Food Research International 114 (2018) 1–9

Contents lists available at ScienceDirect

Food Research International

journal homepage: www.elsevier.com/locate/foodres

Efficacy of light-protective additive packaging in protecting milk freshness in a retail dairy case with LED lighting at different light intensities

Aili Wang[a,*], Catherine H. Dadmun[b], Rachel M. Hand[c], Sean F. O'Keefe[a], J''Nai B. Phillips[a], Kemia A. Anders[a], Susan E. Duncan[a]

[a] Department of Food Science and Technology, Virginia Polytechnic Institute and State University (Virginia Tech), Blacksburg 24061, United States
[b] Department of Chemistry, College of Charleston, Charleston 29424, United States
[c] Department of Food Science and Human Nutrition, Michigan State University, East Lansing 48824, United States

ARTICLE INFO

Keywords:
Milk
Oxidation
LED
Light intensity
Packaging
PET
Freshness

ABSTRACT

Light emitting diodes (LED) are rapidly developing as dominant lighting systems in dairy retail cases. Bright light is typically chosen to best exhibit milk products. However, high intensity LED lighting may create high potential for detrimental oxidation and destroying milk freshness. In this study, we investigated the interaction between LED light intensity, exposure time, and packaging material on limiting milk oxidation and protecting milk freshness and vitamins. Within 4 h of LED light exposure at an intensity as low as 1068 lx, light-induced oxidation occurred on 2% milkfat milk with commercial packaging including glass and translucent high-density polyethylene (HDPE) bottles. Higher light intensity (> 4094 lx) and longer light exposure time (> 24 h) rapidly increased the oxidation rate in milk. Polyethylene terephthalate (PET) packaging with lower oxygen permeability rate effectively reduced ($P < 0.05$) vitamin A degradation under low light intensity within 24 h. A combination of light-protective additive (TiO_2) and oxygen barrier material (PET) successfully reduced ($P < .05$) the loss of dissolved oxygen and riboflavin, and decreased the formation of final oxidation products in milk, as measured by thiobarbituric reactive substances (TBARS), when exposed to high light intensity within 24 h. Lower LED light intensity in retail case was preferred by 50% of participants in a visual acceptance test; consumers are willing to consider pigmented packaging with limited visibility. Results of this study provides guidance for dairy industry in choosing appropriate LED lighting conditions and packaging to adequately display the milk products as well as minimize the degradation of milk nutrients and flavor.

1. Introduction

Retailers choose lighting in dairy retail cases commonly based on aesthetics and display of products, but with little awareness of the destructive impact of lighting intensity and exposure time on milk quality. Impact of traditional fluorescent lighting intensity and display time on milk nutrients and flavor has been well studied (Mestdagh, De Meulenaer, De Clippeleer, Devlieghere, & Huyghebaert, 2005; Walsh, Duncan, Potts, & Gallagher, 2015; Webster, Duncan, Marcy, & O'Keefe, 2009). However, light emitting diode (LED) lights are rapidly developing as dominant lighting in retail dairy cases to address both marketing needs and U.S. Department of Energy (DoE)-imposed mandates on energy conservation. Few studies have investigated the effect of emerging LED lighting on milk quality (Brotherson, McMahon, Legako, & Martini, 2016; Martin et al., 2016; Potts, Amin, & Duncan, 2017).

Milk oxidation mainly occurs when exposed to natural or artificial light, including sunlight, fluorescent, and LED light. Activated photosensitizers in milk (such as riboflavin) excite oxygen to its singlet state, which actively reacts with other nutrients in milk such as unsaturated lipids, vitamins, and proteins (Skibsted, 2000). Light-induced oxidation then rapidly forms off-flavor in milk, which resulted in a profound negative effect on consumer acceptance of milk (Chapman, Whited, & Boor, 2002; Heer, Duncan, & Brochetti, 1995; Walsh et al., 2015). Potts et al. (2017) reported untrained consumers could detect the off-flavors in 2% milkfat milk within only 4 h of fluorescent light exposure at low intensity (1460 lx), with significant decrease in acceptability rating.

Two most important factors that cause oxidation in packaged milk are oxygen permeation and light transmission rate of packaging material. However, current packaging options are not sufficient to protect milk freshness (Duncan & Webster, 2010; Johnson et al., 2015; Walsh

* Corresponding author at: Department of Food Science and Technology, Virginia Tech, HABB1, 1230 Washington St SW, Blacksburg, Virginia 24061-0924, United States.
E-mail address: waili9@vt.edu (A. Wang).

https://doi.org/10.1016/j.foodres.2018.07.053
Received 8 May 2018; Received in revised form 11 July 2018; Accepted 30 July 2018
Available online 31 July 2018
0963-9969/ Published by Elsevier Ltd.

et al., 2015). Glass provides excellent oxygen barrier properties (Kontominas, 2010) but non-colored glass allows approximately 90% of visible light transmission (Duncan & Hannah, 2012; Singh & Singh, 2005). Paperboard packaging largely reduces light transmission but its oxygen transmission rate was 54 times higher than clear polyethylene terephthalate (PET) bottle and 19 times higher than pigmented high-density polyethylene (HDPE) bottle (Brotherson et al., 2016). Commercial translucent HDPE packaging provides insufficient protection against light exposure and allows for extensive light-induced oxidation to occur in milk (Brotherson et al., 2016; Martin et al., 2016).

Although packaging with complete light block has been shown to be most effective at protecting milk freshness, it is not economically feasible on a mass scale (Mestdagh et al., 2005; Moyssiadi et al., 2004; Webster et al., 2009). Therefore, application of light-protective additives (LPA) in milk packaging is developing as an economic option for milk industry. Titanium dioxide (TiO_2) is a white pigment that can scatter light and absorb UV light energy and may be added in HDPE and PET plastics to create varying levels of opaqueness (Dupont, 2018). Using a novel light protection performance assessment, the efficacy of titanium dioxide pigments in plastic packaging for protection of riboflavin has been estimated (Stancik et al., 2017). However, little guidance is available for the dairy industry to identify the necessary level of TiO_2 in packaging to protect milk freshness under varying LED lighting intensity conditions.

The objective of this study is to investigate the influence of LED lighting in retail cases at low and high intensity on milk oxidation rate, and compare the effectiveness of packaging materials (glass, HDPE, PET) with and without LPA and oxygen barrier properties for protection of milk freshness during LED lighting exposure. Quantification of packaging performance in preserving milk nutrients and oxidative stability was evaluated through riboflavin and vitamin A degradation, dissolved oxygen concentration, formation of oxidative products, and *E*-nose analysis for milk volatiles composition. In addition, consumers' preference for milk packaging under low and high LED light intensity in retail case was also evaluated.

2. Materials and methods

2.1. Survey of lighting condition in retail stores

Survey of lighting condition and milk turnover time in dairy retail cases was conducted by interviewing store managers in ten national chain stores located at Blacksburg, Christiansburg, and Roanoke in Virginia. This study was approved by the Virginia Tech Institutional Review Board (IRB #15–1117). Results of this survey were blind to the name of the stores. LED light intensity of retail case in each store was detected by a handheld light meter (Model SN400, Extech Instruments, Nashua, NH). Light readings were recorded at milk bottles placed most closely to the LED bulb in each shelf and data of at least three shelves was collected. The light meter was placed at a 45° angle at bottle neck in order to record the most intensive light exposure on each bottle.

2.2. Packaging

HDPE packaging was commercial high-density polyethylene bottles (1.89 L) blow-molded using HDPE resin (Consolidated Container Co., Atlanta, GA). Package dimensions were 25.1 cm height × 9.8 cm width. Wall thickness was detected by an electronic digital caliper (Mitutoyo 500–196-30, Tokyo, Japan); measurements were taken at the center of wall from three different sides. Polyethylene terephthalate (PET) packaging was made (PTI Technologies, Holland, OH) following standard injection blow-molding processes from PET resin, yielding a shape like a standard 2-L soda bottle. Package dimensions were 25.08 cm height × 9.84 cm diameter.

Titanium dioxide (specialty grade, The Chemours Co., Wilmington, Delaware) was used as light-protective additive (LPA) in the tested packaging in this study. Three HDPE and three PET packaging were designed for this study, including TiO_2-added HDPE (4.9% TiO_2), light-exposed control (translucent HDPE, ~ 86% of light transmission), light-protected control (translucent HDPE bottle overwrapped with foil, ~ 0% of light transmission), TiO_2-added PET (4.0% TiO_2), light-exposed control (clear PET bottle, ~ 100% of light transmission), and light-protected control (clear PET bottle overwrapped with foil, ~ 0% of light transmission).

Glass bottles (0.5 gal) were purchased from Amazon online store. Package dimensions were 25.4 cm height × 12.7 cm width. Glass bottle was transparent and allowed full visibility of milk (~90% of visible light transmission).

2.3. Filling milk into treatment packages

High-temperature-short-time [HTST] pasteurized fluid milk (2% milkfat, vitamin A and D fortified) packaged in commercial translucent HDPE packages (1.89 L) was purchased from a local supermarket (Kroger, Blacksburg, VA). Milk was purchased directly from the dairy manager on the day of delivery soon after receipt to ensure freshness and limit light exposure in the store. Milk was transported in light-blocking coolers with ice for light and temperature protection (estimated 2–4 °C) to the Virginia Tech pilot plant within 15 min (Blacksburg, VA).

Milk was rapidly transferred into package treatments under a clean-fill positive flow laminar hood (Thermo Fisher Scientific, Waltham, MA), capped by hand, and stored in a dark walk-in retail case (model 3800, HillPhoenix, Chesterfield, VA) until transferred to the lighted retail case. The filling process was conducted by continuously pouring milk from commercial packaging into a sanitized 10-L container for homogenization, then milk was transferred into each packaging bottle through the faucet at the bottom of the container leaving a headspace of 30 ± 10 mL for each bottle. Milk was clean-filled into experimental packages under positive laminar flow hood (Atmos-Tech Industries, Ocean, NJ) to prevent contamination. Filled packages were immediately placed in dark, refrigerated walk-in coolers until light exposure experiments.

2.4. Lighting treatments

Two refrigerated cases were used to model retail conditions in the current study. The closed-door retail case (Model ONRB4, Hillphoenix, Chesterfield, VA) was equipped with LED light bulbs of 9 watts and the walk-in/closed-door retail case (Model 3800, Hillphoenix, Chesterfield, VA) was installed with LED light bulbs of 18 watts. Milk-filled packages were placed only on the front row on each shelf and water-filled bottles were placed behind the front row to simulate a fully stocked retail case. To ensure each tested milk bottle received identical light exposure, light intensity of each position in the front row was detected by a handheld light meter (Model SN400, Extech Instruments, Nashua, NH). Fourteen positions in each retail case were identified with similar lighting exposure, which generated an average light intensity of 1068 ± 91 lx in closed-door retail case and 4094 ± 110 lx in walk-in/closed-door retail case.

Each packaging treatment ($n = 7$) was tested in duplicate under each light intensity, creating a total of 14 bottles in each retail case at each time treatment. Milk-filled package placement was randomized by JMP 10.0 Statistical Discovery Software (SAS Institute, Cary, NC) within each retail case so that all treatments were distributed randomly at 14 lighting positions in the case, in order to reduce effects of variation in light intensity within each case. Temperatures of all three retail cases were maintained at 4 °C ± 1 °C throughout the experiment.

Tested milk packaging ($n = 7$) for each light intensity ($n = 2$) was stored under light exposure for 3 time intervals (0, 4, 24 h) for each replication. Three replications were completed for this study. Milk samples saved for riboflavin (10 mL/each), TBARS (1 mL/each), and