7 Packaging and the Shelf Life of Milk Powders

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7.1 MILK POWDER

7.1.1 Introduction

The use of milk powders for recombination and manufacturing of various food products has increased in recent years, placing greater importance on the definition of the functional properties of powders. The functionality, particularly the reconstitution properties, of milk powders can be highly variable and occasionally unpredictable. Spray-dried dairy powders are common ingredients in many food and dairy products. The nutritional quality of dairy powders depends on the intensity of the various thermal treatments during processing.

Lipid oxidation in whole milk powders (WMPs) is a major cause of deterioration during processing and storage. Light-induced degradation reactions in milk create a serious problem for the dairy industry, through the development of off-flavors, leading to the formation of volatile secondary oxidation products. Lipid oxidation has received much attention because of its undesirable implications for human health and its contribution to a decrease in the nutritional value of foods. Many factors can influence lipid oxidation in milk powder, such as water activity, temperature, O_2, and light.

7.1.2 Manufacture

Drying means that the water in a liquid product—in this case milk—is removed, so that the product acquires a solid form. The water content of milk powder ranges between 2.5% and 5%, and no microbial growth occurs at such a low water content. Drying extends the shelf life of the milk, simultaneously reducing its weight and volume. This reduces the cost of transporting and storing the product (Bylund, 2003). Preheating conditions are used to a large extent to control the functional properties of the powder. A number of changes occur in milk during preheating: whey protein denaturation, association of denatured whey proteins with the casein micelle, transfer of soluble calcium and phosphate to the colloidal phase, destruction of bacteria, and inactivation of enzymes (Singh and Newstead, 1992).

The manufacture of milk powder involves a series of continuous or semicontinuous steps, such as milk standardization, thermal treatment, evaporation, spray drying, and fluidized bed drying, each of which has associated process variables that affect the efficiency of the process and the quality of the product (O'Callaghan and Cunningham, 2005).

The manufacturing process for skim milk powder (SMP) involves heating the skim milk (known as preheating), concentrating the skim milk solids by evaporation to 45–50% total solids, heating the skim milk concentrate, and then spray-drying the milk concentrate to produce a powder (Oldfield et al., 2005). Depending on the intensity of the heat treatment, milk powder is classified into categories related to the temperature–time combinations the skim milk has been exposed to prior to evaporation and drying. High temperature denatures whey proteins, the percentage denatured increasing with the intensity of the heat treatment. The degree of denaturation is normally expressed by the whey protein nitrogen index (WPNI) as milligrams of undenatured whey protein (u.w-p) per gram of powder. SMP is classified into the following three types based on the WPNI, which is correlated to the spray-drying conditions: low-heat powder (70°C/15 sec, WPNI >6.0 mg g^{-1} u.w-p), medium-heat powder (85°C/20 sec, WPNI 5–6.0 mg g^{-1} u.w-p), and high-heat (~135°C/30 sec, WPNI <1.4 0 mg g^{-1} u.w-p) (Bylund, 2003).

In the manufacture of WMP, milk is subjected to a range of processes such as agitation, pumping, heating, concentration, homogenization, and spray drying. These processing treatments cause a number of physical and chemical interactions of the milk components (Ye et al., 2007).

7.1.3 Spray Drying

Spray drying is the most common method of dehydrating milk and milk products. It involves rapid removal of moisture, leading to the formation of amorphous lactose, which forms a continuous matrix in which proteins, fat globules, and air cells disperse (Shrestha et al., 2007). Spray-drying technology in combination with other unit processes plays an important role in responding to market demands for powders with a wide range of functional properties (Kelly et al., 2002). Spray-drying technology involves the transformation of the milk emulsion into a great number of small droplets that are exposed to a fast current of hot air as they fall into the spray chamber. As water is evaporated from the droplets they become powder particles (Birchal et al., 2005).

7.1.4 Properties of Spray-Dried Milk Powders

The quality of food powders is based on a variety of properties, depending on the specific application. In general, the final moisture content, insolubility index, dispersability index, free fat, rheological properties, and bulk density are of primary importance (Straatsma et al., 1999a). These characteristics depend on drying parameters (type of spray dryers, nozzles/wheels, pressure, agglomeration, and thermodynamic conditions of the air: temperature, relative humidity, and velocity) and characteristics of the concentrate before drying (composition/physicochemical characteristics, viscosity, thermosensibility, and availability of water) (Schuck, 2002).

The insolubility index is of primary importance for the quality of instant powders. Insoluble material is formed during spray drying of concentrated milk. The actual amount depends on the temperature and moisture content during the drying period (Straatsma et al., 1999b). An important quality attribute of milk powder is the bulk density. It is obviously of considerable interest from an economic point of view because it influences the cost of storage, packaging, and transport (Robertson, 2006).

7.2 FOOD QUALITY ATTRIBUTES OF MILK POWDERS

7.2.1 Whole Milk Powder

WMP consists mainly of whey proteins (almost 4%), caseins (almost 20%), milk fat (almost 26%), and lactose (almost 38%). The particles of milk powder consist of a continuous mass of amorphous lactose and other low-molar-mass components in which fat globules and proteins are embedded (Walstra et al., 1999). The physical processes, involving mainly milk fat and lactose, together with chemical reactions, have the ability to reduce the shelf life of WMP and other dry products based on milk powder. These other products include infant formula and instant powders for coffee, cocoa, and chocolate-flavored beverages. Long-term storage of milk powder affects the nutritive value, mainly due to loss of lysine, and the sensory qualities of the reconstituted milk, as well as the functional and physical properties that are so important for the use of milk powder as a food ingredient (Thomas et al., 2004). In coffee whitener applications, WMP must contribute adequate whitening ability and stability to the relatively low-pH and high-temperature conditions inherent in coffee solution (Oldfield et al., 2000).

Milk powder quality is influenced by various factors during processing or storage:

1. Manufacturing techniques and parameters
2. Drying techniques and conditions
3. Storage conditions

Three deteriorative reactions determine the shelf life of milk powder in practice: lactose crystallization, lipid oxidation, and Maillard reactions (nonenzymic browning) (Carić, 1994).

The basic properties that determine milk powder quality, and where defects mainly appear, include powder structure, solubility, water content, scorched particles, flowability, oxidative changes, flavor, and color (Carić, 1994; Schuck et al., 2007). Hence, milk powder quality should be quantified by the relationship between the operational process variables that best describe these properties (Birchal et al., 2005).

7.2.2 Low-Fat Milk Powder or Skim Milk Powder

Low-fat milk powder or SMP is produced as a result of the removal of milk fat and water from milk. It contains a maximum of 1.5% fat and a maximum moisture content of 5% (Clark, 1992). The quality of this product is determined by the total heat treatment (i.e., temperature and time of all operations in processing). Most of the properties mentioned (solubility, water content, flavor, color, and others) are strongly affected by the intensity of the applied heat treatment. The storage time and the temperature influence the entire quality of the powder. SMP has low bulk density; an increase in bulk density is accompanied by a corresponding improvement in other quality characteristics such as wetting, sinking, and dispersing abilities (Carić, 1994).

7.3 DETERIORATIVE REACTIONS AND INDICES OF FAILURE

7.3.1 Cohesion/Flowability

Powder deposition on processing equipment is a problem in the dairy industry, particularly in the spray-drying process, and results in economic disadvantages. Cohesion increases with a reduction in particle size; fat also plays an important part in the observed trend toward higher cohesion with increasing temperature. More surface area is available for cohesive forces, in particular, and frictional forces to resist flow (Fitzpatrick et al., 2004). Melting of fat is likely to cause the major increase in cohesion, but there are several possible mechanisms. The liquid fat may have formed bridges between the particles, which increases the bonding strength. Alternatively, fat liquefaction could have softened the powder, resulting in deformation of the powder particles, which would have increased the contact area between the particles, thus enhancing already present attractive forces (Rennie et al., 1999). During processing, the behavior of powders is strongly influenced by particle properties as well as the design and operating conditions of the equipment. The flowability of powders in such equipment is an important issue as it can strongly influence the efficiency and reliable operation of these processes (Moreno-Atanasio et al., 2005). Intuitively, one would expect particle shape to affect flowability, as shape will influence the surface contacts between particles; however, there is not much reported work on the influence of shape on powder flowability (Fitzpatrick et al., 2004).

7.3.2 Caking

Several properties of powders with amorphous lactose can be related to its glass transition temperature T_g. These include surface stickiness and caking, time-dependent lactose crystallization and release of encapsulated lipids, and increasing rates of nonenzymic browning and lipid oxidation. When an amorphous component is given suitable conditions of temperature and water content, powder can mobilize as a high-viscosity flow, which can make it sticky and lead to caking (Fitzpatrick et al., 2007). The changes in mechanical properties and diffusion are responsible for stickiness, caking, and lactose crystallization. Caking is a deleterious phenomenon by which a low-moisture, free-flowing powder is first transformed into lumps, then into an agglomerated solid, and ultimately into a sticky material, resulting in loss of functionality and lowered quality (Aguilera et al., 1995). Amorphous lactose is generally present in high-fat powders and can contribute to flowability problems. However, these problems also arise under conditions [a_w (water activity) and powder temperature] where the amorphous lactose is stable (Foster et al., 2005a). This indicates that milk fat also contributes to caking (McKenna, 1997; Peleg, 1977). The changes in the reaction rates are more complex and are affected by other factors, including pH, heterogeneities in water distribution, and miscibility of proteins and carbohydrates (Roos, 2002).

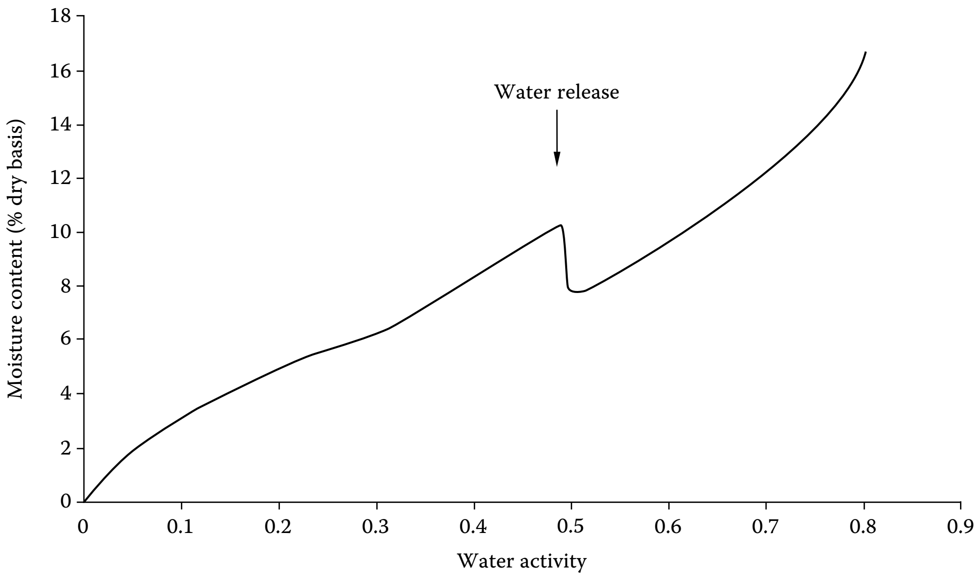

FIGURE 7.1 Generalized moisture sorption isotherm for milk powders showing a break at $a_w = 0.5$ due to lactose crystallization. (Redrawn from Thomas M.E.C., Scher J., Desobry-Banon S., Desobry S. 2004. Milk powders aging: effect on physical and functional properties. *Critical Reviews in Food Science and Nutrition* 44: 297–322, with permission.)

7.3.3 Maillard Reactions

Maillard reactions are an important class of deteriorative reactions in milk products. This type of chemical reaction is initiated by condensation of lactose with the free amino group of lysine in milk proteins (Thomsen et al., 2005). In milk products such Maillard reactions are induced by heating during processing and long-term storage at moderate to high temperatures (O'Brien and Morrisey, 1989). Crystalline forms of lactose depend on the preservation time and many other conditions, such as humidity, storage temperature, and preparation process. The crystalline state is thermodynamically favored as it has a lower free energy due to the structured arrangement of the molecules. During crystallization, the amorphous lactose will initially absorb moisture from the surroundings due to its hygroscopic nature, and subsequently release moisture as it crystallizes, as shown in Figure 7.1. The crystallization kinetics can be determined from the mass change of the powder (Ibach and Kind, 2007). Lactose crystallization modifies the microstructure and chemical composition of the surface of powder particles (Thomas et al., 2004).

7.3.4 Lipid Oxidation

Lipid oxidation in WMPs is also a major cause of deterioration during processing and storage (McCluskey et al., 1997). The reaction of unsaturated lipids with molecular O_2 results in the formation of hydroperoxides, which then break down to off-flavor compounds (Liang, 1999a). Many factors are responsible for the degradation of lipids due to oxidation, and one of the major causes of this defect has been identified as the oxidation of unsaturated lipids (Cadwallader and Howard, 1998). Lipid peroxidation is responsible for changes in the taste and odor of milk powders through the development of off-flavors, which are caused by the formation of secondary reaction products (alkanes, alkenes, aldehydes, and ketones) (Romeu-Nadal et al., 2007). These compounds impart off-flavors and loss of nutrients to milk powders and thus limit their shelf life stability (Fenaille et al., 2003). Oxygen, light exposure, storage temperature, water content, percentage of unsaturated fatty acids, and process parameters are the most important factors that affect oxidation.

7.3.4.1 Water Activity

The shelf life of WMP clearly depends on the preheat treatment of the milk, the a_w of the product, and the storage temperature. One of the factors influencing the rate of autoxidation in milk powder, although less investigated, is a_w (Roos, 2002; Stapelfeldt et al., 1997). Loncin et al. (1968) found that autoxidation in an unspecified milk powder, as measured by peroxide values, was stimulated by an a_w below 0.11 and unaffected by $a_w s$ between this value and 0.75. Stapelfeldt et al. (1997) found that WMP retained its quality best within an a_w range of 0.11–0.23. The preheat treatment of milk prior to the manufacture of milk powder is the major factor controlling the oxidative stability of the product, as heat treatment at high temperatures, apart from increasing the microbial safety, delays the onset of oxidized flavor, which is the limiting factor for the storage of milk powder (Baldwin et al., 1991).

7.3.4.2 Temperature

According to Stapelfeldt et al. (1997), Thomsen et al. (2005), and Augustin et al. (2006), it was expected that long-term stability of milk would be influenced negatively by a low preheat intensity, a high storage temperature, and a high a_w during storage. Although the effect of preheat treatment and storage was in qualitative agreement with earlier findings, the effect of a_w should be noted, especially as these findings were further substantiated by the techniques used to follow different stages of oxidation in the main experiment. There has been increasing interest in the supplementation of milk powder formulas with long-chain polyunsaturated fatty acids (LC-PUFAs) especially with arachidonic acid (C20: 4n-6, AA) and docosahexanoic acid (C22: 6n-3, DHA). High temperatures and the presence of O_2 lead to increased oxidation of PUFAs (Romeu-Nadal et al., 2007).

7.3.4.3 Oxygen

As O_2 is consumed during oxidation, the O_2 content will also influence lipid oxidation. In addition, the O_2 concentration in the headspace and the product is important, as this can influence the oxidation rate. Oxygen concentration could also influence the oxidation pathways and lead to different oxidation products (Grosch et al., 1981). It has been shown by numerous authors that if O_2 in milk powder or infant formula packages is replaced by N_2 and CO_2, the oxidation is not detectable and the peroxide value does not increase (Van Mil and Jans, 1991). Oxidation increases during storage; for example, WMP has a maximum shelf life of 6 months at room temperature (Anon., 1989). However, it was found that WMP could have a shelf life in excess of 12 months if it was packed in cans under vacuum or an inert gas such as N_2 to inhibit the development of off-flavors (Kieseker and Aitken, 1993).

The amount of O_2 needed to cause unacceptable oxidative changes is usually very small (Labuza, 1971). There is little detailed knowledge about what levels are acceptable for specific food products and how the storage stability is related to the amount of O_2 available for oxidation, especially at very low O_2 levels, that is, below 1 mL L^{-1}. Andersson and Lingnert (1997) reported on the influence of O_2 levels down to 0.6 mL L^{-1} on the oxidation of cream powder. An increased temperature also increases the effect of O_2 concentration. At high partial pressures of O_2, the oxidation rate should, theoretically, be independent of O_2 concentration and be directly dependent on substrate concentration. A decrease in O_2 concentration increases the effect of the O_2 partial pressure, which leads to a situation, at low O_2 partial pressures, where the oxidation rate is independent of substrate concentration but directly dependent on O_2 partial pressure (Labuza, 1971). Oxygen levels can be reduced by the traditional method of N_2 flushing or by the more recently developed approach of using O_2 absorbers or scavengers. Nitrogen flushing generally reduces the O_2 to 2–5% (Warmbier and Wolf, 1976), which is not enough to prevent oxidation (Bishov et al., 1971; Labuza, 1971; Lloyd et al., 2004).

7.3.4.4 Light

The rate of lipid oxidation is greatly influenced by light; this has created a serious problem for the dairy industry because of the development of off-flavors, a decrease in nutritional quality, and the severity and speed at which these phenomena develop (Bossett et al., 1994). Most ultraviolet (UV) light damage to lipids occurs at wavelengths less than 200 nm. Although UV light is thermodynamically capable of producing radicals directly in lipids, the process is not a competitive reaction. The principal light-absorbing groups of lipids are double bonds, peroxide O–O bonds, and carbonyls; the last two are most important (Schaich, 2005).

It is well known that exposure of foods and beverages to light may result in oxidation of lipids and other constituents, leading to the formation of off-flavors, discoloration, and loss of vitamins, especially riboflavin and β-carotene. Important factors influencing the deteriorative effect of light are the intensity and spectrum of the light source, the duration of light exposure, and the light transmittance of the packaging material. The effect of light on lipid oxidation and flavor stability of a particular food can be explained by both photolytic auto-oxidation and photosensitized oxidation (Bradley and Min, 1992).

Sattar et al. (1976) investigated the effect of light on the oxidation of milk fat and found that although there was an induction period for light-induced oxidation of milk fat, there was not for light-induced oxidation of vegetable oils. It was suggested that the induction period was due to the presence of α-carotene acting as a built-in light filter. Even though the presence of α-carotene in milk fat slowed down the rate of oxidation at the beginning of the trial, the light-exposed samples still showed a much higher oxidation rate than the samples kept in the dark.

7.4 IMPACT OF PACKAGING ON INDICES OF FAILURE

7.4.1 Moisture Transfer

Absorption or desorption of moisture can significantly affect the shelf life of foods. This is particularly the case for dry, powdery products such as milk powders. The main purpose of packaging is to protect the powder from moisture ingress to preserve the product characteristics. When they gain moisture, powdery products become lumpy or cake. In addition, the moisture may lead to deleterious changes such as structural transformations, enzymic reactions, browning, and oxidation, depending on temperature and the availability of O_2 (Roos, 2001). Moisture or water vapor ingress in combination with light, O_2, and an elevated temperature can result in physical loss of texture and caking due to lactose crystallization, microbial spoilage, nonenzymic reactions (such as Maillard browning), and fat oxidation (Uppu, 2002). The effectiveness of a package can be determined during shelf life testing or by combining information from break-point testing (holding at increasing humidities) and knowledge about the characteristics of the moisture permeability of the packaging material (Brown and Williams, 2003).

Although an $a_w < 0.6$ is considered sufficient to prevent the growth of microorganisms, chemical reactions and enzymic changes may occur at considerably lower levels (Roos, 2001). It is important for the determination of the maximum shelf life for milk powders (especially WMPs) not to exceed a moisture content corresponding to an a_w at which the rate of lipid oxidation is at a minimum (Robertson, 2006). Commonly the a_w of WMP varies from 0.25 (low) to 0.35 (high) (Baechler et al., 2005) and for SMP from 0.32 to 0.43 (Shrestha et al., 2008).

Moisture sorption isotherms (MSIs) for powders describe the equilibrium relationship between the moisture content of the powder and the relative humidity of the surrounding environment at a specific temperature. Such MSIs are major sources of information for optimizing concentration and dehydration processes, microbial growth conditions, and the physical and chemical stability of the product (Hardy et al., 2002). Knowing the MSIs of powdered milk products is essential to be able to predict their stability in association with packaging characteristics (Foster et al., 2005b). Figure 7.2 depicts a stability map for dairy powders containing amorphous lactose.

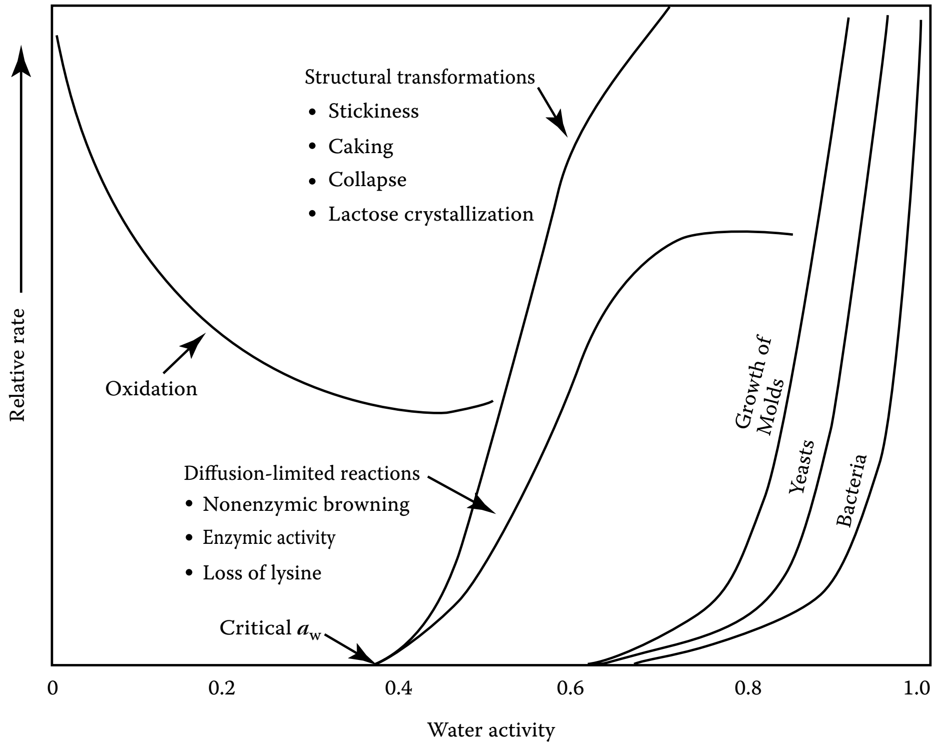

FIGURE 7.2 Stability map for dairy powders containing amorphous lactose. The critical water activity corresponds to the glass transition depression of amorphous lactose to 24°C, which may enhance deteriorative changes and loss of quality. (Redrawn from Roos Y.H. 2002. Importance of glass transition and water activity to spray drying and stability of dairy powders. *Lait* 82: 475–484, with permission.)

Changes in the immediate environment (i.e., temperature, moisture, and gas composition) can cause different types of reactions that may be interrelated and sometimes act synergistically. Therefore, it is very difficult to control a particular reaction (Uppu, 2002).

Moisture content and a_w can often determine the rate of deteriorative reactions as well as microbial growth. As indicated earlier, prevention of microbial growth can be achieved provided $a_w < 0.6$ (Roos, 2001). However, increased moisture levels due to transmission or condensation of water vapor (due to temperature fluctuations) could result in favorable conditions for microbial growth. Off-flavors, increased acidity, and visual and textural changes may be additional negative effects of microbial growth.

Another significant factor that causes caking in milk powders is lactose. Lactose is highly hygroscopic, but crystallization does not occur if $a_w < 0.43$, the moisture content <8.4%, and storage temperature <20°C (Vernam and Sutherland, 1996). A generalized MSI for milk powders was shown in Figure 7.1 with a break at $a_w = 0.5$, where water is released due to lactose crystallizing (Thomas et al., 2004). With the relatively high lactose content in filled milk powder (FMP) (~35%), the powder may be prone to caking with an increase in free moisture due to lactose crystallization. Difficulties in dispersing the powder in water (i.e., diminishing the instantizing properties) may be the result.

Therefore, in selecting a suitable packaging system for milk powders, three factors must be taken into account: the initial moisture content of the powder, the final acceptable moisture content of the powder, and the required shelf life (Robertson, 2006).

7.4.2 Oxidation

A number of food components react chemically with O_2, affecting the color, flavor, nutritional status, and occasionally the physical characteristics of foods. In some cases, the effects are deleterious and reduce the shelf life of the food; in others they are essential to achieve the desired product characteristics. Many studies have reported the development of off-flavors in milk after various storage times, usually at the end of their shelf life (Chávez-Servín et al., 2008; Contarini and Povolo, 2002; Cormier et al., 1991; Vallejo-Cordoba and Nakai, 1994). Packaging is used to exclude, control, or contain O_2 at the level most suited for a particular product.

Oxidation of powdered milk products is predominantly associated with unsaturated fats present in milk fat. Oxidation of unsaturated fats results in aldehydes and ketones, which are subsequently converted into alcohols (Nursten, 1997). Fat oxidation occurs in the presence of O_2 and moisture and can be catalyzed by light. The O_2 atmosphere inside the package, the presence of antioxidants, the a_w, and the temperature all influence the rate of oxidation (Uppu, 2002).

Powders containing a high percentage of fats, particularly unsaturated fats, are susceptible to sensory effects, collectively called oxidative rancidity, and changes in flavor. Saturated fatty acids oxidize slowly compared with unsaturated fatty acids (Brown and Williams, 2003). The presence of unsaturated bonds in fat will increase oxidation. In general, the higher the level of unsaturation, the greater the chance of fat oxidation.

It is therefore not surprising that to prevent oxidation of milk powder, the packaging should provide a high-level O_2 barrier and be able to retain that barrier during the anticipated shelf life. Gas flushing with a chemically inert gas such as N_2 may be essential to replace O_2 present in the package before closing. This is particularly true for WMP, where the shelf life is governed to a large extent by the rate of oxidation of the unsaturated fats and the consequent development of objectionable flavors (Robertson, 2006). Most of the common spoilage bacteria and fungi require O_2 for growth. Therefore, to increase the shelf life of foods, the internal package atmosphere should contain a minimum concentration of residual O_2.

In addition to fat oxidation, atmospheric O_2 and light are the prime factors influencing the stability of vitamins A and D. These factors, in combination with environmental factors such as temperature and moisture, influence the rate of reduction in the vitamin content (Ottaway, 1993).

7.4.3 Light

Light-induced degradation reactions in milk create a serious problem for the dairy industry because of the development of off-flavors, the decrease in nutritional quality, and the rate at which these phenomena develop (Mestdagh et al., 2005). Like many other foods, milk and dairy products are susceptible to oxidation, as mentioned earlier. Dairy products in particular are very sensitive to light oxidation because of the presence of riboflavin (vitamin B_2). This strong photosensitizer is able to absorb visible and UV light and transfer this energy into highly reactive forms of O_2 such as singlet O_2 (Min and Boff, 2002). Packaging materials that can provide a barrier to light are essential to avoid this particular deteriorative reaction in milk products (Mestdagh et al., 2005).

As mentioned earlier, light in combination with O_2 and moisture affects the quality of milk powder, and therefore light ingress via the package should be avoided. A package with a high barrier to the transmission of visible and invisible wavelengths is important. Therefore, packaging materials that are highly opaque are essential.

In summary, the packaging of powdered milk needs to be considered in terms of its ability to block light, avoid transmission of water and water vapor, and prevent permeation of O_2. The fourth factor influencing the indices of failure of milk powder is the ambient temperature. Although temperature is a prime factor determining the shelf life of milk powders, these products are not usually stored under controlled temperatures. Therefore, storage of milk powders at high ambient temperatures will accelerate deteriorative reactions, particularly if plastic barrier packaging materials are used, as the permeability of O_2 and water vapor increases at higher temperatures.

7.5 SHELF LIFE OF MILK POWDERS IN DIFFERENT PACKAGES

Shelf life is defined as the period between production and the time the food item loses its state of safe and satisfactory quality in terms of nutritional value, microbial status, flavor, texture, and appearance. The packaging plays a fundamental role in maintaining the quality and therefore the shelf life of foods. The package is an integral part of the preservation system and functions as an interface between the food and the external environment; the package should be designed and developed not only to contain the food product but also to protect it and add value to it, as its design may directly affect the purchase decision of the consumer (Da Cruz et al., 2007; Robertson, 2006; Sothornvit and Pitak, 2007). A range of variables influence packaging development. In designing a packaging system, trends, prerequisites, conditions, and developments in the external environment must be taken into consideration (Sonneveld, 2000).

For retailing to consumers, milk powder is packed into either metal cans or multilayer pouches. The type and construction of the package depends on the type of milk powder (e.g., skimmed, whole, filled, vitamin-added), the surface area:volume ratio of the package, the desired shelf life, the ambient storage and transport environment, and the anticipated market environment. WMP, for example, is often packed under N_2 gas to protect the product from fat oxidation, maintain its flavor, and extend shelf life. Packaging performance specifications therefore vary and depend on variations in product characteristics, the ambient distribution environment, and the market environment (Sonneveld, 2000). Essentially, packaging systems for milk powder must protect the powder from exposure to moisture, O_2, and light and anticipate the likely external environmental factors, which include temperature, time, relative humidity, light, and physical hazards.

7.5.1 Metal Cans

Packaging milk powder in metal cans has been highly popular for a long time, particularly for retail packaging. For example, cans are commercially available with capacities of 400, 900, 1800, and 2500 g. The main reason for using metal cans is their excellent physical strength, durability, absolute barrier properties to moisture, O_2, and light, absence of flavor or odor, and rigidity (Robertson, 2006).

Because bare steel is susceptible to corrosion, it is commonly electrolytically coated with a very thin layer of tin; in addition, an organic lacquer is applied to further protect the metal from corrosion and avoid metal–food contact (Robertson, 2006). Among the organic polymeric coatings, epoxy-phenolic lacquers are often used on tinplate, although waterborne polymer coatings have been playing an increasingly important role as well (Manfredi et al., 2005).

A recent concern has been the presence of natural and synthetic chemicals in foods that exhibit estrogenic affects and act as endocrine disrupters. Powdered milk (including infant formulas) may have hormonally active contaminants introduced in the manufacturing process or leached from containers (Casajuana and Lacorte, 2004). Bisphenol A (BPA) has recently been found to be one of the more potent anthropogenic estrogen mimics (Kim et al., 2001). It is a monomer used to produce (among other things) epoxy resins that are widely used to coat the interior of cans, leading to potential human exposure. Kuo and Ding (2004) detected BPA in powdered milk and infant formulas on the Japanese market at concentrations from 45 to 113 ng g^{-1}.

The milk powder steel can is commonly cylindrically shaped and may feature a reclosable (tight fit) lid. In the standard version the can features a cylindrical body with “can ends” on both ends. The can body is welded longitudinally, and the can ends are seamed onto the can body. To obtain appropriate closure (i.e., to maintain the integrity of the pack) an elastomeric compound is included in the end seam. In cans with a reclosable lid it is common to seal the underside of the can end with an aluminum foil laminate to ensure integrity during storage and distribution.

Milk powder has a long shelf life when packed in metal cans due to their excellent barrier properties. The exchange of moisture and O_2 and the influx of light are not possible. Powders with a higher fat content are more susceptible to oxidation, and most powders are susceptible to deteriorative effects such as lumping and caking from moisture ingress. With adequately constructed cans, a shelf life in excess of 5 years is realistic, particularly when FMP products have been gas-flushed with N_2 to minimize the amount of available O_2. However, national food safety authorities often adopt a conservative approach by reducing the nominated shelf life.

Nonfat dry milk (NDM) and powdered whey beverages are available at the retail level in the United States and many other countries packaged in no. 10 cans (157 × 178 mm with a capacity of 3108 mL) in a reduced-O_2 atmosphere to prolong shelf life (up to 54 months). Lloyd et al. (2004) found that in the 10 US brands tested, wide variation existed in headspace O_2, can seam quality, sensory quality, and vitamin A (with 6 of 10 brands entirely lacking the vitamin). The a_w of the brands ranged from 0.14 to 0.28 (a typical range), corresponding to 3–5% moisture content. The brand that scored highest in overall acceptability had an average headspace O_2 of 7% and poor can seams, calling into question the ability of the package to maintain product quality over an extended storage time.

7.5.2 Multilayer Pouches

In recent years, aluminum foil/plastic film laminates have been introduced as a replacement for the tinplate can. The laminates can be formed, filled, gas-flushed, and sealed on a single machine from reel stock (Robertson, 2006). Such flexible pouches or sachets are well positioned to exploit the opportunities for convenience food markets. Flexible packages reduce the volume of traditional packaging such as metal cans, reduce transport costs, reduce the cost of the packaging, and require less material, thus minimizing postconsumer waste (Twede and Goddard, 1998). However, in many developing countries milk powder in metal cans is still the preferred packaging option for larger capacities because of recloseability and the fact that the empty can can be reused as a household utensil.

Milk powder packed in pouches is commercially available in a capacity range of 250–2500 g. In addition, sachets with smaller capacities are also available to provide convenient single-serve portions of up to 35 g. As with metal cans, milk powder packed in multilayer pouches is predominantly destined for retail distribution. The single-serve sachets are mainly distributed in developing countries because of the need to provide an affordable but highly nutritious food product. This type of retail distribution usually entails exposure to high humidity, high temperature, high levels of light, and relatively long storage times (Uppu, 2002). To maintain the quality of the milk powder in such small sachets is a challenge given the very high surface area:volume ratio. A 2-year shelf life for milk powder in portion packs is normally required when distributing in the relatively complex environments of developing countries. In countries with more highly developed economies a maximum shelf life of up to 12 months is common.

Commonly, a laminated multilayer pouch for milk powder must comprise a barrier to water vapor, O_2 (at least for WMP products), and light. Aluminum foil is capable of providing such a barrier provided the foil does not have pin holes in it. Aluminum foil built into a flexible material provides a close-to-absolute barrier. Building into a flexible material is essential because the foil does not have any mechanical strength by itself and therefore needs protection from mechanical damage. A sandwich construction with two plastic layers—one on the inside, such as low density polyethylene (LDPE), so that the pouch can be sealed and one on the outside, such as biaxially oriented polypropylene (BOPP) or poly(ethylene terephthalate) (PET), to provide mechanical protection and also carry information—is common practice (Uppu, 2002).

Alternatively, with pouches for which a shorter shelf life is acceptable, the alufoil layer may be replaced with a high-barrier plastic layer such as a copolymer of ethylene vinyl alcohol (EVOH) or polyvinylidene chloride (PVdC), possibly with the addition of a thin layer of metal or silica oxide

(SiO_x) deposition to enhance its O_2 barrier characteristics (Lange and Wyser, 2003). However, the shelf life will likely be less than that of a pouch containing an alufoil layer. A shelf life of up to 2 years is not feasible with portion pouches in a challenging distribution environment, such as exists in many developing countries, other than with the inclusion of an alufoil layer. Sachets with larger capacity (in excess of 250 g) comprising a high-barrier plastic layer sandwiched between LDPE and BOPP or PET would be able to achieve a similar shelf life to an alufoil-sandwiched portion pack pouch.

As indicated earlier, the shelf life of milk powder is not determined solely by the package construction and the amount of product packed. External factors such as variations in the physical distribution environment, the retail business setting, the demographic, social, and ethnic conditions, the regulatory environment, and, importantly, the costs of the systems affect the required shelf life and the required packaging performance associated with it (Sonneveld, 2000).

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