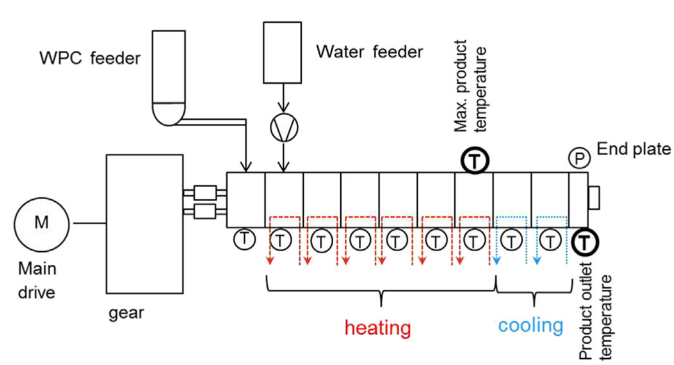

Fig. 1. Schematic illustration of the applied extrusion process.