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PHYSICO- CHEMICAL AND TECHNO- FUNCTIONAL ATTRIBUTES OF DAIRY POWDERS

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ABSTRACT

Newer milk powder and milk-based powder types are being developed and are looking for potential end customers. Milk is highly perishable. The shelf life of milk is increased by using different heat treatments like pasteurization and ultra high temperature (UHT). Apart from that, the shelf life of milk is increased by converting it into various products through heat desiccation, heat and acid coagulation, fermentation, phase inversion and frozen procedures. Converting milk to milk powder extends its shelf life. Milk powder offers greater convenience for both manufacturers and consumers in terms of packing, handling, storage, transportation costs and ease of preparation. Powder is used in a wide range of applications because of its physicochemical and techno-functional properties. Physical and chemical criteria are commonly used to ensure the quality of milk powder. The physical quality and functional properties of the powder are affected by how it is handled during manufacture (flowability), shipping (bulk density) and by the consumer (wettability). Physico- chemical reactions associated with the components cause lactose crystallization, maillard reaction and fat oxidation. These changes affect the techno- functional properties of milk powders. In this review, some of the physicochemical and techno- functional attributes of milk powder and milk-based powders are discussed.

Keywords: Milk Powder, Functional Properties, Physical Properties, Chemical Properties.

I. INTRODUCTION

Milk is acknowledged as an ideal food with a special property for human nutrition and it has the disadvantage of being highly perishable because it supports the luxuriant growth of microbes. Microbial contamination may also come from a variety of sources in that Salmonella sp., Listeria monocytogenes, Yersinia enterocolitica, Campylobacter jejuni, Staphylococcus aureus, Escherichia coli and other pathogenic microbes commonly found in milk and many food borne disorders are caused by these bacteria [1]. Shelf life of milk is increased by using different heat treatments like pasteurization and ultra high temperature (UHT). Apart from that, the shelf life of milk is increased by converting it into various products through heat desiccation, heat and acid coagulation, fermentation, phase inversion and frozen procedures. Milk converts to milk powder through heat desiccation and it is used in a wide range of applications due to its physico- chemical and techno- functional properties. Some of the properties like powder structure, solubility, water content, scorched particles, fowability, oxidative changes, flavour and colour are the basic attributes that determine the quality of milk powder and where defects are most prone to occur. Physical processes and chemical reactions associated with the components (lactose, fat and protein) such as lactose crystallisation, fat oxidation and the Maillard reaction, limit the shelf life of milk powder. These changes have a negative impact on milk powder's physical and techno- functional properties, as well as their nutritional and sensory values [2].

II. PHYSICOCHEMICAL PROPERTIES OF MILK POWDERS

1. Moisture:

Moisture content is a quantitative term that refers to the overall amount of water in a food component and it is expressed as a weighted percentage. Milk powder and milk-based powders should maintain a moisture content of below 5% in the final products. Moisture content in the powders is mainly influenced by the temperature used during drying. Selecting appropriate inputs is critical for achieving the optimum moisture content in the end product. 1 % increase in powder moisture is obtained by a 5 ºC decrease in outlet temperature or a 50 ºC increase in input temperature at a constant outlet temperature, while the particulate temperature remains nearly unchanged [3]. Moisture content increased from 4.5 to 5.1 % as outlet temperature decreased from 87 ± 3 to 82 ± 2 ºC. Modification of outlet air temperature (77 ± 2 to 87 ± 3 ºC) by varying inlet air temperature (178

± 1 to 210 ºC) and concentrate flow rate (97 ± 5 to 110 ± 5 kg/h) did not affect the moisture content (4.9 to 5.2 %). The moisture content of skim milk powder increased from 5.1 to 5.6 % as relative humidity of outlet air increased from 7.0 to 9.0 %. Relative humidity of outlet air affects the moisture content in the skim milk powder. In order to modify the relative humidity of the outlet air as well as the water activity and moisture content of the skim milk powders, the spray-drying parameters (absolute humidity of inlet air, inlet and outlet air temperatures and concentrate mass flow rate) were adjusted [4]. Whole milk powder produced at inlet air temperatures 165 ºC, 175 ºC and 185 ºC, outlet temperature 83.7 ± 0.1 ºC, 91.8 ± 1.9 ºC and 93.8 ± 0.8 ºC followed by relative humidity 13.1 ± 0.1 %, 9.7 ± 0.8 % and 9.6 ± 0.4 % has moisture content of 4.33 ± 0.04 %, 3.11 ± 0.20 % and 2.99 ± 0.02 %, respectively. Inlet air temperature had a greater impact on the temperature of the output air and the moisture content of the powder. The efficiency of heat and mass transmission, as well as the temperature of the output air increases as the temperature of the inlet air increases. It produced a greater driving force for moisture evaporation, resulting in low-moisture powder [5]. Increasing the inlet air temperature from 180-200 ºC and outlet air temperature from 80 – 90 ºC, there was an increase in the moisture content of the infant milk formula powder (2.14 ± 0.04 to 2.46 ± 0.05 % at 80 ºC and 0.83 ± 0.03 to 1.28 ± 0.05 at 90 ºC). The higher the outlet air temperature from 80-100 ºC at 180 ºC inlet air temperature shown final moisture content was 2.14 ± 0.04 to 0.34 ± 0.07 %. The final moisture content of the powder is controlled by the inlet and outlet air temperature could be due to the at higher inlet air temperature, evaporation of moisture occurs very rapidly and promotes the formation of crust or skin on particle surface which prevents the further moisture evaporation [6].

2. Fat:

The most important source of flavour and off-flavour components in milk powders is probably milk fat. It influences the behaviour of powder during reconstitution and contributes to the dangers that can occur during powder drying. The most frequent cause of fire and explosions in milk powder plants is auto-oxidation of fat during the drying of milk, which can induce self-ignition of dry milk deposits in the dryer. At an exit air temperature of 80–90 ºC, fat-filled powders oxidise rapidly; the rate of oxidation at a given temperature increases with the degree of unsaturation. Fat content in Goat, Cow and Camel milk powder was 33.28±0.05%, 31.57±0.04% and 29.28±0.03% [7]. The fat content in medium fat liquid dairy whitener and full fat liquid dairy whitener was about 2.9 % and 6.6 % as compared to market powdered dairy whitener samples A and B, which contained 19 % and 20 % [8]. Milk fat levels in the UF dairy whitener were 20.16±0.29 % as compared to market dairy whitener samples A and B, which contained 20 % and 19 %, respectively [9]. Fat content in full cream milk powder available in Sri Lankan market was ranges from 23.23±0.18 % to 26.80±0.69 % [10].

3. Protein:

Milk main functional components are proteins. Protein functional qualities are defined as aside from nutrition, those influence their suitability for use in food items. Intrinsic qualities, or structural properties such as size, charge and surface hydrophobicity, affect the functional properties of proteins. Many extrinsic or environmental factors, such as pH, ionic strength and temperature, as well as interactions between proteins and other materials in the food system, affect these intrinsic properties. Whitening power derives mostly from a colloidal protein. Furthermore, milk protein leads to other significant dairy whitener quality characteristics such as feathering, mouthfeel and other organoleptic propertie. Protein content in Goat, Cow and Camel milk powder was 24.84±1.03%, 22.44±1.03% and 20.85±0.03% [7]. The protein content in medium fat liquid dairy whitener and full fat liquid dairy whitener was about 10.89 % and 37.85 % as compared to market powdered dairy whitener samples A and B, which contained 20.5 % and 20 % [8]. Milk protein level in the UF dairy whitener was 40.07 ± 0.66 % as compared to market dairy whitener samples A and B, which contained 20 % and 20.5 % respectively [9]. Protein content in full cream milk powder available in Sri Lankan market ranged from 23.44±0.57% to 25.29±3.15% [10].

4. Lactose:

Lactose can be seen in a crystalline or amorphous glassy condition in the solid state. An amorphous state of lactose is developed when milk is rapidly dehydrated during spray drying, which prevents the crystallisation. Hygroscopic amorphous lactose has a small quantity of water bonded to its irregular structure. The fat globules and proteins in milk powders are enclosed in amorphous lactose. Spray drying the amorphous lactose causes deposits on the drying chamber walls, resulting in product losses. Amorphous lactose, on the other hand, can soften and form lactose crystals above the glass transition temperature. Tg is thus influenced by the amount of water in the powder and its water content. Lactose can transition from its amorphous to crystalline state when exposed to high humidity or high temperatures. This phenomenon has been observed in the storage of milk powder. Lactose content in Goat, Cow and Camel milk powder was 28.97±0.02%, 33.79±0.05% and 33.52±0.04% [7]. Lactose content in full fat liquid dairy whitener was 4.055% [8]. The lactose content in dairy whitener was 37 % and UF dairy whitener was 13 % [9]. Lactose content in full cream milk powder available in Sri Lankan market was ranges from 41.48±2.70 to 47±2.38 % [10].

5. Scorched particles:

Burnt particles are widely accepted as a measurement for any deposits in the drying chamber that have been scorched, discoloured and become insoluble as a result of exposure to high temperatures. However, it is not simply the dryer that adds to the burned particles; raw milk may have some dirt or silt that will be detected in the powder if not purified in a separator. If deposits have accumulated in the tubes due to poor tube coverage or cleaning, brown, insoluble jelly lumps from the evaporator may also contribute to the burned particles. WMP was stored at room temperature or 15 ºC for 18 months, scorched particle content did not exceed disc A [11]. Scorched particles in skim milk powder weighed 17 ±2.43 mg, which was much higher than those found in half cream milk powder (mean 10.5 ±1.22 mg) or full cream milk powder (9.75 ±1.14 mg). Skimmed milk powder satisfies the standard grade of spray dried milk and/or the extra grade of roller dried milk powder requirements of 17 ±2.43 mg (Disc C- 22.5mg) [12].

6. Particle size:

A powder's particle size distribution is a measurement of the average particle diameter and the range of sizes on each side of it. Smaller particle size distribution and mean particle size are merely suggestive features, and no specific standards are required as long as the functional properties meet the requirements. The drying system, speed of rotation or pressure applied, feed rate of concentrate, velocity of concentrate through orifice, temperature difference between the drying droplet and the hot air in the dryer are all factors that affect particle size. The particle size in the UF dairy whitener was 74.93 µm as compared to market dairy whitener samples A and B, which contained 91.56 ± 18.68 µm and 98.48 ± 14.21 µm, respectively. The UF retentate dairy whitener particle size was less compared to market samples, which could be due to low feed concentration and no agglomeration [9]. The average particle size of skim and whole milk powders was 83.87 µ and 128.76 µ [13]. Spray-dried skim milk powders had particle sizes ranging from 14 to 20 micrometres [14].

7. Water activity

Water is one of the most crucial components influencing the rate at which food deteriorates, whether due to microbial or non-microbial factors. Water activity (a_w) is used in food preservation, food supply stabilisation and the development of various shelf-stable foods. Foods that are dried or low-moisture have less than 25% moisture. Lower water activity in foods inhibits the growth of vegetative microbial cells, spore germination and mould and bacterium toxin production. Microorganism's lag phase extends when water activity diminishes and slowing their development rate. Dehydration, crystallisation and the addition of solutes are three common strategies for lowering water activity. Water activity of skim milk powder increased from 0.23 to 0.27 with a decreasing outlet temperature from 87 ± 3 to 82 ± 2 ºC. The water activity of skim milk powder increased from 0.28 to 0.33 as the relative humidity of the outlet air increased from 7.0 to 9.0 %. The relative humidity of outlet air affects the water activity content in the skim milk powder [4]. Water activity of local and imported whole milk powders available in the Sri Lankan market ranged from 0.30 to 0.39 [15]. The final water activity of the powder was controlled by the outlet air temperature; the higher the outlet air temperature from 80-100 ºC at 180 ºC inlet air temperature, the lower the final water activity was 0.19 ± 0.01 to 0.05 ± 0.00 [16].

III. FUNCTIONAL PROPERTIES OF MILK POWDERS

1. Wettability

Wettability refers to a powder's ability to be wet and absorb water at a specific temperature and large, porous particles favour fast wetting. Instant SMP is defined as one that is wet in less than 15 sec and WMP is defined as one that is wet in 30 to 60 sec [17]. At 20 °C, wettability of skim agglomerated milk powder had the lowest wettability time of about 19 sec as compared to instant whole milk powder, instant coffee whitener "Cremilka," and coffee powder, which were 45 sec, 47 sec and 17 sec, respectively and this variation in wettability among powders could be due to the presence of free fat on the surface of particles [18]. Wettability of UF dairy whitener was higher for about 19.50 min as compared to market dairy whitener samples A and B, which were 8.20 min and 5.35 min, respectively and this could be due to the presence of higher protein content, fat content and lower total carbohydrate content [9].

2. Sinkability

Sinkability is caused by the fact that, after completion of wetting of powder particles, they begin to dissolve, disperse and sink into the water. Milk powder agglomeration increases sinkability due to the larger aggregate density especially for skim milk powder. Whole milk powder has low sinkability because of its high fat content. Goat milk powder produced at 140 ºC has a high sinkability (0.46 transmittance at 760 nm wavelength) as compared to milk powder produced at 180 ºC (0.20 transmittance at 760 nm wavelength) and at 200 ºC (0.22 transmittance at 760 nm wavelength), which could be due to the higher bulk density of powder and low amount of fat content resulting in less surface hydrophobic characteristics [19].

3. Dispersibility

The ability of wetted, aggregated particles to become equally dispersed when exposed to water is referred to as dispersibility. The instant coffee whitener "Cremilka" had the highest degree of dispersibility (95.6 %), followed by skim agglomerated milk powder (94.5 %) and instant whole milk powder (92.3 %) [18]. Dispersibility of skim milk powder at 24 ºC was higher (21.30 ± 1.40 and 19.30 ± 1.32 sec, respectively) as compared to dispersibility at 40 ºC (13.80 ± 0.99 and 11.80 ±0.98 sec, respectively) and at 60 ºC (9.90 ± 0.99 and 8.20 ± 0.87 sec, respectively) [12].

4. Solubility

Solubility is a key characteristic for milk powder. Processing challenges and economic losses can be caused by poorly soluble powder. Solubility index of instant whole milk powder, coffee whitener and skim agglomerated milk powders are recorded below 0.05 ml [18]. Solubility index of UF dairy whitener was 0.25 ml as compared to market dairy whitener samples A and B, which contained 0.30 ml and 0.20 ml, respectively [9]. Solubility of skim dromedary milk powder obtained at 85 °C air outlet temperature was much greater (95.26 ± 0.87 %) than that of the identical formulation spray-dried at 75 °C air outlet temperature (91.95 ± 0.36 %) and cow skim milk powder produced at 85 ºC (78.31 ± 2.64 %) was lower than the identical formulation spray dried at 75 ºC (88.00 ± 0.36 %). Solubility index of skim dromedary milk powder was higher at both air outlet temperatures compared to cow milk powder, which could be due to the sensitivity of cow' s proteins to thermal denaturation [14].

5. Foam capacity and stability

The principal macromolecular surfactants found in milk are caseins and whey proteins, which adsorb at the air-serum interface of milk foam. The stability of steam – frothed milk is mainly dependent on the state of proteins present in the milk. Skim milk foam (25 %) and foam enriched with higher amounts of whey protein concentrate (15%) had the best overall foaming qualities (459 and 534 % foaming capacity). Although foams fortified with a higher concentration of sodium-caseinate (5 %) had the best foaming capacity (1422 %) but their stability was inferior. Skim milk powder and whey protein concentrates are perfect for foam generation because they have strong foaming properties and stability [20]. The reconstituted camel milk powder showed the highest foaming properties with 78.33 ± 2.63 % and 480 ± 60 sec for foam capacity (FC) and stability (FS), respectively. The skimmed camel milk before drying showed an FC and FS of 68.33 ± 2.88 % and 253 ± 50 sec, respectively. Reconstituted bovine milk of FC and FS had 72.33 ± 3.05 % and 330 ± 36 sec, respectively and these values were significantly higher than those observed for skimmed bovine milk, which was 57.0 ± 2.63 % and 210 ± 30 sec for FC and FS, respectively [21].

6. Emulsification capacity and stability

Emulsification is defined as the ability to keep two immiscible liquids in a stable solution and emulsion stability is determined by heating and centrifuging. Protein in the oil–water interface reduces the interfacial tension in emulsions significantly. The protein-rich interfacial layer acts as an electrostatic, structural and mechanical energy barrier, which prevents instability. Succinylation of NaCas (96 % succinylation) led to significant increase in emulsion activity and stability of about 100 % and 98.2 % as compared to NaCas reported values of 99.8 % and 99.2 % could be due to increased solubility and structural flexibility of modified protein and these changes facilitate the diffusion of protein at the oil – water interface [22].

7. Water binding capacity

Water holding capacity is an important protein-water interaction i various food systems. It refers to a protein matrix's ability to absorb and hold binding, hydrodynamic, capillary and physically entrapped water or oil in the presence of gravity. [23] evaluated the physicochemical, functional and rheological properties of milk protein concentrate 60 powders and reported that water binding capacity of cow milk protein concentrate 60 powder was 5.22 g/ g of protein. Water binding capacity of MPC 60 powder was low which could be due to the high bulk density. [24] evaluated the physicochemical, functional and reconstitution properties and reported that oil binding capacity of buffalo milk protein concentrate 60 powder was 5.49 ±0.05 g/ g of protein. Water binding capacity of MPC 60 powder was low which could be due to the low bulk density.

8. Oil binding capacity

The texture and other sensory qualities of food are influenced by fat binding or entrapment in a food matrix. As a result, proteins ability to absorb and store fat in food formulations as well as interact with it in emulsions and other food systems is essential. Proteins having lower water solubility usually have a better fat binding ability. Protein rich powders with a low density and small particle size absorb and entrap more oil than protein powders with a high density and large particle size. [23] evaluated the physicochemical, functional and rheological properties of cow milk protein concentrate 60 powders and reported that oil binding capacity of cow milk protein concentrate 60 powder was 3.38 g/ g of protein. Oil binding capacity of MPC 60 powder was low which could be due to the high bulk density. [24] evaluated the physicochemical, functional and reconstitution properties and reported that oil binding capacity of buffalo milk protein concentrate 60 powder was 5.18 ±0.05 g/ g of protein. Oil binding capacity of MPC 60 powder was low which could be due to the low bulk density.

9. Flowability

Powder flow characteristics are a major issue in the industry. Powder flow parameters were determined by using the Carr index and Hausner ratio. The Hausner ratio defines the powder's cohesiveness, while the Carr index determines its compressibility or free-flowing quality. Materials with a greater than 1.34 Hausner ratio are considered cohesive and consequently less free to flow. Non-free-flowing powders have a Carr index of more than 25% [25]. Hausner ratio and Carr index of skim milk powder and whole milk powder were 1.37±0.04, 1.39±0.02 and 26.71±2.16, 28.13±0.75, respectively [26]. Camel milk powder produced by spray drying has a low Hausner ratio of about 1.21-1.37 compared to freeze dried milk powder ranging from 1.15-1.31 because of particle shape (rough shape and voluminous particles) [27].

10. Coffee stability

Dairy powders as whiteners or creamers have found a vital role in coffee. Popular coffee additives are dried milk concentrates, evaporated milk, coffee cream, liquid milk and coffee whiteners. Milk proteins react with tannins in coffee and provide a pleasant, slightly creamy flavour. Instant coffee whitener "Cremilka" and evaporated UHT milk showed satisfactory stability but these products only at extreme conditions regarding both temperature 90 ºC and coffee infusion 5 g/ 100 ml strength resulted in a considerable increase in the amount of residues from 0.15–0.40 ml of residues [18].

11. Bulk density:

The weight of a volume unit of powder, given in g/cm^3 or g/ml, is referred to as bulk density. In order to save shipping and packing expenses, producers attempt to transport vast quantities of their products in small containers. Instant powders have a low bulk density, which is modified by agglomeration. Adjusting the amount of occluded air can help control bulk density because as particle volume increases, particle density and bulk density decrease. Bulk density of nonfat dry milk varies from 0.18 to 1.25 g ml^{-1}. Roller-dried nonfat dry milk is 0.30–0.50 g ml^{-1}, while regular spray-dried nonfat dry milk was 0.50–0.60 g ml^{-1} [28]. Loose density of the skim and whole milk powders was between 407 and 666 kg/m^3. The loose density of skim milk powders was much higher than that of whole milk powders, with an average of 541.36 and 449.75 kg/m^3, respectively [13]. The loose bulk density and tapped bulk density of UF dairy whitener were 0.27 g/ml and 0.37 g/cc, respectively, when compared to market dairy whitener samples A and sample B, which were 0.40 g/ml, 0.61 g/cc and 0.48 g/ml, 0.68 g/cc, respectively [9].

IV. CONCLUSION

Converting milk to milk powder through heat desiccation extends its shelf life and allows it to be stored for longer periods of time without losing quality, even at room temperature. Physical and chemical criteria are commonly used to ensure the quality of milk powder. People are currently interested in purchasing instant powders because they offer greater convenience for both manufacturers and consumers in terms of packing, handling, storage, transportation costs and ease of preparation because of its functional properties. These physio- chemical and functional properties are affected by variety of factors including raw milk quality, drying procedures and storage temperature and time can able to reduce the quality of milk powder. Functional properties were mainly depends on the physicochemical characteristics of components present in the milk powder. Free fat present in high fat milk powder might be released during storage period caused decreasing wettability of milk powder. Solubility of milk powder is declined with increasing storage period. Moisture content is mainly affected by relative humidity during storage period. Moisture content is increased during longer storage period causes caking of powder. So, physicochemical properties were important for maintaining functional properties of milk powder thought out storage time.

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