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Packaging modifications for protecting flavor of extended-shelf-life milk from light

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ABSTRACT

The effectiveness of titanium dioxide (TiO_2)-loaded high-density polyethylene (HDPE) to reduce light-induced oxidation of extended-shelf-life milk (2% total fat) was studied. The objective was to determine differences over time in sensory quality, vitamin retention, and oxidative chemistry as a function of packaging and retail light exposure duration. Effectiveness of packaging for protecting milk quality was assessed by sensory evaluation (triangle tests, untrained panel), changes in volatile compounds, thiobarbituric reactive substances (TBARS), and riboflavin concentration. Milk (2%) was stored in HDPE packages consisting of TiO_2 at 3 levels (low: 0.6%; medium: 1.3%; high: 4.3%) at 3°C for up to 43 d. Light-protected (translucent, foil-wrapped) and light-exposed (translucent) HDPE packages served as controls. The high TiO_2-HDPE package provided protection similar to light-protected control package through d 22 of light exposure, with less consistent performance by the medium TiO_2 package. The TBARS increased in all treatments during storage. Under the experimental conditions used, a TBARS value of 1.3 mg/L could be considered the limiting sensory threshold for differentiating oxidized milk from light-protected milk. Riboflavin concentration decreased 10.5% in the light-protected control and 28.5% in the high TiO_2 packaged milk past 29 d of light exposure, but losses were greater than 40% for all other packages. The high TiO_2 package protected riboflavin concentration from degradation and controlled aldehyde concentration throughout the test period.
Key words: oxidation, sensory, riboflavin, extended shelf life

INTRODUCTION

Milk and milk products are susceptible to light-induced oxidation reactions, which can negatively affect odor and flavor attributed to increased oxidation-derived volatile compound production and leading to reduced shelf-life. Photooxidation of milk occurs under the presence of light (artificial, sunlight) and in both UV and visible light wavelength regions (Webster et al., 2009). This process is of particular concern in milk because it occurs quickly and influences consumer perception of milk flavor (Heer et al., 1995; Chapman, 2002; Chapman et al., 2002; Duncan and Webster, 2010).

Although no direct evidence exists that light-oxidized off-flavors contribute to decreased sales of fluid milk, the relationship of light-oxidized flavor to milk acceptability and emotional response has recently been reported (Walsh et al., 2014). Light-exposed milk (2% milkfat; 8 h light exposure) was rated lower in acceptability, corresponding to "neither like nor dislike," than milk that did not receive light-exposure, which was rated as "like moderately" (Walsh et al., 2014). With continued light exposure (up to 168 h), milk acceptability scores decreased to "dislike moderately." The experience of drinking high-quality milk without light-oxidized flavor is characterized with positive emotional terms such as content, good, calm, satisfied, pleased, and happy (Walsh et al., 2014). In contrast, emotional terms that suggested withdrawal and had negative connotations, including disgusted and worried, were frequently selected for the disliked light-exposed milk (Walsh et al., 2014). Such responses illustrate that light exposure during retail storage can be detrimental to milk acceptability and increase negative emotional responses.

Specialty and single-serve milk products are often processed for extended shelf life (**ESL**), allowing for distribution across greater distances and limited processing schedules of products that have lower turn over or are seasonal products. Longer storage periods increase the risk of light exposure with the subsequent risk of altering milk quality before purchase. Milk is commonly displayed under fluorescent or light-emitting diode (**LED**) lighting in retail dairy cases in supermarkets, convenience stores, as well as vending machines. Whereas fluorescent lighting is most common in retail dairy cases, LED lighting use in open dairy retail cases is rapidly increasing, from about 15% in 2010 to almost

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40% in 2014 (Jack Sjogren, Hillphoenix, Chesterfield, VA, personal communication). Both LED and fluorescent lighting sources deliver light energy in UV and visible wavelength regions that cause excitation of photosensitive molecules, specifically riboflavin (**Rb**), in milk.

Several molecules in milk are responsive to light, acting as photosensitizers, including Rb, protoporphyrin, hematoporphyin, chlorophyll a and b, and unidentified tetrapyrroles (Webster et al., 2009, 2011; Duncan and Chang, 2012). Photosensitizers initiate oxidation after being activated by light. Photosensitizers are important because they cause the destruction of milk components usually unaffected directly by light (Boff and Min, 2002). Excitation of Rb, the most studied photosensitizer in milk (Sattar et al., 1976; Wold et al., 2005; Webster et al., 2009), occurs when exposed to light at 250, 270, 370, 400, 446, and 570 nm wavelengths (Kyte, 1995). Some LED lights have visible light spectrums with greatest intensity at the wavelengths of greatest concern. Detrimental retail case lighting effects may be alleviated by selecting appropriate packaging materials to minimize the transmission of light (Duncan and Hannah, 2012).

In the United States, milk is commonly packaged in waxed paperboard, high-density polyethylene (**HDPE**) or polyethylene terephthalate (**PETE**). The HDPE transmits 57 to 60% of light wavelengths between 300 and 700 nm (van Aardt et al., 2001; Duncan and Hannah, 2012). The packaging material frequently used for single-serve milk products, PETE, transmits up to 75 to 85% of visible light. Packaging material can have a protective effect on milk quality through blocking or reducing the transmission of certain light wavelengths (Webster et al., 2009). It is important, then, to develop packaging materials that are consumer friendly yet block the most damaging wavelengths to milk quality.

One possible packaging innovation that has shown usefulness in protecting against photooxidation is titanium dioxide (TiO_2). Since its commercial production in the early 20th century, TiO_2 has been widely used as a leading white pigment in paints, toothpaste, and packaging. Titanium dioxide is a photo-responsive material and its importance is steadily increasing in the polymer and plastic industry (DuPont, 2007). Due to its ability to scatter light and absorb UV light energy, TiO_2 has been added at different concentrations to HDPE and PETE (Robertson, 2006). Moysssiadi et al. (2004) showed that a multilayer HDPE package pigmented with TiO_2 and carbon black protected milk better than a monolayer HDPE package pigmented with TiO_2, clear PETE and PETE pigmented with TiO_2 when stored under fluorescent light at 4°C for 7 d. They found the multilayer HDPE package protected milk quality and suffered only a 28% Rb loss. The particle size of TiO_2 can be altered to affect color of light wavelengths transmitted (DuPont, 2007). Innovation in the use of TiO_2 particle size and refraction properties may improve packaging materials for milk quality protection.

Almost 30 yr ago, White (1985) evaluated consumer (n = 393) response to pigmented HDPE packaging options [opaque white, cream colored, yellow, and a natural (translucent)] for milk; opaque white packaging was most frequently selected as the preferred package if no additional cost was incurred. This study also indicated that most respondents (75%) did not think product visibility was a concern, suggesting that pigmented packaging could be successful. Respondents were equally concerned about the effects of light on nutrition and flavor. This early study suggests that consumers are willing to consider packaging modifications that protect milk flavor and nutrient quality. However, little guidance is available to the industry to identify the level of TiO_2 that is needed for milk quality protection.

The overall purpose of this research was to quantify performance of TiO_2-dosed HDPE packaging on preserving milk sensory quality and oxidative stability through prevention or control of photochemically induced reactions.

The objective of this research was to determine changes in sensory characteristics, vitamin (Rb) retention, and oxidative stability of 2% milk packaged in HDPE bottles with different TiO_2 modifications up to 36 d of refrigerated (3°C) storage under fluorescent lighting, simulating retail storage.

MATERIALS AND METHODS

Packaging

The HDPE bottle types were differentiated using commercially available titanium dioxide pigments contained within the bottle resin, yielding bottles with different levels of light protection. Four levels of TiO_2 in HDPE (total of 5 packaging treatments) were tested, including 0% (translucent) serving as controls (light exposed: no light barrier; light protected: foil overwrap) and the 3 experimental TiO_2-modified packaging treatment levels (low: 0.6%; medium: 1.3%; high: 4.3%). Bottle dimensions were 7.16” height × 3.29” width × 2.1” depth and a volume of 528 mL. We could readily see the milk in the control HDPE packages (translucent), but the visual appearance of the experimental TiO_2-loaded packages was opaque white and prevented visualization of the milk.