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Exposure to light-emitting diodes may be more damaging to the sensory properties of fat-free milk than exposure to fluorescent light

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ABSTRACT

Light exposure can damage the sensory properties of milk, leading to adverse consumer responses. This is presumed to be through the action of photosensitive compounds such as riboflavin, present in milk and capable of releasing energy when irradiated, leading to damage of proteins and fats in the milk. Light-emitting diode (LED) lighting is assumed to be less damaging to milk due to lower inherent power consumption. In this study, fat-free milk was exposed to LED and fluorescent light at 2,000 lx to compare the sensory thresholds of exposure, the flavor profile of milk produced by these exposures, and resultant consumer acceptance of the samples. Additionally, the effectiveness of light-protective packaging and supplementation with antioxidants was evaluated. The sensory threshold from LED exposure was no longer than from fluorescence, whereas with antioxidants (tocopherols and ascorbic acid), the majority of the panelists failed to discriminate milk exposed to LED light even at 48 h of exposure. Trained panelists described light-exposed milk as significantly higher in cardboard, old oil, and plastic, with LED exposure resulting in a marginally more plastic aroma, and fluorescent marginally more cardboard. Consumers reported higher liking for fluorescent-exposed samples versus those exposed to LED. The antioxidant-supplemented samples, and those exposed to LED light engineered to eliminate wavelengths below 480 nm (thus most of riboflavin's absorption peaks), resulted in significantly higher old oil aroma; however, the former received higher liking scores than LED-exposed samples. Light-protective packaging offered near-complete protection from LED exposure, with a similar flavor profile as unexposed milk, and the best liking scores of any treatment. Nevertheless, consumers disliked its appearance, due to unfamiliarity, suggesting some consumer education may be needed if this were to be an efficient protective strategy.

Key words: fluid milk, sensory, consumer, hedonic, light, light-emitting diode

INTRODUCTION

Americans are not fulfilling their daily recommended intake of dairy products (Stewart et al., 2013), partly due to a decrease in fluid milk consumption. Milk flavor and nutritional content are affected by light. This process begins with riboflavin, porphyrins, chlorins, and other photosensitive components (Wold et al., 2005), once activated, producing singlet oxygen that can react with proteins, vitamins, and lipids (Choe et al., 2005), leading to sensory defects in the milk. The off-flavors generated are mainly attributed to AA and UFA oxidation, forming methionine sulfoxide, dimethyl disulfide, and various aldehydes and ketones (Jung et al., 1998; Min and Boff, 2002; van Aardt et al., 2005).

Light-emitting diode (**LED**) light usage in retail stores is increasing, but some disagreement is present about the details of the sensory effects of LED on milk. Brothersen et al. (2016) found that fluorescent (at 2,200 lx) compared with LED light (at 4,000 lx) had faster and higher production of off-flavor-generating compounds in 1% milk. In sensory testing, a more complex story emerged. At 12 h, the trained panel detected a bigger decrease in cooked sweet in the LED sample, with a bigger increase in butterscotch and cardboard in the LED samples. However, at 24 h, the majority of the more extreme sensory changes were in the LED sample, with lower milk fat, alongside a higher perception of cardboard in the LED-exposed samples. It should be noted plastic was 0.5 units higher in LED than fluorescent at 24 h, versus only 0.1 units higher in fluorescent at 12 h; thus, presumably we can assume from this result that LED lights are more damaging to milk over long exposure times. Although consumers reported higher liking for the 12-h-exposed LED samples versus fluorescent, no differences in consumer response were reported at 24 h of exposure.

On the other hand, Martin et al. (2016) demonstrated that consumers robustly reject LED-exposed milk (at 1,200 lx), particularly if fat free. When evaluating

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several samples fresh or near code, light exposed or not, consumers rated those exposed to light as less liked than even those approaching code, as long as they were not exposed to light. This came with corresponding increases in plastic aroma in trained panel results. Consequently, it is necessary to characterize and contrast the sensory effect of LED and fluorescent light on fat-free milk (De Jesus and Dando, 2016), and moreover to evaluate possible protective strategies to safeguard milk quality. It is reasonable that light damage favors AA damage, rather than lipid oxidation, in fat-free milk, thus resulting in a differing pattern of sensory damage. Methionine for instance, which breaks down readily in the presence of light and riboflavin (Bradley and Min, 1992), can form multiple species linked to light-activated flavor (Finley and Shipe, 1971).

Protective packaging materials, light wavelength tailoring, and antioxidant supplementation have been studied as possible interventions to prevent milk off-flavors from developing during light exposure. Potts et al. (2017) exposed milk for 4 h to LED and fluorescent light in high-density polyethylene (**HDPE**) and polyethylene terephthalate (**PET**) packages with and without TiO_2. Consumers' overall liking did not decrease in any LED condition, only decreasing for the fluorescent light conditions, with translucent materials offering some protection. In another approach, a mixture of tocopherol and ascorbic acid was able to avoid off-flavor development after 10 h of fluorescent light exposure (van Aardt et al., 2005), with oxidation presumably mitigated due to antioxidants reacting with singlet oxygen, or protecting photosensitive compounds (Hall et al., 2010).

The purpose of this study was (1) to determine the minimum duration of exposure to fluorescent and LED light in fat-free milk, and to evaluate the efficacy of antioxidant enrichment, (2) to compare the flavor profile via descriptive sensory of fat-free milk exposed to LED and fluorescent light, as well as determine the effectiveness of protective measures in milk exposed to LED, and (3) to characterize consumer acceptance for all these conditions.

MATERIALS AND METHODS

All procedures in this report were approved by the Cornell Institutional Review Board for testing with human subjects. Testing consisted of 3 phases of testing, each with a different design and panel. Full details of each session are given below. In the first, samples were tested for the threshold time of exposure sufficient for panelists to notice a difference between nonexposed and exposed samples, for milk exposed to LED, to fluorescent, and to LED with antioxidant enrichment. In the second phase, descriptive analysis examined samples over multiple sessions, exposed to LED and fluorescent, as well as a control, samples enriched with antioxidants and the same samples later exposed to LED, a sample exposed to LED light lacking riboflavin excitation bands, and samples exposed to LED while in light-protective packaging. In the final phase, consumers assessed their liking for the same samples as phase 2.

Sensory Threshold Testing

Three sessions were scheduled to test the minimum duration of exposure to fluorescent light; to LED light (hereafter referred to as the sensory threshold of light exposure); and to exposure to LED with antioxidants. The sessions took place 1 wk apart, from a separate lot of fresh milk each time. In each part of the study, fat-free milk was purchased from the Cornell dairy plant, with each day of testing using samples from the same production run. Milk was HTST pasteurized at 173°F (78.3°C) for 22 s. Control milk bottles were wrapped in aluminum foil after processing and were not exposed to light. All samples were stored at 4°C in high-density polyethylene half-gallon containers with lids. Bottles were not open until pouring and had minimal headspace. Samples were exposed at 2,000 ± 100 lx to either LED (Zhejiang Yankon Group Co. Ltd., China) or fluorescent (Lab Supplies Co. Inc., Hicksville, NY) light. Rigs were custom made, and each bottle was positioned using a light meter so the light-facing edge was at a position corresponding to 2,000 lx. For the antioxidant treatment, food-grade mixed tocopherols and L-ascorbic acid were purchased from Sigma-Aldrich (St. Louis, MO) and added at 0.025% tocopherols and 0.025% L-ascorbic acid. Thirty-milliliter samples were poured into 5-oz plastic cups with plastic lids. An ascending exposure forced-choice method was used. A 3 alternative forced choice threshold test with 8 steps (0.5, 1, 2, 4, 8, 12, 24, and 48 h) was used. Participants were presented with sets of 3 samples, 2 of which were controls and 1 of which was the light-treated sample. Panelists were instructed to identify the odd sample. Participants evaluated the sets starting with the least exposed sample (1 h) and ending with the most exposed (48 h). Samples were presented at 4 to 6°C. Each session was conducted on a separate day, with panelists recruited from Cornell University's staff, student, and faculty population. Participants received a $5 compensation for each session and a $10 bonus if they attended all 3 sessions. Fifty-six panelists attended the fluorescent session, 67 panelists the LED session, and 66 panelists the LED with antioxidants session.

Participants performed the test in separate sensory booths on computers using RedJade sensory evalua-