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Effect of whole milk concentrate carbonation on functional, physicochemical and structural properties of the resultant spray dried powder during storage

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ABSTRACT

The effect of carbonation (1000 and 2000 ppm) on whole milk concentrate and the resultant spray dried whole milk powder (WMP) was investigated in this research. Carbonation was found to produce WMP with reduced surface fat content, dispersibility, solubility and true density, and increased occluded air content. During accelerated storage at 37 °C for 18 weeks, the surface coverage of fat on powder particles increased from 51, 29 and 8 to 94, 88 and 69% (WMP without treatment and treated with 1000 ppm and 2000 ppm CO_2 respectively) due to the release and spreading of encapsulated fat. In addition to the release of fat onto the surface, microscopy observations showed the migration of free fat into the powder particle vacuoles. Meanwhile, dispersibility and solubility of the powders decreased during storage for 18 weeks. These results suggest that carbonation may result in powders with better shelf life due to the reduced surface fat content. Improvements in functional properties was not observed, possibly due to the fine size of the powders (<15 μm) that may have masked the positive effect of carbonation.

1. Introduction

Milk powder is produced from milk concentrate to prolong its shelf life. It may be consumed as a fresh milk substitute and also used as a food ingredient. There are several types of milk powder. Among them, two common types are skim milk powder (SMP) and whole milk powder (WMP). The main difference between these powders is the fat content, in which SMP contains very little or no fat (<1.5% w/w), whereas WMP contains about 26% fat (Kim et al., 2002; Murrieta Pazos et al., 2012). The removal or presence of fat causes distinct functionality changes between SMP and WMP. It also affects their shelf life and quality, especially during storage.

The presence of fat causes WMP to undergo several changes associated with quality deterioration during storage. These include lactose crystallization, which involves puncturing of fat globule membranes and the generation of capillary interstices network that stresses and causes fat droplets disruption and eventual migration towards the surface of powder particles when fat is under a melted form (Thomas et al., 2004). Free fats are also susceptible to oxidation and produce volatile compounds, such as aldehydes, ketones and lactones, which are responsible for the development of off-flavour and off-odour in milk powders (Li et al., 2012). In addition, the presence of fats on the surface provides hydrophobic layers that cause milk powder to become less flowable and soluble in water (Bhandari, 2013; Kim et al., 2009a). Surface fat may also form weak bridges between powder particles and promote agglomeration and caking, thus reducing powder's functional properties (Kim et al., 2009a; Nijdam and Langrish, 2006; Ye et al., 2007). Additionally, lipase enzyme which is active even at low water activity (0.1–0.6), reacts with lipid and releasing free fatty acids (Thomas et al., 2004). These factors cause free fats to accumulate during storage and accelerate powder deterioration. During storage, both SMP and WMP particles may collapse and shrink due to the release of entrapped air and cause the particle volume and surface area to diminish (Thomas et al., 2004). Consequently, powder density will increase and powder rehydration properties will deteriorate because there is less contact area for water interaction and limited access for water penetration (Thomas et al., 2004).

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The addition of CO_2 in dairy products such as raw and pasteurized milks, cheese and fermented milk products has been investigated in the last decade for improvement in their shelf life, quality and yield (Hotchkiss et al., 2006). Most of these studies mainly focus on the effect of CO_2 acidification in skim milk concentrates. Few researchers have also studied its effect on the resulting powders (Marella et al., 2015). It was demonstrated that carbonation modified micellae structure and mineral contents of milk that led to improved functional properties. CO_2 addition increased milk acidity, which causes release of calcium phosphate, which in turn destabilizes and releases casein micelles (Akissi-Kouame et al., 2009; Raouche et al., 2008, 2007). This induced reorganization of micellae structure and modification of its surface activity, improves renneting properties (Akissi-Kouame et al., 2009; Guillaume et al., 2004a,2004b; Klandar et al., 2009). In addition, increased amount of soluble calcium and phosphate ions in the serum phase of milk protein concentrate (MPC) helps to produce high protein MPC powder with reduced ionic calcium content, that contributes to reduced amount of solubility loss during storage (Marella et al., 2015).

On the other hand, there has been a lack of research related to the application of CO_2 in whole milk concentrate. In fact the effect of carbonation on the functionality of WMP has never been studied before. The effect of CO_2 on fat is also poorly reported. The current commercial application of CO_2 for milk powders is modified atmosphere packaging, which is defined as the replacement of air surrounding the product at the headspace of the packaging with CO_2 or a mixture of CO_2 and N_2 gases (Hotchkiss et al., 2006; Singh et al., 2012). This method effectively improves WMP shelf life during storage mainly due to retardation of fat oxidation. However, its protective effect is terminated once the package is opened and WMP is exposed to oxygen in the atmosphere. CO_2 is more soluble in hydrophobic materials, such as lipids, because it is non-polar and has a dipole moment of zero (Arul et al., 1994; Ma and Barbano, 2003). Therefore, the presence of fat in whole milk concentrate may demonstrate different effect of CO_2 from that seen in skim milk concentrate. It is expected that CO_2 will dissolve in milk fat and provide protection against oxidation and improve functional properties and shelf life of the resulting powders.

The overall objective of this study is to investigate the effect of carbonation of whole milk concentrate, at 1000 and 2000 ppm CO_2 concentrations, towards the functional, physicochemical and structural properties of the resulting spray dried powder during an accelerated storage at 37 °C.

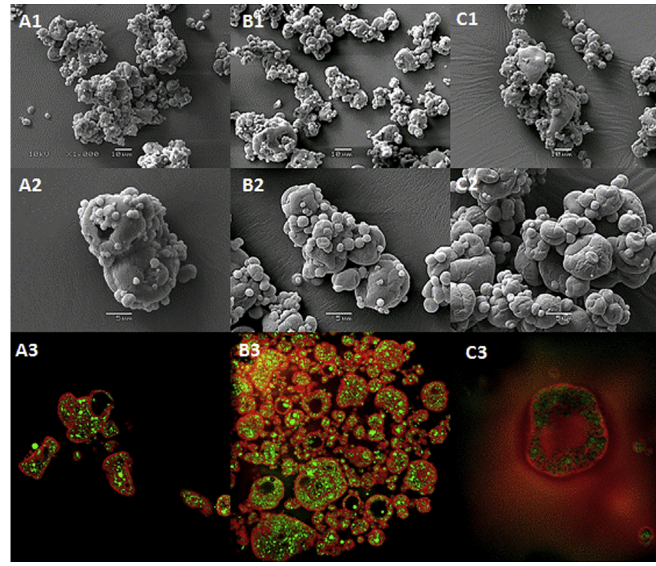

Fig. 2. Spray-dried WMP untreated with CO_2 (0 ppm) images observed by SEM and CLSM during storage. A: fresh powder; B: 6 weeks storage; C: 18 weeks storage. 1: SEM (×1000); 2: SEM (×3000); 3: CLSM with fat (green) and proteins (red) labelling (40 × 40 μm). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

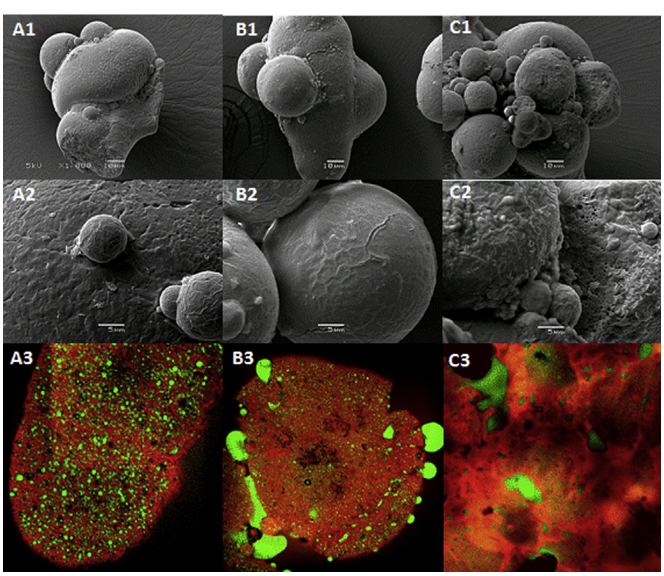

Fig. 1. Industrial powder images observed by SEM and CLSM during storage. A: fresh powder; B: 6 weeks storage; C: 18 weeks storage. 1: SEM (×1000); 2: SEM (×3000); 3: CLSM with fat (green) and proteins (red) labelling (100 × 100 μm). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

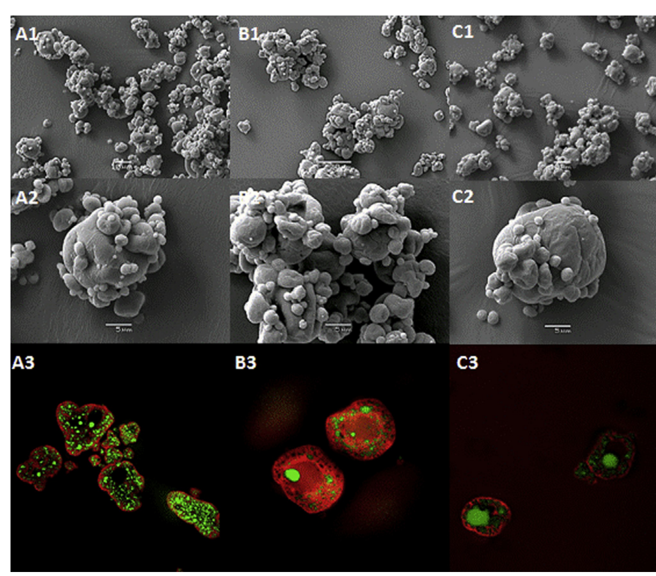

Fig. 3. Spray-dried WMP treated with CO_2 (2000 ppm) images observed by SEM and CLSM during storage. A: fresh powder; B: 6 weeks storage; C: 18 weeks storage. 1: SEM (×1000); 2: SEM (×3000); 3: CLSM with fat (green) and proteins (red) labelling (40 × 40 μm). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)