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Dry fractionation for production of functional pea protein concentrates

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ABSTRACT

Dry milling in combination with air classification was evaluated as an alternative to conventional wet extraction of protein from yellow field peas (*Pisum sativum*). Major advantages of dry fractionation are retention of native functionality of proteins and its lower energy and water use. Peas were ground by impact (ZPS50) and jet milling (AFG100) at various classifier wheel speeds to provide pea flours with different particle size distributions, protein contents and damaged starch levels. Peas were milled under various conditions to maximally disentangle starch granules from the surrounding protein bodies. The optimal milling conditions were confirmed by particle size analysis and scanning electron microscope imaging. Too extensive milling, e.g. using ultrafine impact or jet milling, resulted in very fine flours (with $D_{0.5} < 10$ μm) with poor flowability, whereas ultrafine jet milling led to an increased percentage of damaged starch. Subsequently, air classification was applied to separate small fragments (primarily protein bodies) from the coarse fraction (starch granules) to obtain enriched protein concentrates. Protein concentrates were obtained with protein contents between 51% and 55% (w/dw) and a maximum protein recovery of 77%. Deviating cut-off size for air classification could be ascribed to build-up of material between the vanes of the classifier wheel. Finally, water holding capacity (WHC) tests were used to evaluate the functional properties of the pea protein concentrates. A liquid pea concentrate comprising 26% (w/w) of protein could be prepared from dry pea concentrates containing more than 30% (w/dw) of pea protein. This was explained by the high solubility of pea protein in its native state. After heat treatment of pea protein concentrates, a gel with a high WHC of 4.8 g water (w/w) was obtained, which decreased with increasing protein content. Functional properties of the pea protein concentrates are interesting for preparation of high-protein foods or for replacement of egg protein functionality.

1. Introduction

Pea protein isolate is used to improve the texture and the nutritional quality of food products (Shand, Ya, Pietrasik, & Wanasundara, 2007) and commonly produced by wet fractionation. Wet extraction starts with dispersion of pea flour in water after which the proteins dissolve and the starch granules are suspended. A hydrocyclone is used to separate the starch granules from the protein solution. The solubilised proteins are then precipitated at their iso-electric point (pH 4.8). Subsequently, the pH is readjusted to 7 and a dry protein isolate is obtained with a final drying step (75–90% protein (w/dw)) (Boye, Zare, & Pletch, 2010). The major drawback of wet fractionation is partial loss of the native functionality of the proteins due to the pH shifts and drying. Moreover, this process uses many chemicals and a lot of energy and water (Schutyser & van der Goot, 2011). It also excludes insoluble proteins from the isolate, which are generally highly aggregated proteins with specific functionality.

Dry fractionation by fine milling with subsequent air classification is a more sustainable alternative to wet fractionation for peas and several other legumes and grains (Bergthaller, Dijkink, Langelaan, & Vereijken, 2001). After fine milling, the larger starch granules (20 μm) are physically detached from the smaller protein-rich particles (1–3 μm), which allows separation (Tyler & Panchuk, 1982). Too coarse milling however leads to the presence of aggregates of protein bodies, starch granules and other cell components, which does not allow subsequent separation. Too fine milling leads to extensive starch damage and affects separation negatively, as the starch granule fragments and protein bodies have similar sizes. During air classification, the smaller protein-rich particles are separated from the larger starch granules based on size, shape and density (Boye et al., 2010). The protein content of the fine fraction depends on the initial protein content of the flour, the dispersibility of the flour and the cut point (Dijkink, Speranza, Paltsidis, & Vereijken, 2007; Reichtert, 1982). The cut point is the size at which a particle has a 50% chance to move either to the fine fraction or to the coarse fraction. It can be adapted by selection of the appropriate air classification conditions, such as the classifier wheel speed and the air flow (Cloutt, Walker, & Pike, 1986). Complete separation of protein from starch is hindered by protein that still adheres to the starch granules after milling (Vose, 1978). A second milling step can be applied to increase the protein yield. However, a side effect is that more damaged starch will be present in the second protein fraction, decreasing purity (Tyler, Youngs, & Sosulski, 1981).

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The pea protein concentrates are used in food products, like meat and sausage substitutes and soups, for their solubility, water and fat binding capacity, gelation, foaming and emulsification capacity (González–Pérez & Arellano, 2009; Swanson, 1990). After a heat treatment the water and fat binding capacity and the gelation properties are improved, while the solubility is decreased (Ma et al., 2011; Sosulski & McCurdy, 1987).

This paper presents a systematic study of milling and air classification for producing pea protein concentrates in combination with their functional analysis. Jet and impact milling were investigated to obtain pea flours with different properties (e.g. disentanglement behaviour, protein concentration) and particle size distributions. Subsequently, air jet sieving and especially air classification were used to prepare pea flour fractions enriched in protein. Air classification was carried out under different conditions to change the cut point and thus the protein shift. The air classification operation was verified with the model described by Bauder, Müller, and Polke (2004). Finally, the functionality of the protein concentrates was evaluated based on their water holding capacity, which is an important property of concentrates in many different food applications (Ma et al., 2011). In the functional analyses, the pea protein concentrates are compared to denatured pea protein concentrates.

It is hypothesized that both the degree of denaturation and the composition of pea concentrate mixtures affects their functionality (Schutyser & van der Goot, 2011). Previous studies did not investigate the influence of the composition of an isolate on its functionality, but only focused on maximising protein content (Sosulski & Youngs, 1979; Wright et al., 1984). Retention of native functionality by prevention of denaturation is expected to increase the solubility of pea proteins (Alonso, Orue, Zabalza, Grant, & Marzo, 2000). The presence of residual starch may have a positive effect on water holding capacity absorption (Damodaran, 2008; Horvath, Ormai-Cserhalmi, & Czukor, 1989; Sosulski & Youngs, 1979).

2. Materials and methods

2.1. Materials

Pre-dried yellow peas, *Pisum sativum*, were purchased from Alimex (The Netherlands). The producer's specifications of the yellow peas were: moisture 10–15% (w/w), protein 23% (w/w) carbohydrate 62% (w/w) (starch 44% (w/w)), fat 2% (w/w) and ash 3% (w/w). Pea protein isolate (NUTRALYS® F85G) and pea starch isolate (PEA STARCH N-735) were supplied by Roquette (France).

2.2. Milling and air classification

A ZPS50 impact mill or an AFG100 fluidized-bed jet mill (Hosokawa-Alpine, Augsburg, Germany) was used for the milling experiments. In impact milling, size reduction is achieved through collisions between powder particles and the wall of the mill, whereas in jet milling, inter-particle collisions are responsible for size reduction. The impact mill speed only influences the milling time and energy use and was fixed for practical reasons at 8000 rpm. Both mills were equipped with an internal classifier wheel that allows fine particles to leave the grinding chamber, while coarse particles are recirculated. The air flow and the classifier wheel speed are the most important parameters in determining the final particle size of the milled flour. The applied classifier wheel speeds were 2500, 4000 and 8000 rpm. The air flow was kept constant at 52 m^3/h and the screw feeder was set at 2 rpm (circa 0.75 kg/h). Each milling experiment was duplicated with 1 kg of yellow peas.

The milled peas were air classified in an ATP50 classifier (Hosokawa-Alpine, Augsburg, Germany). In an air classifier, flour is taken up in the classifier chamber by air flow. Small and light particles will be taken higher than heavy and large particles. At the top, a classifier wheel with slits rotates. Small particles go through the slits. Larger particles leave the classifier at the bottom (Fig. 1). The size of the particles that can pass the slits decreases with the speed of the classifier. The applied classifier wheel speeds were 5000, 6000, 8000, 10,000 and 12,000 rpm. The air flow was again fixed at 52 m^3/h. The screw feeder rate was set at 20 rpm (circa 1 kg/h). This rate was not varied as it is generally accepted not to influence the air classification (Wright et al., 1984). The peas were not de-hulled: the hull fibres were collected predominantly in the coarse fraction (Vose, Basterrechea, Gorin, Finlayson, & Youngs, 1976). Each air classification experiment was duplicated with 500 g of flour.

The air classification process can be characterised by a cut point, which is the diameter of the particle that has equal chance to end up either in the fine or the coarse fraction. It can be varied by controlling the air flow and the classifier wheel speed. Cut points were determined experimentally on the basis of the particle size distributions and the yields of the fine, coarse and original flour fed to the air classifier. A Tromp curve was constructed to determine the cut point as a function of the classifier wheel speed (Leschonski, 1984):

$$T(x) = \frac{g * q_G(x)}{q_A(x)} \tag{1}$$

in which x is the particle size, $T(x) = 0.5$ is the cut point, g is the weight of the coarse fraction divided by the sum of the weights of the coarse and the fine fraction (–), $q_G(x)$ is the frequency distribution of the coarse fraction (–), and $q_A(x)$ is the frequency distribution of the feed material (–).

Alternatively, the cut point can be approximated from the classifier configuration and the settings of the air classifier (Bauder et al., 2004). In the Hosokawa classifier, the separation is determined by the ratio between the centrifugal force created by the classifier wheel and the drag force of the sifter gas flowing through the wheel. For the fine particles, the drag force is dominant allowing them to pass the classifier wheel. For the coarse particles the centrifugal force is stronger than the drag force, which deflects them from the classifier wheel. The cut point is the particle size at which the drag force equals the centrifugal force (Bauder et al., 2004):

$$x = \frac{3}{4} c_w \frac{\rho_a}{(\rho_p - \rho_a)} \frac{v_r^2}{v_\varphi^2} r \tag{2}$$

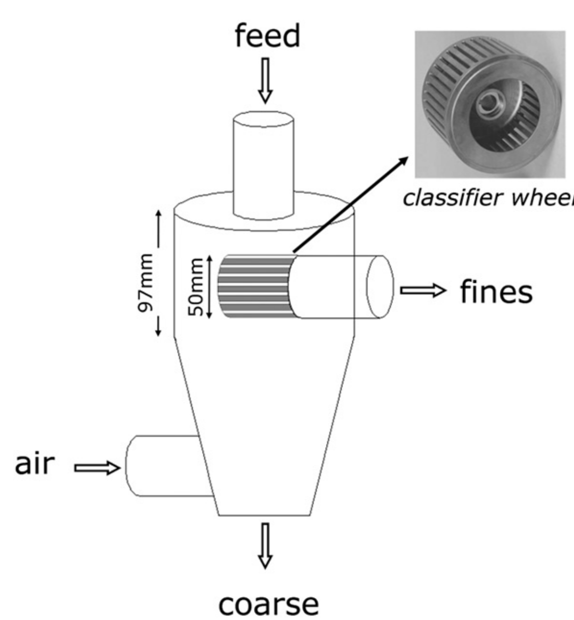

Fig. 1. Schematic overview of the air classifier used in this study (ATP50).