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Manufacturing of reverse osmosis whey concentrates with extended shelf life and high protein nativity

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ABSTRACT

The suitability of a two-step preservation process for whey concentrates consisting of cold microfiltration (MF) (1.4 μm pore size) and gentle heat treatment was investigated. The purpose was to produce reverse osmosis (RO) whey concentrates [dry matter (DM) contents: 12–30%] showing high native protein levels and sufficient shelf life as a substitute for whey powder. Strong bacterial reduction of 4.8–6.0 log cycles could be achieved by MF in whey concentrates with 12, 18 and 24% DM. Concurrently, low whey protein denaturation of 0.1–6.6% and 2.3–12.7% was found after pasteurisation at 75 °C and 80 °C, respectively, for 30 s. Microbiological shelf life of the whey concentrates was at least 4 months at 4 °C storage temperature. The applied process is suitable to produce extended shelf life (ESL) whey concentrates with DM of up to 24% that might serve as energy efficient substitutes for whey powder.

1. Introduction

Fluid whey concentrates could be an energy efficient alternative to whey powder. Since spray drying and the preceding evaporation are the most energy intensive processing steps in the dairy industry, huge amounts of energy could be saved by substituting whey powder by shelf-stable whey concentrates produced by membrane filtration, e.g., reverse osmosis (RO). However, whey powder can only be replaced by fluid whey concentrates with high volume reduction factors if negligible denaturation of whey protein and sufficient shelf life of concentrates are guaranteed.

To gain knowledge about the reaction kinetics in sweet whey concentrates, we investigated thermal spore inactivation as well as whey protein denaturation kinetics in differently composed whey concentrates in previous studies (Marx & Kulozik, 2018a,b). The results of these studies showed that, on the one hand, a decrease of the water activity and an increase of the concentration of lactose and proteins seem to protect the spores during heat treatment depending on the composition of the whey concentrate and on the heating temperature. On the other hand, an increasing dry matter (DM) content of whey concentrates leads to enhanced whey protein denaturation caused by thermal treatment. Thus, the preservation of fluid RO whey concentrates results in a conflict of aims between microbiological shelf life and negligible denaturation of whey protein. In conclusion, a one-step heating process does not appear to be adequate for the preservation of fluid whey concentrates.

A promising option for a preservation process keeping whey proteins in their native state and guaranteeing satisfying microbiological shelf life of whey concentrates is therefore the combination of microfiltration (MF) and gentle heat treatment such as shown in Fig. 1. The combination of crossflow MF and subsequent pasteurisation is a concept already known from the production of extended shelf life (ESL) milk. MF provides a mechanical alternative for reducing the number of microorganisms without thermal impact on the product. As shown in previous studies, ceramic MF membranes with a pore size of 1.4 μm are able to effectively reduce bacterial levels in skim milk. At the same time these membranes facilitate a long-term MF flux with nearly no retention of valuable milk solutes, e.g., proteins and lactose (Fernández García & Riera Rodríguez, 2014; Kaufmann, Scherer, & Kulozik, 2010; Pafylias, Cheryan, Mehaia, & Saglam, 1996; Skrzypek & Burger, 2010). However, it is not known if MF is also an adequate method for germ removal from concentrated sweet whey with DM contents of up to 30%. The higher viscosity could, possibly, lead to reduced performance of the MF.

The average decimal reduction of bacteria from skim milk is above 3.5. Pathogenic bacteria, e.g., *Listeria monocytogenes* or *Salmonella typhimurium*, are also reduced by 3.5–4 log cycles.

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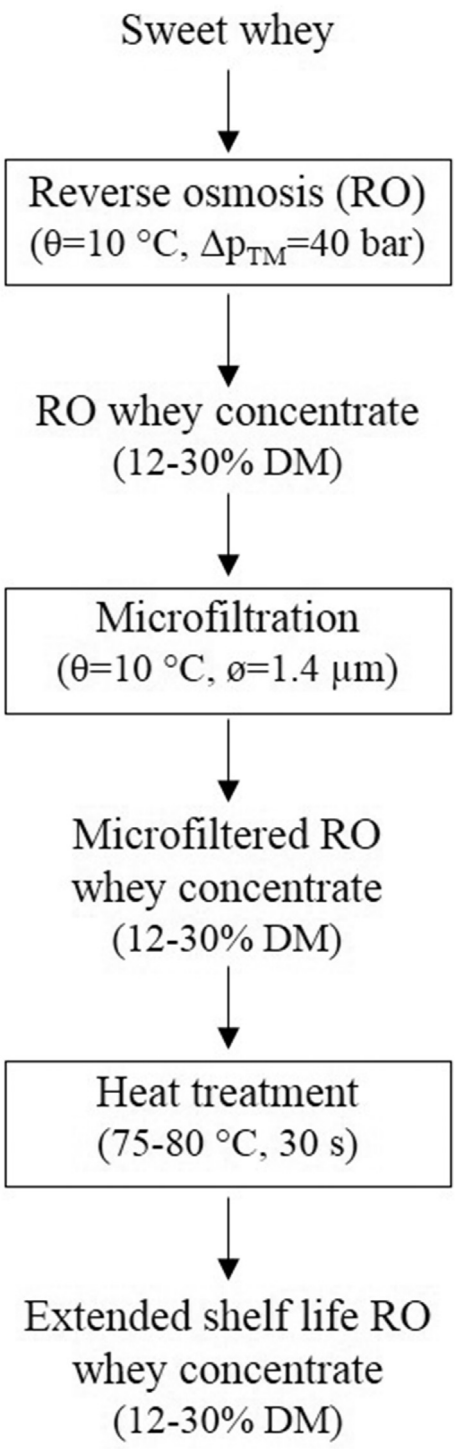

Fig. 1. Manufacturing process for reverse osmosis (RO) whey concentrates with extended shelf life (ESL).

Spore forming bacteria as the species with the highest survival rates after pasteurisation are rejected to an even higher proportion by MF membranes due to their large cell volume. The decimal reduction determined for spore forming bacteria was higher than 4.5.

Even the decimal reduction of spores obtained for MF lays between 2.3 and 4.5 (Olensen & Jensen, 1989; Saboya & Maubois, 2000; Tomasula et al., 2011; Trouvé et al., 1991). Typical operating temperatures for MF of skim milk are 35–55 °C (Gésan-Guiziou, 2010). Due to the mesophilic or thermophilic cheese culture present in whey, MF should be carried out at temperatures <15 °C or ≥50 °C to prevent microbial growth during filtration (Weber & Müller, 2006). To keep the thermal impact on whey proteins during the MF of whey concentrates as low as possible, an operating temperature of 10 °C would therefore be recommended. However, a lower filtration temperature results in an increased viscosity of the whey concentrate, especially, when concentrated to higher DM contents. The viscosity of the feed solution is an important influencing factor for the performance of the MF. Kaufmann (2012) reported lower protein permeation as well as lower decimal reduction at 10 °C as compared with 50 °C for the MF of skim milk as part of the ESL process. The MF process for germ removal from concentrated sweet whey, however, has not been studied so far at a low filtration temperature of 10 °C, where concentrated fluids assume high viscosity levels.

To guarantee a complete inactivation of pathogenic bacteria in the product, MF has to be followed by heat treatment. For the production of ESL milk by means of this combined process, typically a gentle heat treatment such as pasteurisation is chosen to obtain the fresh milk flavour and high nativity of milk proteins. After heat treatment at 73 °C for 25 s, β-Lg showed a degree of denaturation (DD) of 10–15% in ESL (MF + pasteurisation) milk (Kaufmann, 2012). It has been shown that whey protein denaturation is strongly dependent on the DM content and the composition of whey concentrates in the temperature range from 90 to 125 °C. The heating-up phase up to 90 °C already induces a DD of β-Lg between 34 and 56% in dependence on the DM of whey (Marx & Kulozik, 2018b). It therefore has to be clarified whether it is possible to keep the whey protein denaturation in concentrated sweet whey at the same low level as in ESL milk by means of heat treatment at 75–80 °C.

For manufacturing whey concentrates as alternative to whey powder, not only a high whey protein nativity is mandatory but also sufficient shelf life has to be guaranteed. For skim milk, Fernández García and Riera Rodríguez (2014) investigated the influence of MF (ceramic membrane with a pore size of 1.4 µm) combined with different heat treatments between 73 and 130 °C for 2–15 s on its shelf life. For the whole temperature range the use of MF additional to the heat treatment led to prolongation of shelf life as compared with heat treatment without MF. The higher the heating temperature the longer the determined shelf life of the milk was. Besides the heat treatment, the storage temperature also influences the shelf life of ESL milk for temperatures between 6.1 and 0.1 °C, as has been shown by Elwell and Barbano (2006). However, there is no knowledge about the microbiology through the shelf life of ESL processed whey concentrates so far.

The higher concentration of solutes in concentrated whey compared with skim milk could influence the removal, the inactivation and the growth of microorganisms. Another quality determining factor is the chemical-physical stability of the whey concentrates during storage. Due to the high concentration of milk salts and lactose in concentrated whey, the solubility limit of these solutes might be exceeded depending on the DM content. Exceeding the solubility limit could result in undesired crystallisation reactions during storage.

The combined ESL process consisting of MF and gentle heat treatment has so far been investigated and applied only for preservation of skim milk, but not for preservation of concentrated sweet whey. This study should, therefore, assess the possibilities and limitations of this process for the manufacture of storable ESL RO whey concentrates.