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Lactose in dairy ingredients: Effect on processing and storage stability[1]

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ABSTRACT

Lactose is the main carbohydrate in the milk of most species. It is present in virtually all dry dairy ingredients, with levels ranging from <2% (e.g., caseinates, milk protein isolates) to 100% in lactose powders. The presence of lactose has a strong effect on ingredient processing and stability. Lactose can negatively influence powder properties and lead to undesirable effects, such as the stickiness of powder resulting in fouling during drying, or caking and related phenomena during storage. In addition, being a reducing carbohydrate, lactose can also participate in the Maillard reaction with free amino groups of proteins, peptides, and free AA. In this review, the influence of the presence (or absence) of lactose on physiochemical properties of dairy ingredients is reviewed, with particular emphasis on behavior during processing and storage. Particularly important features in this respect are whether lactose is in the (glassy) amorphous phase or in the crystalline phase, which is strongly affected by precrystallization conditions (e.g., in lactose, permeate, and whey powders) and by drying conditions. Furthermore, the moisture content and water activity of the ingredients are important parameters to consider, as they determine both mobility and reactivity, influencing Maillard reactions and concomitant browning, the crystallization of amorphous lactose during storage of dairy ingredients, glass transitions temperatures, and associated stickiness and caking phenomena. For the stickiness and caking, a crucial aspect to take into account is powder particle surface composition in relation to the bulk powder. Lactose is typically underrepresented at the powder surface, as a result of which deviations between observed lactose-induced caking and stickiness temperatures, and determined glass transition temperatures arise. By considering lactose as an integral part of ingredient composition along with all other compositional and environmental properties, lactose behavior in dairy ingredients can be understood, controlled, and optimized. Routes to achieve this are outlined in this review paper.

Key words: amorphous lactose, lactose crystallization, stickiness, caking, glass transition

INTRODUCTION

In the milk of most common dairying species, lactose (β-D-galactopyranosyl-(1→4)-D-glucose) is the most abundant constituent after water. In addition to being unique to milk, lactose is also the main carbohydrate in the milk of virtually all mammalian species. Smaller amounts of mono- and oligosaccharides may also be present in the milk of most species, with particularly the latter having a crucial nutritional role. From a technological perspective, lactose is the most important carbohydrate in milk and its behavior can have a strong effect on a variety of dairy products. For instance, it is crucial in the fermentation by lactic acid bacteria in the preparation of yogurt and many other acid-coagulated dairy products, as well as in many cheese varieties (Walstra et al., 2005). Furthermore, lactose can be isolated and subsequently applied in a wide range of dairy and nondairy food products, as well as in nonfood products (Holsinger, 1997). Lactose is used as the source material for several lactose derivatives, including galacto-oligosacchrides, lactulose, lactitol, and lactobionic acid (Gänzle et al., 2008). Furthermore, because lactose is a reducing carbohydrate, it can participate in the Maillard reaction, which can occur in heated dairy products, particularly when heated at sterilization conditions (Walstra et al., 2005).

A further category of dairy products in which lactose plays a key role is in dairy ingredients. In virtually all dairy ingredients, lactose is present, ranging from either large concentrations (e.g., lactose, permeate, and whey powders) to low concentrations or even trace levels (e.g., caseinate, whey protein isolate, milk protein isolate). Particularly in ingredients where lactose constitutes more than 50% of DM (e.g., skim milk powder, whey powder, permeate powder), lactose has a strong effect on the behavior and properties of the ingredients during processing and storage. Particularly notable effects are on the powder handling properties such as stickiness and caking behavior of powder particles during drying

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and during storage, particularly at elevated temperature and water activity ($\mathbf{A_w}$; Kelly, 2009). Because caking and stickiness of ingredients can present big issues for the dairy industry, considerable effort has been dedicated to understanding these phenomena (O'Callaghan and Hogan, 2013). With increased understanding of the underlying mechanisms of stickiness and caking of powder particles, the realization has grown that control of the behavior of lactose in dairy ingredient powders containing high levels of lactose, as well as in products containing high levels of lactose (e.g., infant formula) is required to ensure desired powder handling properties and powder stability.

In this review, we will focus on the behavior of lactose in dry dairy ingredients and the effect thereof on powder handling properties and powder stability. Particular emphasis will be paid to the aforementioned lactose-rich dairy products (e.g., milk powder, whey powder, and permeate powder). Pure lactose powder is largely outside the scope of this review but is dealt with extensively by Paterson (2009) and Wong and Hartel (2014). To place the behavior of lactose in relation to the properties of these industrially relevant powders, the effect of concentration and drying will be considered. Particular focus will be paid to the state of lactose (i.e., amorphous, crystalline, or both) in dairy ingredients and factors determining it, the distribution of lactose between the surface and the bulk of the powder, and how these factors affect powder handling properties and browning in powders.

PHYSICAL AND CHEMICAL PROPERTIES OF LACTOSE IN SOLUTION

All dried dairy ingredients are produced from liquid dairy streams. This may be (standardized) milk or whey from the manufacture of cheese, Greek-style yogurt, or acid casein. In addition, lactose-rich dairy ingredients can be prepared from ultrafiltration permeates of milk or whey. Hence, before considering the influence of lactose on handling and storage properties of dried dairy ingredients, it is important to first consider the properties of lactose in solution, and how these are affected by the presence of proteins and salts.

Mutarotation

One important property of lactose to consider is that 2 anomers of lactose are observed (i.e., α-lactose and β-lactose), which have specific optical rotations $[\alpha]^{20}_{D}$ of +89.4 and +35°, respectively (Walstra and Jenness, 1984; Holsinger, 1997). The conversion between these forms of lactose occurs via the open chain form of the glucose moiety of lactose. An equilibrium will establish at $[\alpha]^{20}_{D} = +55.3°$, representing ~37% α-lactose and 63% β-lactose (Walstra and Jenness, 1984; Holsinger, 1997). This equilibrium is dependent on both lactose concentration and temperature, with increases in both these parameters shifting the equilibrium optical rotation to lower values (i.e., to somewhat a higher percentage of β-lactose). The pH does not affect the equilibrium value. Hence, at typical conditions encountered in the dairy industry, lactose in solution should be considered a mixture of α- and β-lactose.

Although it does not affect the mutarotation equilibrium, pH does strongly affect the rate at which the equilibrium establishes; the minimum in mutarotation rate is found at pH 5, and particularly $pH < 2$ and $pH > 7$ result in very rapid mutarotation (Walstra and Jenness, 1984; Holsinger, 1997). The rate of mutarotation also increases rapidly with increasing temperature [i.e., ~2.8-fold for every 10°C temperature increase (Walstra and Jenness, 1984)]. Hence, whereas it may take hours for equilibrium to establish at room temperature, this only takes minutes or less at temperatures >70°C. In addition, mutarotation rate of lactose is strongly enhanced by the presence of milk salts. Mutarotation rate was found to be 1.8- and 2.2-fold higher in a simulated milk ultrafiltrate compared with water for α-lactose and β-lactose, respectively (Haase and Nickerson, 1966).

Solubility

One aspect that is strongly affected by the different anomers of lactose is solubility, which is rather low compared with many other mono- and disaccharides. Lactose solubility can be described by the function $C_{LAC} = 10.9109 \times e^{0.02804T}$, where C_{LAC} is the concentration of lactose in grams per 100 g of water and T is the temperature in °C (Butler, 1998; Paterson, 2009). From this equation, it follows that at 20°C, solubility of lactose is ~20 g of anhydrous lactose per 100 g of water, which increases to ~30, 60, or 100 g lactose per 100 g of water at 40, 60, or 80°C, respectively.

When dissolving lactose, the rate of dissolution depends strongly on the type used. α-Lactose has a lower solubility in water, so when an overdose of α-lactose is added to water, the initial solubility will be at the solubility limit of α-lactose in water; subsequently, however, some α-lactose will be converted to β-lactose, and as a result the solution becomes unsaturated again and more α-lactose can dissolve. This process will continue until the final equilibrium between α-lactose and β-lactose is achieved. The solubility of α-lactose increases strongly with temperature, whereas that of β-lactose shows considerably less temperature dependence (Hodges et al., 1993; Lowe and Paterson, 1998; Walstra et al., 2005; Paterson, 2009). When lactose solutions are con-