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Comparing quality and emotional responses as related to acceptability of light-induced oxidation flavor in milk

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ABSTRACT

Off-flavors in fluid milk often result from light exposure during retail display if milk packaging does not provide light-blocking protection. There is no direct evidence that light-induced oxidation affects milk acceptability. In this 2-part study, effects of fluorescent light exposure (375 lx at the package) on fluid 2% milk packaged in HDPE without and with a (foil) light-blocking overwrap for periods of 8, 72, and 168 h (4 °C) were determined. Study 1 evaluated oxidative stability of milk, as well as consumer acceptability (hedonic 9-pt scale) and explicit emotional response (check-all-that-apply terminology selection) at 8 and 168 h ($n = 41$). Oxidative stability was measured by riboflavin (Rb) and thiobarbituric reactive substances (TBARS) assays. Rb, a photo-initiator of the oxidation reaction, decreased significantly, with 71% loss by 168 h. TBARS assays showed significant increases in oxidative by-products by 168 h. Within 8 h of light exposure, acceptability decreased significantly from 7.20 ("like moderately") to 5.85 (below "like slightly") and decreased further to 3.46 (between "dislike moderately" to "dislike slightly") by 168 h. Light-protected milk (control) maintained a score of 7.0 over 168 h. Emotion term selection reflected acceptability response; the term disgust was used more frequently for both the 8 h (17.1%) and 168 h (46.3%; $p < 0.05$) light-exposed milk compared to both light-protected milks (2.4% 8 h; 12.2% 168 h). Light-protected milk had higher frequency of positive emotion term selection (content, calm, good, happy, and pleased) than did light-exposed milk (168 h). In study 2, automated facial expression analysis was completed ($n = 12$) at 72 h light exposure. Automated facial expression analysis provided evidence for great variety of unique responses from individuals. Light-induced reactions in fluid milk affect emotional response and flavor acceptability of milk, which may be contributing to the reduction in fluid milk sales and decreased milk consumption.

1. Introduction

Consumption of fluid milk and milk products is decreasing in all age groups. The most significant difference is among adolescents, where milk consumption has declined about 25% since 1977, putting this age group at increased risks of osteoporosis later in life. Adolescents who are consuming milk are drinking only half as much milk as 28 years earlier (Sebastian, Goldman, Enns, & LaComb, 2010). Competition against other beverages in the market place may be one cause of declining milk consumption.

Flavor quality of fresh milk, which is affected by light exposure in retail dairy display cases, may also be a contributor to declining milk sales and consumption. Quality standards are primarily based on microbial assessment as an indication of shelf life (Chandan, Kilara, & Shah, 2008). Industry standards for milk quality, as well as retailer efforts for marketing milk using bright retail lighting, do not consider the rapid changes in fresh milk flavor that occur between display storage prior and consumer purchase.

In retail refrigerated dairy cases, fluorescent and/or LED lights are used to display milk products. It is well documented that light exposure causes oxidative chemical changes to milk proteins, fats, and other nutrients, leading to off-flavors, as reviewed by Duncan and Webster (2010). These chemical changes are initiated when riboflavin (Rb) and other photosensitive molecules in milk are activated by light energy. Light energy is transferred from these photosensitive molecules to other molecular species in milk, with the subsequent production of volatile aldehydes and other flavor compounds. The increase in flavor-contributing volatiles overrides the bland, slightly sweet flavor of high-quality milk (Alvarez, 2009). In addition, many vitamins can be degraded during light exposure, reducing nutritional value (Duncan & Chang, 2012; Duncan & Webster, 2010). Light protection of photosensitive molecules in milk is needed to protect milk flavor and nutrient quality.

Commonly used plastic milk packaging, such as natural (translucent) high density polyethylene (HDPE) and clear polyethylene terephthalate

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(PET), do not sufficiently protect milk from light-induced oxidation reactions during retail storage conditions (Johnson et al., 2015). Flavor changes due to light exposure occur rapidly and off-flavors can be detected within 54 min to 2 h of light exposure by untrained panelists (Chapman, Whited, & Boor, 2002). From the point of processing until retail purchase, milk may receive 7 or more days of light exposure (Senyk and Shipe, 1981). About 50% of milk packages remain in the retail lighted dairy case for 8 h or more, providing ample time for flavor and nutrient degradation (Chapman et al., 2002). The incentive for the dairy industry to identify optimized packaging options to protect fresh milk quality is related to improving milk sales, which corresponds to increasing consumer acceptability and motivation for consuming milk. However, there is limited evidence that describes the effect of retail dairy case lighting on consumer acceptability.

Consumer acceptability, traditionally measured using the hedonic scale, is not always successful at predicting consumption or product success (Schroder, 2003). Acceptability does not give adequate insight into how the consumer truly feels about a product (Köster, 2007). The 70–80% failure rate of new products on the market suggests that better techniques for evaluating product acceptability would be advantageous (Stanton, 2013). The addition of emotion assessment is an emerging area of research, as it provides information to better understand how to differentiate between similar consumer responses to a product (Cardello et al., 2012).

In psychology literature, six universal emotions are identified and classified as either "approach" (happy, surprise and anger) or "withdrawal" (fear, sadness, and disgust) (Alves, Fukusima, & Aznar-Casanova, 2008; Ekman et al., 1987). In literature outside of the psychology domain, these emotions are often classified as positive (happy) and negative (anger, fear, sadness, and disgust) (King & Meiselman, 2010); surprise can be either negative or positive (Alves et al., 2008). Even though this categorization is rudimentary, identifying evoked "approach" and "withdrawal" emotions may help predict product success.

To further increase market success, evaluating cognitive (explicit) and subconscious (implicit) expression of emotions for understanding product acceptability may have value (Cardello et al., 2012). Explicit, or conscious responses, to a product, such as hedonic scoring, are widely used (Peryam & Kroll Research Corporation, 1998). An example of an explicit emotion-based tool used for evaluating potential new products is the check-all-that-apply (CATA) emotional terminology selection approach (King & Meiselman, 2010; King, Meiselman, & Carr, 2010). Implicit emotions are more difficult to understand and measure but may also describe underlying emotional influences on product acceptability. Automated facial expression analysis (AFEA) technology monitors many points on the face to determine the expression of the 6 universal emotions (as well as a neutral state) using differences in facial movements and textures (Loijens & Krips, 2012). Movement of the eyes, eyebrows, lips, head orientation, gaze, nose, and cheeks are monitored. Using software to integrate the movements into emotional categorization, the identification of and intensity of each of the universal emotions is computed (Loijens & Krips, 2012; Noldus Information Technology, 2012). This technology potentially provides value for understanding unstated emotional response to a food or beverage product and reduces the influence of thoughts and external factors on participant response. Only one study has applied AFEA analysis to assessing emotional response to fluid milk (Arnade, Duncan, Rudd, Dunsmore, & O'Keefe, 2013a). The combined understanding of both implicit and explicit emotions has potential for greatly enhancing traditional sensory methods for greater consumer insight and the possibility of improved market success.

Milk, having many nutritional benefits, is particularly important to consume within the young adult population when bone structure is in its final stages of being established (Heaney et al., 2000). It is thus important to understand flavor influence on acceptability and emotions of young adults to improve purchasing and consumption behaviors. The objective of this project was to evaluate the influence of light exposure on milk quality, acceptability and emotional responses in a young adult (college) population. We hypothesized that light exposure of milk for as little as 8 h causes sufficient oxidation to reduce consumer acceptability and negatively affect emotional response, providing significant evidence for the need to improve milk packaging.

2. Materials and methods

2.1. Overview of design

This project consisted of two studies. Study 1 focused on analytical measures of milk quality, acceptability and explicit emotions in response to milk stored for two lighting durations (8 h and 168 h; 4 °C) compared to light-protected control conditions. Study 2 added implicit emotional responses relate to acceptability of light-protected and light-exposed fluid milk over 72 h.

2.2. Experimental storage conditions

High temperature short time (HTST) pasteurized fluid milk (2% milk fat; 3.78 L, natural (translucent) high density polyethylene (HDPE) packages; study 1: $n = 12$; study 2: $n = 6$)) was obtained directly from the dairy manager at the local grocery store (Kroger, Blacksburg, VA) within an hour of product delivery to obtain the freshest, highest quality milk available and minimize potential for light exposure. Each package was immediately wrapped in aluminum foil to prevent incidental light exposure and transported on ice to the research laboratory (Food Science and Technology Department (FST), Virginia Tech, Blacksburg, VA). Milk was stored in a refrigerated walk-in cooler (4 °C; study 1: Tonka, Hopkins, MN; study 2: Harris Environmental Systems, MA) equipped with fluorescent lights (studies 1 and 2: Sylvania Designer cool white 30 W, F30T12/DCW/RS, Ontario, Canada). Two 2-bulb lighting units (4 ft length) were positioned horizontally (12.7 cm) above the milk packages from the shelf above to mimic environmental conditions in a retail dairy case. During storage, milk in HDPE packages was exposed to light (light-exposed (LE); no foil overwrap) or was light-protected (LP; control treatment) by retaining the foil overwrap. Lights over the packages remained on 24 h/d and had a mean measured light intensity of 1,738 lx (model 407026, Heavy Duty Light Meter with PC Interface, ExTech Instruments, Nashua, NH). Products were protected from incidental lighting in the environment by creating a foil shield over the shelving unit. Light intensity (lux) received by each package was measured in between each bottle at the package shoulder (average lux = 375). Gallon packages were rotated daily to avoid differences due to variability in light intensity within the storage unit. In study 1, milk (LE: $n = 6$; LP: $n = 6$) was stored for 8 h or 168 h, yielding 3 packages per treatment per lighting duration. In study 2, six milk packages (LE: $n = 3$; LP: $n = 3$) were exposed to light for 72 h.

2.3. Analytical evaluation of quality

2.3.1. Sampling and conditions for sample storage

Samples for microbial analyses were collected under aseptic conditions from each milk package for immediate analysis. Samples (30 mL per package) for milk composition analyses were transferred to sterile glass vials and refrigerated until delivered (within 5 h) to the United Dairy Herd Information Association (United DHIA) extension laboratory on campus (Department of Dairy Science, Blacksburg, VA). Samples for assessing the light effects on oxidation (Rb, 12 mL per vial/treatment, multiple vials per treatment; thiobarbituric acid reactive substances (TBARS), 7 mL per vial/treatment, multiple vials per treatment) were collected and immediately frozen (−75 °C) from each milk package until analytical analyses could be completed.