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System parameters in a high moisture extrusion process for microparticulation of whey proteins

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ABSTRACT

Whey proteins can be texturized by thermo-mechanical treatment during high moisture extrusion. Thereby, protein aggregates with specific functional properties can be obtained. In this study, a heated co-rotating twin screw extruder was used to particulate whey protein concentrate. For data evaluation, process, product and system parameters affecting the extrusion process were distinguished. To characterize the process by system parameters is an important step towards an improved process understanding. The maximum product temperature ($T_{P,max}$) correlated linearly with the extruder barrel temperature and the mass flow. The specific mechanical energy input (SME) was found to be mainly affected by screw speed and mass flow. Independent of the respective adjusted process parameters, aggregate size was only affected by the resulting SME value. Equally, the degree of denaturation was only affected by the $T_{P,max}$. Thus, manipulation of system parameters (SME and $T_{P,max}$) can be applied for an indirect control of micro-particle properties.

1. Introduction

Microparticulation is a controlled, thermally induced aggregation process, during which shear forces are applied simultaneously or sequentially to limit the aggregate growth or to reduce the resulting aggregate sizes. Microparticulation of whey proteins can be realized in a scraped surface heat exchanger (SSHE) (Spiegel and Huss, 2002) or in a tubular heat exchanger followed by high-pressure treatment (Iordache and Jelen, 2003; Paquin et al., 1992). The downside of the established approaches is that only diluted solutions ($c_{Protein} \leq 10\%$ (w/w)) can be handled. Furthermore, shear stresses do not reach higher levels compared to SSHE. However, shear stress is a key factor in terms of aggregate size. This is of significant importance, as particles exceeding a certain size would create a mealy or even sandy mouthfeel. This would affect consumer acceptance negatively. We therefore applied the concept of extrusion for the microparticulation of whey proteins as an alternative to SSHE. In a previous publication, we reported that high moisture extrusion is a suitable technique to produce micro-particles in a desired size range of 0.5–10 μm at neutral pH. The targeted control of the resulting particle sizes in the low μm-range as achieved with extrusion technology, cannot be realized by any other technical devices with simultaneous application of heat and shear (Wolz et al., 2016a).

What remained to be studied is the functional relationship between the prevalent processing and technical conditions and the resulting product properties. The aforementioned study, as well as most of the other food extrusion studies focused on the direct influence of process parameters and raw material characteristics on product properties. However, due to the interdependence of influencing factors, e.g., screw speed, volume flow, and residence time, this is of limited success. The extrusion process is a complicated, empirically controlled multi-input–output system for which it is hardly possible to establish process-function-property correlations (Emin and Schuchmann, 2017). Therefore, the concept of system parameters will be applied, which analyzes the process and the outcome at a higher level above individual processing or technical factors. Thus, the number of variables can be reduced by defining system parameters, which describe the effects an extruder has on the material processed by it. As direct and in-line measurements of product properties is challenging, other approaches are required. In this context, system parameters offer the potential to control the product quality during processing (Chen et al., 2010; Onwulata et al., 1994). Moreover, manipulation of system

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parameters can be applied for an indirect control of product properties. Furthermore, this can simplify process control and optimization, transfer to other extruder systems and scale-up processes. The systems can be compared in the case of comparable values for the system parameters (Meuser et al., 1992), similar to the concept of dimensionless numbers in engineering in general.

Shearing by the screws and heating of the extruder barrel induce mechanical and thermal stress on proteins during high moisture extrusion. This thermo-mechanical treatment can modify the native structure of proteins from different sources in terms of denaturation and aggregation (Chen et al., 2010; Fang et al., 2014; Koch et al., 2017; Liu and Hsieh, 2007; Osen et al., 2014; Pietsch et al., 2017). The fundamental mechanisms of thermally induced denaturation and aggregation of whey protein in absence of shear (Havea et al., 2001; Roefs and Kruif, 1994; Tolkach and Kulozik, 2007; Zuniga et al., 2010) or presence of shear (Byrne et al., 2002; Cheftel et al., 1992; Simmons et al., 2007; Steventon, 1992) have already been extensively studied. The heating temperature was identified as the rate-determining factor of protein denaturation. Aggregates are built during denaturation where disulfide bonds and hydrophobic interactions are formed between the protein molecules (Havea et al., 2001; de La Fuente et al., 2002; Nicolai et al., 2011; de Wit, 2009). The aggregate size can be limited by shear stress acting on the particles. Quéguiner et al. (1992) also used extrusion for the microparticulation of whey proteins. With the process conditions used in the aforementioned study, low pH values (<3.9) were necessary to achieve small micro-particles.

The approach of this study was to distinguish between independent processing and technical parameters, to combine these into system parameters and to correlate these with the resulting product properties. The fundamental approach is similar to the concept first proposed by Meuser et al. (1992) for the extrusion of cereals. In this study we extend this concept for the microparticulation of whey proteins. Fig. 1 depicts the influencing factors for the microparticulation of whey proteins by extrusion. Independent process parameters and raw material characteristics affect the properties of the final product by influencing the extruder response inside the barrel, and thus, the system parameters. Such parameters include the specific mechanical energy input (SME), specific thermal energy input and the residence time distribution. System parameters combine the effects of the different process parameters and raw material characteristics on the processed product. As a result of different combinations of extrusion conditions, the system parameters can be used to describe or to compare extrusion processes under different operating conditions or machine sites.

The aim of this study was to correlate process and system parameters as well as system and product parameters by evaluating extrusion data. Thus, a tool for the control of the process and the product properties by inline-measurement of system parameters should be proposed. This is still a major gap in empirically controlled practical applications. The processing parameters barrel temperature, screw speed and mass flow were varied to assess their effects on the system parameters SME, maximum product temperature ($T_{P,max}$) as well as on the product properties particle size and degree of denaturation.

2. Material and methods

2.1. Materials

Whey protein concentrate WPC80 was kindly supplied by Germanprot Sachsenmilch (Leppersdorf, Germany). Its composition was: protein 80.0%; lactose 4.4%; ash 3.2%. By addition of deionized water during the extrusion process, the protein concentration was adjusted to 30% (w/w). This corresponds to a dry matter concentration of 38%, the pH was 6.7.

2.2. Extrusion process

A co-rotating intermeshing twin-screw extruder (ZSK25, Coperion, Stuttgart, Germany) equipped with two screws with a diameter of 25 mm and a die end plate with a hole of 10 mm in diameter was used. Due to the process design and the high moisture content, there was no pressure build-up towards the extruder exit. The barrel length was 38D. The barrel was divided in a heating and a cooling zone consisting of nine single segments, each with the option of individual temperature set points (except segment 1). Barrel temperature (ϑ_{Barrel}) was varied as shown in Table 1. The extrusion process and the screw profile applied are described in more detail by Wolz et al. (2016a). The screw speed was set to 100–800 rpm. A screw feeder (K-Tron Soder, Niederlenz, Switzerland) was used to feed the whey protein powder based on weight. The powder feed rate ranged from 2 to 8 kg h^{-1}. A membrane pump (Grundfos, Erkrath, Germany) was used to dose the

Table 1
Barrel temperature settings (ϑ_{Barrel}) for segment 1 to 9.

1	2	3	4	5	6	7	8	9
_	30 °C	50 °C	90 °C	90 °C	90 °C	90 °C	50 °C	30 °C
_	30 °C	50 °C	100 °C	100 °C	100 °C	100 °C	50 °C	30 °C
_	30 °C	50 °C	110 °C	110 °C	110 °C	110 °C	50 °C	30 °C
_	30 °C	50 °C	120 °C	120 °C	120 °C	120 °C	50 °C	30 °C

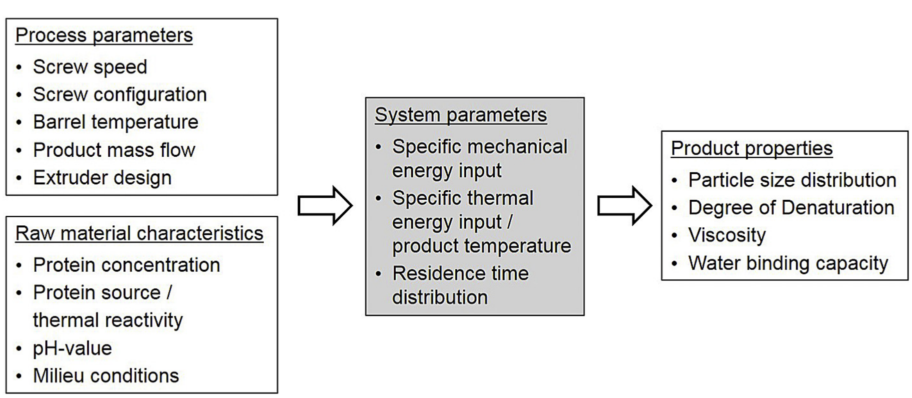

Fig. 1. Factors influencing the high moisture extrusion process for microparticulation of whey proteins.

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