CHAPTER I

Introduction and Justification:

Manufacture and trade in preserved milk have increased significantly as new markets open around the world. The many advantages of dairy powders over liquid milk include lower shipping costs, increased microbial stability, a unique functionality, convenience in transport, and reasonably good preservation (Shiratsuchi et al., 1994; Schwambach and Peterson, 2006). Approximately 1.74 billion pounds of nonfat dry milk were produced in 2005 in the United States, and that number is projected to continue rising (IDFA, 2005). Additionally, around 22 million pounds of whole milk powder and as much as 84 million pounds of buttermilk powder were produced in America last year (USDA-FAS, 2006). As demand and consumption continue to increase, it is important to create a product of the highest quality possible.

Liquid milk is often spray-dried in order to preserve it from microbial spoilage. Unfortunately, drying makes dairy products much more susceptible to spoilage by another means—lipid oxidation. This is one reason that dairy powders do not have the same desirable qualities as fresh milk when they are reconstituted. Although relatively lengthy, their shelf life is also limited. In order to combat the effects of lipid oxidation, oxygen absorbers and scavengers are often used. Current technologies for the removal of oxygen using oxygen scavengers have two main drawbacks—they neither work effectively for dry powders nor have a sufficient capacity. Thus, the use of a non-permeable package containing a modified atmosphere and a novel oxygen catalyst to remove all oxygen would increase the quality and acceptance of beverages made from these dried dairy products and prolong shelf-life.

The focus of this research is to determine if using a new palladium catalyst is effective in slowing or even eliminating oxidation in non-permeable packages of various dairy powders.

Objectives:

1. Evaluate the effectiveness of palladium-based oxygen scavenging catalyst in preventing oxidation of nonfat milk powder (NMP), whole milk powder (WMP), and buttermilk powder (BMP) in a modified system.
2. Compare the overall changes in NMP, WMP, and BMP stored with the oxygen catalyst to those stored without it.

Literature Review:

Shelf-life:

The shelf-life of a product is defined as the finite length of time after production that a food will retain a required level of quality. In order to elongate the shelf-life of a product, one must first assess the rate of change in food quality as it ages. Thus, it is important to identify the chemical and biological reactions influencing the quality and safety of the food. Once this is done, the reaction or reactions having the most critical impact on the rate of deterioration must be determined and dealt with (Taoukis et al., 1997). Usually, there is one limiting reaction that most affects the quality of the product and others are so excessive that their change in concentration with time is negligible.

The shelf-life of a product depends on four main considerations: formulation, processing, packaging, and storage conditions. For packaging and storage conditions, the keeping properties of the product are a function of its microenvironment. This includes temperature, relative humidity, gas composition, light, and pressure. Any or all of these components may be manipulated to lengthen shelf-life.

Temperature:

There are many factors to consider when examining shelf-life. The extrinsic factor most affecting shelf-life is temperature because it is directly imposed to the food. Reaction rates increase as temperature increases; shelf-life decreases with increasing temperature. Shelf-life has been found to be adversely affected when storage temperatures are higher than $30^{o}C$ (Lloyd et al., 2004b). In order to determine the temperature sensitivity or a reaction, a Q_{10} model is often employed. This describes how much faster a reaction will go if the product is held at temperatures differing by $10^{o}C$. Q_{10} models can be used to predict quality and nutrient loss, as well as shelf-life of a product (Fu and Labuza, 1993; Taoukis et al., 1997; Labuza, 2000).

Relative Humidity:

The second most important extrinsic factor is relative humidity (RH), which affects both moisture content and water activity (a_w). At RH higher than 5%, shelf-life can be adversely affected (Lloyd et al., 2004b). Controlling a_w (the degree of boundness of water contained in food and availability to act as a solvent and participate in chemical reactions) is the basis of

preservation in dry foods. Deterioration reactions increase exponentially in rate with increasing a_w. This is because the ability of water to act as a reaction medium or reactant increases as well. Many deterioration reactions increase exponentially in rate with increasing a_w above the monolayer moisture value (the value at which most reactions have their minimum rate). Lipid oxidation reactions are unique in that rates increase again while a_w decreases below the monolayer (Taoukis et al., 1997; Labuza, 2000). Another benefit to the low a_w of milk powders is a resistance to anaerobic bacteria.

Quality:

      Quality is negatively affected by the amount of time spent in storage, even at optimal conditions. Some researchers have found that although sensory quality decreases with time, nutritional quality often remains unaffected (Lloyd et al., 2004b; Ramaprasad et al., 2006). As an extreme example, some researchers found that a 23-year-old sample of dried milk had the same nutritional qualities as fresh milk (Lloyd et al., 2004a). They concluded that it was indeed possible to preserve dried milk for a long period of time under ideal conditions. Those ideal conditions can be determined by studying the rate of quality degradation, which is a function of factors like concentration of reactive species, microorganism levels, catalysts, reaction inhibitors, pH, a_w, and environmental factors like temperature, RH, light, and total pressure. Further, one must ascertain the chemical and biological reactions likely to have the most critical impact on lowering quality.

Lipid Oxidation:

      The reaction known to be the limiting factor in the shelf-life of dried foods is lipid oxidation since these products have been made stable to microorganisms. Dry products are very susceptible to lipid oxidation because they have a large surface area and more lipid is therefore exposed to the environment (Heath and Reineccius, 1986; Stapelfeldt et al., 1997). Since autoxidation is due to the addition of oxygen to unsaturated fatty acids, it is a major concern for dried dairy products, especially those of full fat (Shipe et al., 1978; Forss, 1979; Wills and Cheong, 1979). The degree of unsaturation of the fatty acids has a strong influence on the rate of lipid oxidation and on oxidative stability—the more unsaturated fatty acids a products contains, the more unstable it is upon storage (Heath and Reineccius, 1986; Hedegaard et al., 2006). Thus,

it is safe to assume that whole milk powder (WMP) would have a shorter shelf-life than nonfat milk powder (NMP). It is important to note that WMP, NMP, and BMP each contain a great variety of fatty acids, including some components not found in high concentrations in other milk fractions (deMan, 1999; Powell, 2004). For example, NMP is typically 49.5-52.0% lactose, while lactose usually makes up about 36.0-38.5% of WMP (Commission, 2007).

Lipid oxidation in processed dairy products is due to the acceleration of oxidation processes already initiated in raw milk (Karatapanis et al., 2005; Hedegaard et al., 2006). Further, the process is autocatalytic since the oxidation products themselves catalyze the reactions and increase the reaction rate as oxidation proceeds (Lillard, 1978; Shipe et al., 1978; Heath and Reineccius, 1986). Because of this, lipid oxidation occurs even in oxygen-impermeable packages, so other measures must be taken to prolong shelf-life.

Three main factors affecting lipid oxidation are water activity, temperature, and headspace oxygen. Water activity (a_w) has a strong relationship with the rate of lipid oxidation (Heath and Reineccius, 1986; Stapelfeldt et al., 1997). According to some researchers, lipid oxidation is stimulated by a_w less than 0.11, but unaffected at a_w between 0.11 and 0.75 (Stapelfeldt et al., 1997). Others agree that the best storage occurs at lower a_w, somewhere between 0.11 and 0.23, but that quality begins to degrade at a_w above 0.31 (Doka et al., 2000; Lloyd et al., 2004a). Regardless, oxidation still occurs even at low a_w because migration of hydrophobic compounds does not depend on water mobility (Thomas et al., 2004).

Temperature of pretreatment and storage also affects the shelf-life of a product. Pretreatment is a major factor in controlling oxidative stability. Increased temperatures delay the onset of oxidative flavor because proteins unfold, exposing and releasing sulfhydryl groups that act as antioxidants and inactivate reactive oxygen species (Azzara and Campbell, 1992; Celestino et al., 1997; McCluskey et al., 1997; Stapelfeldt et al., 1997). However, in addition to decreasing the development of off-flavors, high-heat pretreatment also makes the powder more susceptible to lipid oxidation (Parks, 1967).

In order to maintain control over oxidation, it is necessary to lower the amount of oxygen in the headspace of the package to lower than 2%. In a sealed environment, less oxygen initially available leads to less oxidation during storage. The best keeping quality is obtained when oxygen content is less that 0.01 mL/g of powder (4.5 mL/lb). Oxygen levels from 3-6% give a significantly increased shelf-life but does not prevent oxidation. Lowering the content to 0.5-1%

retards the development of the tallowy off-flavor. However, at any concentrations above 2%, oxidation is not inhibited. (Shipstead and Tarassuk, 1953; Jeon, 1996; Lloyd et al., 2004a)

Products:

The primary products of lipid oxidation are hydroperoxides, which have little to no flavor or odor. However, these compounds decompose into low molecular weight carbonyls (mostly aldehydes). These secondary products are responsible for the formation of off-flavors in stored milk powders (Forss, 1979; Wills and Cheong, 1979; Grosch, 1987; Min et al., 1990; Jacobsen, 1999). Common descriptors of these off-flavors are cardboardy, metallic, oily, tallowy, buttery, and hay-like (Shipe et al., 1978; Shipe, 1980; Shiratsuchi et al., 1994; Barrefors et al., 1995; Jeon, 1996; Jacobsen, 1999; van Aardt et al., 2001b; Karagul-Yuceer et al., 2002; van Aardt, 2003).

The precursors to the most prevalent off-flavor-causing compounds are linoleic, linolenic, oleic, and arachidonic acids. More specifically, the most significant contributor to off-flavors in milk are the alkanals and alkenals with six or more carbons derived from the aforementioned acids (Shiratsuchi et al., 1994; Barrefors et al., 1995; Przybylski and Eskin, 1995). They are the source of the cardboardy off-flavor. Hexanal, which originates from either linoleic acid or further oxidation of 2,4-decadienal (see **Figure 1**), and oxidative rancidity have been found to be highly correlated. Reduced oxygen content has been found to lead to less hexanal generation (Berenzon and Saguy, 1998; Karagul-Yuceer et al., 2002). Heptanal and pentanal are also known contributors, but hexanal is the major aldehyde formed at ambient temperatures (Grosch, 1987; Garcia-Llatas et al., 2006; Hedegaard et al., 2006). One study in particular determined hexanal to be the preferred chemical marker in testing milk powders due to its presence in every sample and its already proven correlation with off-flavors (Fenaille et al., 2003).
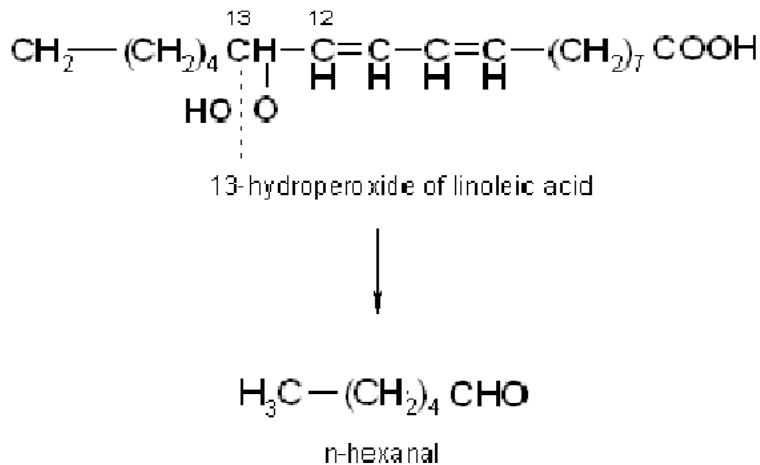
Figure 1: Oxidation of linoleic acid to form hexanal

The metallic off-flavor is due to the generation of 1-octen-3-one from either linoleic or arachidonic acids or their esters (Shipe et al., 1978; Shipe, 1980; Azzara and Campbell, 1992; Barrefors et al., 1995; Jeon, 1996; van Aardt et al., 2001b; Karagul-Yuceer et al., 2002; van Aardt, 2003; van Aardt et al., 2005a). Only when combined with an aldehyde does 1-octen-3-one produces the metallic off-flavor (Jeon, 1996; Karagul-Yuceer et al., 2002).

Prevention:

Active packaging is packaging that performs some desired role other than just providing an inert barrier to external conditions. Other constituents can be added to enhance performance or the environment might be changed (Berenzon and Saguy, 1998; Robertson, 2006). Although active modified atmosphere packaging (MAP) and other physical methods for oxygen elimination such as flushing or vacuum-packing do retard the onset of oxidation, they are not always satisfactory since some oxygen (about 20-30 mL/L) still remains (Jeon, 1996; Berenzon and Saguy, 1998; Charles et al., 2006). As oxygen is consumed during oxidation, the amount of oxygen available will limit the extent of oxidation, so it is important to remove as much as possible in the packaging steps. Indeed, as a specific example, (Andersson and Lingnert, 1998b) found that samples of cream powder stored with reduced oxygen content were significantly different from an air-packed sample in both hexanal concentration and sensory analysis.

Selecting a package for storage is key in giving the product the longest shelf-life possible. Selection depends on factors affecting the transport of low molecular weight compounds from the internal or external environment through the package wall. For milk powders, these factors include initial moisture, final acceptable moisture, shelf-life required, and light protection. The package must be oxygen- and light-impermeable for best results (van Aardt, 2003; Lloyd et al., 2004a; Karatapanis et al., 2005). Less headspace oxygen means less oxidation. Thus, when comparing a plastic bag with a glass jar, some investigators found that a higher degree of oxidation occurred in the plastic bag (Chan et al., 1993). This was due to attack by atmospheric oxygen, while the oxidation in the glass jar was due to oxygen incorporated in the milk powder as well as residual oxygen.

Research has been done to prove that an important factor in protecting milk from lipid oxidation is light protection. Off-flavors increase more rapidly when samples are exposed to light. Volatile analysis has shown that the relative concentrations of four volatile compounds commonly associated with oxidation off-flavors in liquid milk were much higher in light-exposed milk than in milk stored in light-protected bottles (van Aardt et al., 2001b). Specifically, from as early as one week of storage under fluorescent lighting, a significant difference was found in the hexanal content of light-protected and light-exposed milk (van Aardt et al., 2005a). When considering powdered milk, some researchers have found the production of hexanal to be 100 times greater in milk powder stored in daylight and at room temperature than in powder stored at $30^{o}C$ in darkness (Ulberth and Roubicek, 1995). Research of cream powder resulted in the sample stored in light having a hexanal increase 330 times larger than the same sample stored in darkness (Andersson and Lingnert, 1998a). Clearly, it is essential to protect the powdered milk samples from light.

Oxygen absorbers are a very common method for the removal of oxygen in a sealed package. The most often-used systems are iron-based. These generally lower headspace oxygen to less than 0.01%, which is significant when compared to the 0.3-3% found in packages that have merely been vacuum-sealed or gas-flushed (Lloyd et al., 2004a; Robertson, 2006). Further, they have been found to delay lipid oxidation regardless of the processing method used (Chan et al., 1993; Andersson and Lingnert, 1997; Berenzon and Saguy, 1998; Lopez-Cervantes et al., 2003; Lloyd et al., 2004a). They work by converting any remaining oxygen into a stable oxide (Grattan and Gilberg, 1994; Robertson, 2006). Other compounds sometimes used are ascorbic

acid, catechol, and glucose oxidase (Charles et al., 2006). The absorbers are usually contained in sachets, often composed of perforated, non-woven polyethylene cloth with pinholes on one side to make it permeable to gases and water vapor to control the flow of oxygen and moisture to the absorbent (Grattan and Gilberg, 1994; Charles et al., 2006).

One specific example is the Ageless Z oxygen absorber. It makes use of iron powder, which is beneficial because of its increased surface area and high reactivity. Its other components include sulfur (which lowers the rate of hydrogen gas evolution by interfering with the hydrogen atom combination reaction), salt (which is hygroscopic and lowers the critical RH by favoring electrolyte formation at low RH), and a natural zeolite (which ensures that the sufficiently high RH is maintained to guarantee the presence of the electrolyte layer, the site of the oxidation of iron). Water and the electrolyte layer must both be present for oxidation to occur (Grattan and Gilberg, 1994).

There are some drawbacks to using traditional oxygen absorbers. Berenzon and Saguy (1998) found that additional means of oxygen removal are required when a milk powder is stored above $25^{\circ}C$. The iron-based systems have a limiting capacity—as moisture is lost from the sachet, the rate of oxygen absorption decreases (Grattan and Gilberg, 1994; Lloyd et al., 2004a). The fact that they are partially expended before packaging must also be considered (Lloyd et al., 2004a). An additional shortcoming of most oxygen scavengers available today that is especially disadvantageous to research dealing with dry products is that moisture is most often required as an activating agent. However, this is not always the case—if the sachet is pre-humidified, Charles, Sanchez et al. (2006) observed no difference in absorbance at 0 and 100% RH.

An ideal scavenger for dairy powders would have no limit and would work effectively without the presence of water. An innovation in oxygen scavenging emerging from the United Kingdom involves the use of elemental palladium to catalyze the formation of water from any oxygen and hydrogen present in the headspace of a packaged product. The palladium would be anchored into a non-woven matrix and covered with a gas-permeable membrane. Since hydrogen is permitted in the modified atmosphere gas mix used for flushing the container before sealing, this concept is highly suitable for controlling oxidation in a package of dry milk powder. Further, this method of oxygen removal has an almost infinite life and will not wear out or reach a capacity. If adapted to the packaging of dairy powders, this technology has the potential to vastly decrease, if not completely eliminate, rancidity in such products.

Tests:

Testing methods range from sensory evaluation to instrumental measurements, assessing everything from odor and flavor to physical properties, such as color and texture. Each method has advantages and inadequacies.

Headspace Measurements:

Several methods exist for measuring volatiles (specifically hexanal for dried dairy products) in the headspace of a container. In static headspace methods, a certain volume of gas from the area above the contained lipid is transferred directly into a GC for separation and quantification. This is a convenient, rapid, and reproducible method, but equilibrium must be reached in the system before measurements can be taken (Przybylski and Eskin, 1995). Alternately, dynamic headspace can be used. Here, a sorbent is used to collect the volatiles. While equilibrium is not required, this method involves intense manipulation and careful quantity control (Przybylski and Eskin, 1995). Further, the irreproducibility of dynamic headspace methods makes them undesirable.

Solid phase microextraction (SPME) is a solventless extraction technique that has two discrete steps. First, the analytes from gaseous, liquid, or solid matrices are released and sorbed onto a fiber coated with a polymer. Next, the analytes are most often transferred into a chromatography inlet system via thermal desorption (Hinshaw, 2003; Jung and Ebeler, 2003). Several researchers have found SPME to be an invaluable and effective technique in the analysis of low levels of flavor volatiles in foods and beverages (Quach et al., 1999; van Aardt et al., 2001a; Biolatto et al., 2007). Its many advantages include its simplicity, ease of use, sensitivity, and low cost (Quach et al., 1999; Marsili, 2000; van Aardt et al., 2001a; Jung and Ebeler, 2003; Garcia-Llatas et al., 2006; Havemose et al., 2007).

Many types of fibers are available. They differ in their polymer coating. Multiple researchers have found that the ideal fiber to use when extracting low molecular weight analytes is the Carboxen/PDMS type (Marsili, 2000; Perkins et al., 2005). Since Carboxen is a porous particle with an average diameter of 10 angstroms, it can selectively retain volatiles of a particular molecular weight. That weight includes analytes with anywhere from two carbons to twelve (Perkins et al., 2005).

The main disadvantage of SPME is its inability to recover trace compounds and strongly bound semi-volatiles. One other drawback is that experimental conditions must remain constant with replicate runs. Even a small change that affects the adsorption distribution will be reflected in the sensitivity and reproducibility of the method (Quach et al., 1999).

Headspace concentration above a food directly represents the availability of volatiles to aroma perception (Jung and Ebeler, 2003). Thus, by examining the development of hexanal in the headspace of jars containing the various dairy powders using measurements obtained via SPME, one can determine if the oxidation process is occurring or if it is, in fact, been slowed or completely halted. Indeed, one study found SPME to be ideal in describing the ongoing oxidation and oxidative capacity of milk (Havemose et al., 2007).

Peroxide Value:

One of the most frequently used ways of measuring primary lipid oxidation products involves finding the peroxide value (PV) (Hahm and Min, 1995; Ulberth and Roubicek, 1995; Jacobsen, 1999; Ruiz et al., 2001; van der Merwe et al., 2003; Chung et al., 2004). Although not indicative of the actual extent of lipid oxidation due to the fast decomposition of peroxides, this method has proved to be accurate and highly suitable (Li et al., 1999; van der Merwe et al., 2003). The key is to check often since peroxides follow a lag phase with a rapid, steady increase, reach a plateau, and then decrease to zero (Labuza, 2000). Thus, the rate of hydroperoxide decomposition eventually exceeds the rate of formation (Wills and Cheong, 1979; van der Merwe et al., 2003). The very fast rates of hydroperoxide generation and degradation make reproducibility difficult (Guillen and Cabo, 2002). Ultimately, the major drawback of PV testing is that it is not indicative of the actual extent of fat oxidation due to this fast decomposition of peroxides (Ruiz et al., 2001).

Shelf-life and PV are closely correlated. Wills and Cheong (1979) stated that PV could be used as in index of potential shelf-life since the maximum value occurs before the onset of rancidity. A rising PV means that considerable shelf-life remains, while a decreasing PV indicates that rancidity would occur soon. Also correlated with PV are the existence of off-flavors and hexanal content (Ulberth and Roubicek, 1995; Berenzon and Saguy, 1998).

Anisidine Value:

A quick and simple way to measure secondary lipid oxidation products occurring after the hydroperoxides have been degraded is by determining the anisidine value (AV) (White, 1995; Jacobsen, 1999; Guillen and Cabo, 2002; van der Merwe et al., 2003). It involves the reaction of α- and β-aldehydes (mostly 2-alkenals) with a p-anisidine reagent, giving information about the products forming after the primary lipid oxidation products (hydroperoxides) have been degraded (White, 1995). It is generally a very reliable indicator of oxidative rancidity, most often determined by a straightforward spectroscopic method (van der Merwe et al., 2003).

Based on its reliability, simplicity, and reproducibility in comparison to alternate methods, measuring the AV seems to be the best method for examining secondary oxidation products formed in dairy powders. Indeed, it has been found to be a straightforward and dependable indicator of oxidative rancidity.

Carbonyl Value:

An alternate way to measure secondary lipid oxidation products makes use of the carbonyl value. It is based on the formation of 2,4-dinitrophenylhydrazines of carbonyl compounds in the presence of a trichloroacetic acid catalyst. An advantage is that samples can be run within one hour. However, this rapidity is not enough to overcome the fact that the hydroperoxides can further decompose under the experimental conditions and often give false results. (White, 1995; Guillen and Cabo, 2002)

Thiobarbituric Acid Reacting Substances:

A third way to measure secondary lipid oxidation products is by testing the thiobarbituric acid reacting substances (TBARS) (Tarladgis et al., 1964; Ohkawa et al., 1978; Guillen-Sans and Guzman-Chozas, 1998; van Aardt et al., 2005b). This method measures the colorimetric reaction occurring between one molecule of malondialdehyde (a major degradation product of lipid hydroperoxides) and two molecules of 2-thiobarbituric acid (TBA). The pink complex that is produced can be quantified using a spectrophotometer with maximum absorbance near 532 nm. Unfortunately, many other substances may react with TBA to yield colored species. These interfering substances, which include protein, sucrose, urea, and others, can result in an overestimation of the complex (Bergamo et al., 1998; Jo and Ahn, 1998; Jardine et al., 2002).

The merits of this assay are highly debated. Some say that the results are highly correlated with sensory descriptors (Hedegaard et al., 2006). Others argue that there is a poor correlation between the results and taste panel scores and that the test is less sensitive to low concentration of carbonyls than human senses (Barrefors et al., 1995). Its low specificity is also a concern (Kishida et al., 1993; Bergamo et al., 1998; Fenaille et al., 2001). Some researchers have concluded that the method was not appropriate for measuring the decomposition products of lipids containing mainly oleic and linoleic acids (which includes dairy products) (Rufian-Henares et al., 2005).

Color:

Although color is usually indicative of degradation by Maillard reaction and non-enzymatic browning, it can also be useful in providing information about the degree of lipid oxidation (Laroche et al., 2005). Further, information about color can be useful in comparing powders receiving different treatments. One investigation revealed that milk powders packed in air discolored a bit more rapidly than those packed in nitrogen (Henry et al., 1948).

One of the most common ways of evaluating color changes involves Hunter's values (L, a, and b) (Phillips et al., 1995; Ameny and Wilson, 1997; Nielsen et al., 1997b). Hunter's L-value describes the lightness of a sample, from black (0) to white (100). This value tends to decrease with time. A positive Hunter's a-value is indicative of a red tint, while a negative value implies green. In contrast, Hunter's b-value denotes a yellow hue when positive and a blue color when negative. Previous research has proven that milk powders turn darker, more red, and more yellow during storage (Nielsen et al., 1997b; Nielsen et al., 1997a; Stapelfeldt et al., 1997).

Hunter's b-value has been found to have a correlation with shelf-life—the higher the value, the longer the expected shelf-life (Nielsen et al., 1997b; Nielsen et al., 1997a). Further, higher a_w usually results in a higher b-value since such conditions promote Maillard reactions and non-enzymatic browning (Stapelfeldt et al., 1997). These observations, along with research done by (Thomas et al., 2004) on the aging of milk powders, indicate that the products of Maillard reactions can act as antioxidants.

Consumption of β-carotene (a sacrificial antioxidant) is also correlated with Hunter's values. An increase in the rate of consumption indicates a longer shelf-life. As the

concentration of β-carotene increases, Hunter's a- and b-values also increase, while the L-value decreases (Nielsen et al., 1997b).

Sensory Evaluation:

Many types of sensory evaluation could be used to compare the aromas of various dairy powders. Difference tests, such as paired comparison and triangle tests, would provide relevant and useful information. Hedonic scales are also frequently used. Since the goal of the experiment is to compare powders stored with the oxygen absorber to those stored without it, it is reasonable to conclude that a simple paired comparison test will be sufficient from a sensory point-of-view. By having panelists determine which of two samples exhibits the greatest off odor, it will be possible to assess if, in fact, the oxygen scavenger has an impact on the sensory aspects (odor, in this case) of the powders. Some research has shown that off-flavors in real, defective samples are often slight, and when combined with the other natural milk odors can lead to difficulties in distinguishing between samples by sensory testing (Hough et al., 1992).

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