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Retail lighting and packaging influence consumer acceptance of fluid milk

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ABSTRACT

Little is known about the effect of retail light-emitting diode (LED) exposure on consumer acceptance of milk. The study objective was to determine effects of fluorescent and LED lighting under retail storage conditions on consumer acceptance of milk. Consumer acceptance of milk stored under retail conditions was determined through sensory evaluation (2 studies; n = 150+ each) and analytical measures (dissolved oxygen, secondary oxidation products, riboflavin retention). Study 1 evaluated milk stored in high-density polyethylene (HDPE) packages for 4 h under LED light (960 lx). Commercially available HDPE package treatments included translucent HDPE (most commonly used), white HDPE [low concentration (1.3%) TiO_2], and yellow HDPE; in addition, HDPE with a higher TiO_2 concentration (high white; 4.9% TiO_2) and a foil-wrapped translucent HDPE (control) were tested. Translucent and control packages also were tested under fluorescent light. Study 2 evaluated polyethylene terephthalate (PET) packages for 4 h under fluorescent and LED light (1,460 lx). The PET packaging included 2 treatments (medium, 4.0% TiO_2; high, 6.6% TiO_2) as well as translucent HDPE (exposed to fluorescent), clear PET (fluorescent and LED), and light-protected control. Overall mean acceptability of milk ranged from "like slightly" to "like moderately" with significantly lower acceptability for milk exposed to fluorescent light. Milk in HDPE and PET packages had comparable overall acceptability scores when exposed to LED light. Only the fluorescent light condition (both PET and HDPE) diminished overall acceptability. Fluorescent light exposure negatively influenced flavor with significant penalty (2.0–2.5 integers) to overall acceptability of milk in translucent HDPE and clear PET. The LED also diminished aftertaste of milk packaged in translucent HDPE. Changes in dissolved oxygen content, as an indication of oxidation, supported the observed differences in consumer acceptance of milk stored under fluorescent and LED light. Consumers like the flavor of fresh milk, which can be protected by selecting appropriate packaging that blocks detrimental light wavelengths.
Key words: milk, oxidation, sensory, light-emitting diode (LED)

INTRODUCTION

Milk consumption in the United States has been declining for several decades. Overall, fluid milk sales decreased 5.2% in 2015 alone (Bauer, 2016). Part of the reason for this decline is increasing beverage competition in the retail case with alternative plant-based milk beverages. This decline may also be attributed to consumer experiences with fresh milk of low flavor quality due to light-induced oxidation reactions. As a result of light exposure in the retail case, milk flavor quickly deteriorates from the sweet, bland flavor of fresh milk, with a clean, pleasing aftertaste (Alvarez, 2009). The oxidation reaction alters milk flavor, with milk becoming less sweet and developing a cardboard flavor (Alvarez, 2009) as a variety of volatile compounds are generated that overwhelm fresh milk flavor. Simultaneously, milk nutrients are affected by oxidation reactions, including vitamins (riboflavin, **Rb**; vitamin A), lipids, and proteins.

Flavor is one of the most important characteristics that influences repeat purchase behavior (Schifferstein et al., 2013). Untrained consumers can detect light-oxidized off-flavor in 2% milk exposed to fluorescent light after as little as 54 to 120 min of fluorescent light exposure (2,000 lx; Chapman et al., 2002), which is well within the timeframe that packaged milk is displayed within the dairy retail case. Heer et al. (1995) reported a threshold of detection for light-oxidized flavor in 2% milk at 150 min (fluorescent; 1,100–1,300 lx). Only a few studies have reported how light-induced flavor affects consumer acceptance, however. Heer et al. (1995) reported mean acceptability scores of light-exposed milk (at threshold of detection) for middle school students as "dislike slightly" (mean = 4.2; n = 17), college students as "neither like nor dislike" (mean = 5.2; n = 30), and adults as less than "like slightly" (mean = 5.6; n = 25). Walsh et al. (2015) found that consumers (n

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= 41 college students; 33 female) expressed decreased acceptability of light-oxidized milk (2% milkfat; 375 lx at the shoulder of the HDPE package; 1,738 lx in lightbox) after 8 h of storage, with mean scores of 5.85 ± 2.23 (less than "like slightly"; 95% CI: 5.15–6.56) for light-exposed milk compared with 7.2 ± 1.05 ("like moderately"; 95% CI: 6.86–7.53) for light-protected milk. Arnade et al. (2013) reported an overall acceptability of 5.7 (less than "like slightly") for milk purchased directly from the retail case (n = 48 college students). These studies, although they indicate that consumers negatively respond to light-induced flavor, are limited by the small sample size.

The adverse effect of fluorescent light on milk quality has been well documented and the subject of primary research and reviews (Chapman et al., 2002; Mestdagh et al., 2005; Duncan and Webster, 2010; Johnson et al., 2015; Brothersen et al., 2016). Many retailers are switching from fluorescent lights to more energy-efficient light-emitting diode (**LED**) lights to meet US Department of Energy mandated energy reduction requirements. However, milk oxidation under LED light is a new area of study that warrants further attention. Brothersen et al. (2016) showed that LED light intensity (4,000 lx) caused less extensive nutritional changes from light-induced oxidation in 1% milk than fluorescent light (2,200 lx) after 24 h of light exposure. Consumer (n = 90) overall liking scores for milk (1% milkfat; vitamin A and D added) stored for 24 h under LED and fluorescent lighting-exposed samples were 5.4 (just above "neither like nor dislike"), whereas milk stored in the absence of light had significantly higher acceptability (mean = 6.3; "like slightly"). Milk for this experiment was processed at the university creamery, packaged into high-density polyethylene (**HDPE**) half gallon containers, and exposed to lighting using light boxes (Brothersen et al., 2016). Martin et al. (2016), using freshly processed milk attained directly from several processing plants, reported the effect of LED light exposure (1,200 lx; 4 h) in a light box on consumer (n = 150) acceptance of both nonfat and 2% milk. Fresh nonfat LED-exposed milk had an overall acceptability score of 5.7 ("like slightly") in comparison to the control, with a score of 6.6. A similar trend was observed with 2% milk. As milk aged (14 d), the influence of the light-induced flavor was less influential on acceptability.

Date coding on milk packages indicate the time frame through which the product will taste and smell good (Keith, 2005; USDA, 2015). When a consumer purchases milk, the code is often used in the decision. Martin et al. (2016) reported that consumers had a more negative reaction to milk illustrating effects of light exposure than they did to milk with early stages of bacterial growth as products approached code. Consumer experience with milk (appearance, odor, taste) at the time of opening and first use contributes to their perception of freshness and, indirectly, in their trust and confidence in the product (Schifferstein et al., 2013), the manufacturer, as well as the dairy industry. Their decision to repeat purchase is influenced by this experience. The effect of light on fluid milk flavor and aftertaste contributes to freshness perception and overall acceptability, especially for milk packaged in traditional translucent HDPE and even for some commercially utilized HDPE packages with light protective additives. Although code date is typically established based on microbial spoilage, consumers may not believe the (light-exposed) milk they just purchased, which is well within code date, is fresh or they may think that fresh milk does not taste good.

The majority of milk is currently packaged in HDPE. However, translucent HDPE packages provide insufficient protection against light exposure and allow for extensive light-induced oxidation to occur in milk (Brothersen et al., 2016; Martin et al., 2016). Polyethylene terephthalate (**PET**), with higher oxygen barrier properties, may offer a higher degree of protection against light-induced oxidation because oxygen availability is limited to the dissolved oxygen (**DO**) in the milk and the package headspace (Potts et al., 2016).

Pigmentation of packaging materials provides additional protection by blocking certain light wavelengths from reaching milk inside the package. White (1985) identified that consumers preferred white and cream pigmented plastic milk packaging more than translucent or yellow. At the time of the study (White, 1985), most consumers surveyed (74%) were not concerned about whether they could see the product; they had equal concern about flavor and nutritional value of the milk. Knowledge is lacking about consumer acceptance of milk packaged in PET and milk stored in LED-lit retail conditions.

The objectives of this experiment were to characterize consumer acceptance of 2% milk when (1) exposed to retail lighting (LED, fluorescent) conditions and (2) in packaging (HDPE, PET) with different light blocking properties. A unique feature of this study is the use of commercially produced retail dairy cases, equipped with LED and fluorescent lighting, to effectively mimic the lighting conditions under which consumers select their milk for purchase.

MATERIALS AND METHODS

Experimental Design Overview

This experiment was completed as 2 studies. Each study assessed acceptability and quality of milk after