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Cheese whey treated by membrane separation as a valuable ingredient for barley sourdough preparation

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ABSTRACT

Utilisation of cheese whey for production of healthier food has been the main task of this study. Cheese whey, which is often considered as a waste material, was treated by a series of processes including fermentation, membrane filtrations, mixing with barley flour, drying, and/or extrusion to produce barley sourdough.

In the first series of experiments, the effect of membrane ultrafiltration (UF) and nanofiltration (NF) on separation of whey components has been studied. Non-fermented sweet cheese whey was treated by pilot-plant membrane ultrafiltration (50 kDa tubular ceramic membrane, TAMI Industries, France), followed by three step diafiltration to minimise losses of lactose, glucose, galactose, and organic acids (namely lactic acid) in retentate. The UF permeates were used for the subsequent nanofiltration and diafiltrations (spiral wound membrane NF 270-2540, Filmtec, Dow Chemicals, USA). The results showed high recovery of proteins (81%) during UF and reduction of lactose and propionate losses by using diafiltration. Rejections of components on the NF membrane were: 93% lactose, 77% galactose, and 76% lactic acid. However, the diafiltration on the NF membrane reduced the relative recovery both for carbohydrates and organic acids.

In the second series of experiments, cheese whey was concentrated by reverse osmosis (RO) and the obtained retentate was fermented with *Lactobacillus plantarum*, *Lactobacillus sanfranciscensis* and *Propionibacterium freudenreichii* subsp. *freudenreichii*. Part of the fermented whey was mixed with barley flour and dried by cold air fluid drying to produce sourdough pellets. The other part of fermented whey was filtered by nanofiltration and both permeate and retentate were sprayed on the surface of sourdough pellets in several layers and dried again. The extrusion of a mixture containing barley flour and fermented whey was tested for pellet production as well. The main aims were to obtain sourdough rich in natural preservatives, and maintain the present microorganisms active. That is why all the technological processes, including drying, were carried out under low temperatures. The content of organic acids (lactic, acetic and propionic) was analysed in final sourdough samples.

1. Introduction

The technology of fermented cereal products is nearly as old as the humankind itself, and seemingly, there is not much to improve. Nevertheless, concerns about food safety and quality, nutritional properties, and positive effect on human health boosted the research even on traditional food products, such as bread. Nowadays, the attention is drawn to sourdough, as well as new types of cereals.

Barley represents such cereal even though it is one of the oldest crops. Barley has been mostly used as animal feed or for malt production, and only 5% is being used in food (FAO, 2009). From a nutritional point of view, barley contains high amount (8–10%) of soluble dietary fibre in form of β-glucans (Dickin et al., 2011; Dieckmann, 2011), which are evenly distributed in the whole grain, including endosperm and pericarp (Baik and Ullrich, 2008; Holtekjølen et al., 2006).

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Many studies have confirmed the positive effect of β-glucans in human diet on the prevention of many life-style diseases, such as type 2 diabetes, cardiovascular diseases, obesity and high cholesterol levels (Andersson and Åman, 2011). For example, according to Collins et al. (2010), a higher dietary fibre intake reduced the risk of cardiovascular disease and myocardial infarction. Barley β-glucans have been proved to lower the glucose and insulin responses in blood serum (Rieder et al. 2012), and reduce the glycaemic properties of bread (Lappi et al., 2010). β-glucans of different origin exhibited a protective activity against different mutagenic agents (Mantovani et al., 2008). However, the effect depends strongly on the amount of beta-glucans in the diet (Wood, 2007). According to the European Food Safety Authority (EFSA, 2011) "4 g of beta-glucans from oats or barley for each 30 g of available carbohydrate should be consumed per meal" to decrease post-prandial glycaemic responses.

Spontaneous fermentation of barley milling represents a great option for using barley in human alimentation. The sourdough fermentation of wholemeal flour or bran by means of yeast and bacteria brought interesting results regarding the improvement of the baking (flavour, structure and stability), nutritional (Torrieri et al., 2014) and also sensory quality of bread (Mariotti et al., 2014). In addition, sourdough can also retard starch digestibility leading to low glycaemic responses and improve bioavailability of minerals and bioactive compounds (Poutanen et al., 2009). Cereal fermentation may produce non-digestible polysaccharides (dietary fibre) or new bioactive compounds (such as prebiotic oligosaccharides) and also reduce gluten to develop gluten-free products (Moroni et al., 2009).

Lactic acid bacteria (LAB), the dominant microorganisms in sourdoughs, produce lactate, acetate and other antifungal compounds. Propionibacteria (PAB), the producers of propionate, have been known in dairy. Both lactate and propionate serve as food preservatives and they are often used in bakery products to prolong the shelf life, especially in wheat white bread. Since the consumers prefer few or no food additives, the sourdough fermentation is another natural way how to improve the shelf life of bread (Zhang et al., 2010; Ryan et al., 2008).

Lactose from cheese whey can serve as a source of carbon for fermentation. Cheese whey is produced in large quantities in cheese manufacture. Despite the whey's high content of valuable substances (lactose, milk proteins), whey is often disposed of in waste waters. Hugenschmidt et al. (2011) used the filtered whey for fermentation of *Lactobacillus plantarum* SM39 and *Propionibacterium freudenreichii* DF13 to obtain high concentration of folate and intra-cellular vitamin B12.

Our research followed several aims. The main aim was to use cheese whey as a beneficial ingredient for preparation of sourdough with high amount of propionic and lactic acids, which are natural preservatives improving the rheological properties of cereal dough. To increase the nutritional value and the shelf life of the final product, barley was chosen to be blended with fermented whey.

Whey was treated by several processes to produce sourdough pellets. First of all, cheese whey was concentrated by reverse osmosis (RO) and the retentate fermented with *L. plantarum*, *Lactobacillus sanfranciscensis* and *P. freudenreichii* subsp. *freudenreichii*. The synergistic effect of lactobacilli and propionic bacteria was used (Zhang et al., 2010; Ryan et al., 2008). Part of the fermented whey was directly mixed with barley flour and the mixture was fluid dried by cold air to obtain barley sourdough pellets. Other part of the fermented whey was processed by nanofiltration, and both the permeate and the retentate fractions were sprayed onto the surface of dried sourdough in several layers and dried again. Low temperature extrusion has been investigated for sourdough preparation using fermented whey as well.

Membrane techniques were tested for possible improvement of whey composition. Therefore, the separation properties of 50 kDa tubular inorganic ultrafiltration (UF) membrane were studied in non-fermented sweet cheese whey. The ultrafiltration aimed at the concentration of proteins in retentate with minimal losses in sugars and organic acids. Ultrafiltration was followed by three step diafiltration using the same UF membrane where sugars and organic acids were expected to be transferred into permeate. UF permeates were treated by nanofiltration (NF) on a spiral wound polymeric membrane to concentrate components important for sourdough quality, such as organic acids and sugars. The three step diafiltration on the NF membrane was carried out as well to study the effect on separation.

2. Material and methods

2.1. Material

2.1.1. Cheese whey and barley flour

1.2 kg of bovine dried sweet cheese whey (Moravia Lacto, Czech Republic) was diluted with 18.8 kg of demineralised water and used as feed solution for ultrafiltration, nanofiltration and all diafiltrations. Dried whey composition was: proteins 11.0%, milk fat 1.5%, lactose 69.5%, mineral substances 7–9%, pH 6.

Bovine sweet cheese whey from a local dairy (Milko, Poděbrady, Czech Republic) was concentrated by reverse osmosis and retentate was used as a substrate for fermentation and preparation of sourdough pellet. Lactose content in concentrated whey (RO retentate) was 12.5% (w/w). Whey was used fresh without any modifications.

Barley flour for sourdough preparation was obtained from a local mill (Automatické mlýny, Klíma, Křesín, Czech Republic).

2.1.2. Microorganisms

Bacteria *L. plantarum* (JM-57V-7A), *L. sanfranciscensis* (CCDM 451), and *P. freudenreichii* subsp. *freudenreichii* were obtained from the Culture collection of The Dairy Research Institute (VUM, Tabor, Czech Republic).

2.1.3. Chemicals

2.1.3.1. Chemicals for anion-exchange chromatography. Lactose standard was purchased from Fluka (Switzerland), galactose and glucose were obtained from Sigma Aldrich (Germany). Ultrapure water (Simplicity, Millipore, USA) with the resistivity of 18.2 MΩ and 50% sodium hydroxide (Fluka, Germany) were used for mobile phase preparation.

2.1.3.2. Chemicals for isotachophoresis. The standards used were: lactic acid (Lachema, Czech Republic), citric acid (Penta, Czech Repulic), acetic acid (Lachema, Czech Republic), and propionic acid (Penta, Czech Republic).

The composition of leading electrolyte (pH 4.5) was: 10 mM hydrochloric acid (Sigma, Germany), 22 mM epsilon-amino caproic acid (Sigma, Germany), and 0.1% hydroxypropyl methyl cellulose (Fluka, Germany). The terminal electrolyte composition was 5 mM caproic acid (P Lab, Czech Republic).

2.2. Filtration stations and membranes

2.2.1. Ultrafiltration

The cross flow ultrafiltration station ARNO 600 (Mikropur, Hradec Králové, Czech Republic) is equipped with a piston pump Hydra-cell (model G13, Wanner Engineering Inc., USA), having a maximum power of 1500 W and a speed of 1450 RPM (Fig. 1). The maximum output is 600 l/h, the maximum operation pressure is