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Effect of annatto addition and bleaching treatments on ultrafiltration flux during production of 80% whey protein concentrate and 80% serum protein concentrate[1]

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ABSTRACT

The goals of this study were to determine if adding annatto color to milk or applying a bleaching process to whey or microfiltration (MF) permeate influenced ultrafiltration (UF) flux, diafiltration (DF) flux, or membrane fouling during production of 80% whey protein concentrate (WPC80) or 80% serum protein concentrate (SPC80). Separated Cheddar cheese whey (18 vats using 900 kg of whole milk each) and MF permeate of skim milk (18 processing runs using 800 kg of skim milk each) were produced to make WPC80 and SPC80, respectively. The 6 treatments, replicated 3 times each, that constituted the 18 processing runs within either whey or MF permeate UF were as follows: (1) no annatto; (2) no annatto + benzoyl peroxide (BPO); (3) no annatto + hydrogen peroxide (H_2O_2); (4) annatto; (5) annatto + BPO; and (6) annatto + H_2O_2. Approximately 700 kg of whey or 530 kg of MF permeate from each treatment were heated to 50°C and processed in 2 stages (UF and DF) with the UF system in batch recirculation mode using a polyethersulfone spiral-wound UF membrane with a molecular weight cutoff of 10,000 Da. Addition of annatto color had no effect on UF or DF flux. The processes of bleaching whey or MF permeate with or without added color improved flux during processing. Bleaching with H_2O_2 usually produced higher flux than bleaching with BPO. Bleaching with BPO increased WPC80 flux to a greater extent than it did SPC80 flux. Though no differences in mean flux were observed for a common bleaching treatment between the WPC80 and SPC80 production processes during the UF stage, mean flux during WPC80 DF was higher than mean flux during SPC80 DF for each bleaching treatment. Water flux values before and after processing were used to calculate a fouling coefficient that demonstrated differences in fouling which were consistent with flux differences among treatments. In both processes, bleaching with H_2O_2 led to the largest reduction in fouling. No effect of annatto on fouling was observed. The reasons for flux enhancement associated with bleaching treatments are unclear.
Key words: ultrafiltration, flux, bleaching, annatto

INTRODUCTION

Flux decline and fouling during UF of whey have been studied extensively (Tong et al., 1989; Heng and Glatz, 1991; Rao, 2002) because they limit processing efficiency. Sweet and acid wheys are usually treated before UF to remove or inactivate potential foulant material that may reduce process flux (Heng and Glatz, 1991; Pouliot, 1996). These pretreatments may involve upstream unit operations such as microfiltration (**MF**) or centrifugal separation to remove foulant, chemical adjustments such as pH modification, mineral chelation, or preheating to inactivate foulant, or a combination of the 2 (Pouliot, 1996). Because proteins, minerals, and lipids are generally considered the most prevalent foulants, pretreatments are usually intended to increase protein solubility, limit calcium phosphate precipitation and calcium bridging during UF, or remove lipids from the whey (Pouliot, 1996). As such, the chemistry and composition of the process feed stream is expected to influence UF fouling and flux decline. Though studies regarding flux decline during UF of MF permeate of skim milk have not been as common, data by Britten and Pouliot (1996) and Nelson and Barbano (2005) indicate that the composition and pH of MF permeate are more similar to those of sweet whey than acid whey.

Whey protein concentrates (**WPC**) and serum protein concentrates are created by ultrafiltering cheese whey or 0.1 μm MF permeate of skim milk, respectively, to concentrate serum proteins (**SP**) and remove lactose and minerals (Nelson and Barbano, 2005). The

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UF retentate can be concentrated by evaporation and spray dried to make a shelf-stable powder. Because SP in these ingredients are highly sought after, producers may further reduce the lactose and mineral contents of WPC and serum protein concentrates below what a single UF step would accomplish by diafiltering (**DF**) the UF retentate before evaporation and drying. Diafiltration involves diluting the UF retentate with water and then repeating the UF process. This step washes out the nonprotein-soluble milk solids that pass through the UF membrane and increases the protein content of the powder. Although serum protein concentrates and 80% serum protein concentrate (**SPC80**) solutions have been shown to exhibit improved sensory characteristics under certain conditions and greater clarities than their WPC counterparts (Evans et al., 2009, 2010), they are not widely available in the dairy industry. Conversely, WPC and 80% whey protein concentrate (**WPC80**) are by-products of cheese manufacture that are widely available. Over 175 million kg of WPC were produced in the United States in 2008 (IDFA, 2009).

In the United States, the majority of WPC and WPC80 are produced from Cheddar and mozzarella whey. Cheddar is often colored using annatto, a yellow to orange food colorant derived from the *Bixa orellana* shrub (Kang, et al., 2010), to maintain cheese color consistency throughout the year. The principal color molecules in annatto are the carotenoids bixin and norbixin (Kang, et al., 2010). Unfortunately, not all of the bixin and norbixin remain in the cheese; some of these colorants pass into the Cheddar whey. Because whey products made from Cheddar cheese whey with added annatto color may contribute an undesirable yellow hue to a food product in which it is subsequently used, manufacturers of WPC and WPC80 often bleach the whey before spray drying to whiten the final protein concentrate. Currently, 2 bleaching agents, benzoyl peroxide (**BPO**) and hydrogen peroxide (H_2O_2), are approved and deemed generally recognized as safe for bleaching whey in the United States (US FDA, 2011a,b). Benzoyl peroxide completely degrades to benzoic acid during the bleaching process and this residue in whey products may not be allowed in some countries. When H_2O_2 is used for bleaching, residual H_2O_2 must be broken down into molecular oxygen and water with catalase enzyme.

When examining the functional properties of WPC80 that had been bleached with BPO or H_2O_2, Jervis et al. (2012) noted that protein solubility increased after bleaching with H_2O_2. Because increased protein solubility has been linked with a more sustainable UF flux (Heng and Glatz, 1991; de la Casa, 2007), it stands to reason that the bleaching treatments described above may improve membrane flux. Currently, BPO may only be added to whey for the purposes of bleaching and H_2O_2 may be used for bleaching or as an antimicrobial during electrodialysis (US FDA, 2011a,b), but neither may be used exclusively for enhancing membrane flux. However, if a processor were to treat colored whey with BPO or H_2O_2 before UF with the intent of bleaching, any flux-enhancing benefits could also be realized. No study has quantified the effects of bleaching whey or MF permeate on UF flux. Moreover, even though annatto addition is not expected to affect UF flux, no study has verified this hypothesis. The objectives of this study were to measure the effects of bleaching treatments and annatto coloring of whey and MF permeate on UF and DF flux during the production of WPC80 and SPC80 and to examine these treatments' effects on a polyethersulfone spiral-wound membrane's tendency to foul during WPC80 and SPC80 processing.

MATERIALS AND METHODS

Experimental Design

For both WPC80 and SPC80 manufacture, a 3 × 2 full factorial design was employed with 3 levels of bleaching (no bleaching treatment applied, 50 mg/kg BPO treatment, and 500 mg/kg H_2O_2 treatment) and 2 levels of coloring (no annatto and 0.066 mL of annatto/kg of milk). The experiments were replicated 3 times, resulting in 18 total processing runs for WPC80 manufacture and 18 total processing runs for SPC80 manufacture. Each individual processing run was conducted over 3 consecutive days in a week.

WPC80 Production

Cheddar Cheese Whey Manufacture. On the first day of processing, raw whole milk (about 900 kg) for Cheddar cheese production was pasteurized with a plate heat exchanger (model 080-S, AGC Engineering, Manassas, VA) at 72°C for 16 s, cooled to 4°C, and held overnight. The following day, the pasteurized milk was manufactured into Cheddar cheese and Cheddar cheese whey as described by Evans et al. (2009). For the treatments with added annatto, the colorant (Annatto cheese color - 2X, P/N 70741, Chr. Hansen Inc., Milwaukee, WI) was added to the milk (0.066 mL/kg of milk) before ripening. The curds and whey were continuously stirred at 38°C until the target whey draining pH of 6.45 was attained. The whey was drained through a sieve to remove cheese fines and immediately pasteurized using a plate heat exchanger equipped with regeneration, heating, and cooling sections (model 080-S, AGC Engineering) at 72°C for 16 s. The whey was cooled to 50°C at the exit of the pasteurizer and immediately processed with a cream separator (model 619,