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Retail Lighting Effects on Fresh Product Stability

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Introduction

LED lighting is quickly replacing fluorescent lighting in refrigerated display cases. While this transition is primarily due to energy savings and DOE requirements, food retailers are recognizing the value that LEDs can provide in better color rendering and lighting control, better enabling retailers to create destination departments within the store.

However, even with LED lighting, it is possible to have too much of a good thing. It is important to remember that all light sources (LEDs included) emit energy, and too much light may not provide the intended result. In fact, too much light can cause 'washing out' of the product colors and is an influencer on food and packaging degradation and discoloration.

Over the past few years, Hussmann has been involved in researching instances where lighting was suspected of being a factor in product discoloration. A key finding of our research is that product discoloration has less to do with the "type" of light source and more to do with interactions between light at a specific frequency and wavelength and the chemical nature of the lighted surface. In addition, our findings identify other factors that further contribute to the rate of discoloration including oxygen availability, packaging materials, distance from light to product, product temperature, and exposure time. Keep in mind that these factors can interact with products anywhere throughout the food supply chain prior to being stocked and maintained in the refrigerated display case.

As Hussmann continues to enable excellence in Food Retailing and Lighting Merchandising, our desire is that this white paper will help our customers better understand the mechanics and factors associated with lighting merchandising for products and the potential effects of product discoloration. This will support better strategies and controlling methods for enhanced product merchandising, extended shelf life, and maintaining food safety.

Light Energy Basics

Light - a form of energy (electromagnetic radiation) travelling through space at various wavelengths and frequencies and expressed through the electromagnetic spectrum.

A **wavelength** is the distance (measured in nm) between two identical peaks at either the highest point or lowest point. In Figure 1 below, the distance between the peaks of each wave is shorter on the left side and increases as you move towards the right side.

Frequency is defined by the number of wave cycles per second. So, if we consider Figure 1 below with Time = 0 on the left and increasing towards the right of the Figure, then we can see that there are more waves (cycles) on the left which represent increased frequency and less cycles on the right for decreased frequency. When the frequency increases, energy is also increased. This is why we can listen to the radio all day with little to no impact on our health (low frequency/energy) but must be careful how often we are exposed to X-rays (high frequency/energy).

The **Electromagnetic spectrum** is the range of all electromagnetic radiations characterized by frequencies and wavelengths as shown in Figure 1 below. The visible light Spectrum represents the portion of the spectrum that we can actually see with our eyes and to which we refer to as "light". There are also light wavelengths that we can't see that are in the UV and Infrared spectrum. Some examples are the Sun, which emits Infrared, UV, and Visible wavelengths; Incandescent bulbs that only emit wavelengths in the visible light spectrum; and Fluorescent & LED lights that both emit in the visible light and UV spectrum.

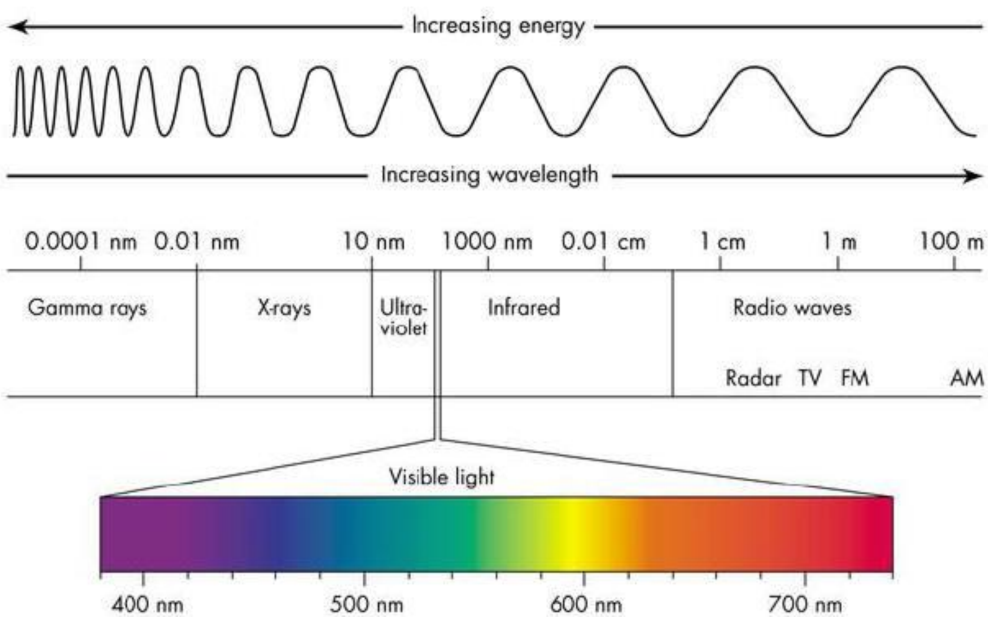


Figure 1. Electromagnetic Spectrum, Source: Wiadomosc.com

What's the deal with UV Light exposure?

Fluorescent lights enable an electric current in a low- pressure mercury vapor that produces UV light, which is then converted to visible light using a phosphor coating inside a glass tube. While the phosphor coating blocks most of the UV light, there is a potential for some UV leakage and thus exposure, although very minimal.

LED lights can produce a small amount of UV light internally, which is then converted to white light by phosphors inside the lamp (phosphor LEDs). The result is very minimal UV exposure from LED lights and much less than fluorescents.

UV light has been commonly attributed to concerns over time regarding color degradation (mustard turning white, carpet fading, window shades, etc.). This is due to the absorption of some of the light into the product and based on Figure 1 above, this would make sense based on the higher energy produced by UV light based on its wavelength and frequency. The next section will present just how fresh foods are affected by light as well as other potential wavelengths that can have a negative impact.

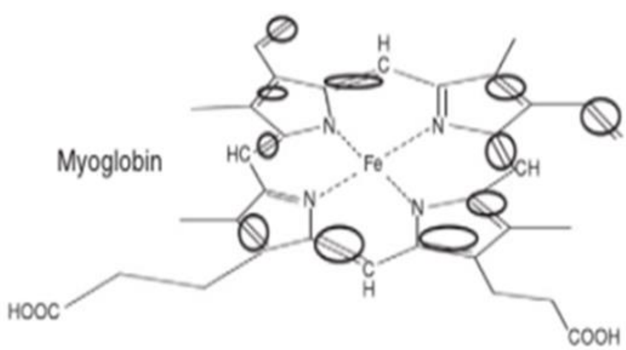
Lighting Effects on Fresh Foods

Fresh foods contain biological molecules that are nutritionally beneficial and vital to sustaining human life. Many of these molecules are also sensitive to light and enable more absorption of light energy into the food. When these photosensitive compounds are exposed to and absorb light at a specific wavelength and intensity, they will undergo a complex series of photo-degradation reactions that adversely impact food color/quality. A substance that absorbs light following a photochemical reaction is called a **Photosensitizer.**

The effects of photo-degradation can be seen by comparing two identical products side by side, one that has been exposed to light over a specific time frame and the other that has not been exposed (i.e. covered with butcher paper) over the same time period. The product that has not been exposed to light will maintain its color longer than one that has been exposed to any light source.

Some food components that have been identified as photosensitizers include chlorophyll, myoglobin, and riboflavin (Foote & Denny, 1968), all of which are excited by light in the UV and blue/green spectrum. The molecules most susceptible to photochemical reactions are the lipids, amino acids, and nucleotides that make up fats, pigments, protein, and vitamins.

A common cause of sensitivity to light is due to the electrons of conjugated bonds as shown in **Figure 2** below. These bonds require very little energy to trigger a reaction. Since all light emitted is a form of energy, the higher the input of energy the more rapid the potential degradation.



Conjugated Bonds in Myoglobin

Figure 2: Structures of photosensitizers in foods and their reactive sites (from Advances in Food and Nutrition Research, Volume 67, pg. 31)

Photosensitizers are mostly activated in the Ultra-violet (UV) and the blue/green region of the visible spectrum which are the shorter, more energetic wavelengths. **Table 1** displays a few photosensitizers and the food item it is commonly found in.

Photosensitizers	Found in Foods:	Absorption Peaks (nm)
Vitamin B12 (Riboflavin)	Fish, meat, poultry, eggs, milk, & milk products	266, 373, 455 (UV and visible light 365 & 500 causes milk photooxidation)
Carotenoids	Carrots, potatoes, spinach, cilatro, and cantaloupe.	UV & Visible Light-400-500
Vitamin C (Ascorbic Acid)	Kale, papaya, pineapple, kiwi, and oranges	265; UV-below 400
Chlorophyll	Cheese, plants, algae, vegetables	400-450, 546; (most damaging 650); 436 & 546 in Cheese
Myoglobin	Meat	206, 275, 408, 504, 603

Table 1: Common Compounds susceptible to product degradation

From Advances in Food and Nutrition Research, Volume 67

Effects of Photochemical Reactions

Photo-degradation is a type of photochemical reaction. The light-induced reactions can result in chemical structure alterations/breakdowns, photo-oxidation and/or oxidation, can trigger secondary or other types of reactions such as biological chain reactions, and ultimately result in undesirable by-products. Table 2 below provides some of the effects and their potential impacts for the retailer.

Effects of Light-Induced Reactions		
Effect:	**Characterized:**	**Example/s:**
Sensory Effects	Observable signs of product alteration	Undesirable Odors and/or flavors; Discoloration from pigment/colorant changes
Nutritional & Bioactive Effects	Loss of nutritional value	Degradation of Vitamin A, B, C, and amino acids found in proteins
Health Risks	Production of compounds that may be carcinogenic/toxic	Hydroperoxides (from Singlet oxygen), disulfide derivatives, lactic acid, pyruvic aldehyde, acetic acid, and acetoin aldehyde

Table 2. Effects of Light-Induced Reactions, From Advances in Food and Nutrition Research, Volume 67

Factors Influencing Food Degradation

Photochemical Reactions are impossible to completely eliminate because products can be exposed to various lighting types and intensities anywhere throughout the food supply chain processes: post-harvesting, transport, primary and/or secondary processing and packaging, and distribution. Once a food photosensitizer molecule absorbs light, the cascade of reactions cannot be avoided.

Oxygen availability and the properties of the packaging, two factors commonly present in the processing, packaging, and distribution methods, can also contribute to degradation before the product even enters the retail environment. These factors, especially when combined with photochemical reactions, can result in more rapid degradation and discoloration which in turn leads to compromised food quality and shorter shelf life.

The below list represents some key factors that impact food degradation and discoloration.

- Environmental Factors
    - Oxygen availability
    - Packaging Properties
- Light
    - Light Intensity & Spectral distribution
    - Distance product is from light source
    - Exposure Time

Before After

Oxygen Availability

Biological molecules & photosensitizers found in fresh food can frequently undergo oxidation or photo-oxidation. An oxidation reaction can occur when a molecule, in an excited state, interacts with oxygen or a substrate causing an exchange of either energy or electrons and/or hydrogen atoms.

Oxidation reactions are highly dependent on the amount of oxygen present. In general, when certain fresh food products are exposed to elevated levels of oxygen (yes…ambient air), this can significantly impact the molecular structure and properties of the product resulting in accelerated oxidation and potentially inducing a cascade of reactions, related or unrelated to photochemistry, further altering the food product and potentially producing volatile compounds. Oxidation is also affected by heat, ionizing radiation, enzymes, and non-enzymatic reactions.

In terms of oxygen availability, an environment where fresh product is exposed to oxygen levels of greater than 1% will result in higher oxidation rates and will lead to discoloration and loss of moisture. The greater the oxygen transmittance, the greater the rate of product degradation.

Optical Packaging Properties

Common packaging materials that provide a barrier to protect food from outside contaminants and physical stresses include cellophane, plastic bags, plastic containers, butcher and bleached paper, and glass containers. **Table 3** below shows some typical packaging material as it relates to light transmittance.

Translucent packaging is preferred by consumers because it provides ease of visibility – allowing the shopper to assess the appearance of the product at the case. However, translucent material offers little protection against photo-oxidation because light energy can pass through the material barrier and penetrate the food product, resulting in photochemical reactions that lead to product discoloration.

Ideally, utilizing packaging that blocks out or minimizes light transmissions at wavelengths less than 450nm and greater than 650nm (see Figure 1) would help to avoid photo degradation. This would limit light-induced reactions, prolong shelf life, preserve quality, and reduce loss of nutritional value.

Light Transmittance of Packaging Material in Visible and UV Spectrum	
Clear Class	91%
Clear Polycarbonate	90%
HDPE	57%
Paperboard	4%

Table 3: Light Transmittance of Packaging Material

Brothersen, C., D. J. McMahon, J. Legako, and S. Martini. 2016. "Comparison of Milk Oxidation by Exposure to LED and Fluorescent Light." *Journal of Dairy Science* 99 (4): 2537–44. doi:10.3168/jds.2015-9849

Light Intensity & Spectral Distribution

Light intensity can be characterized by the brightness of a light from the amount of energy transmitted (luminous lux). The higher the light intensity, the greater amount of energy is present that can be absorbed by photo-sensitive molecules. Since photo-sensitive molecules are easily excited, less energy is needed to induce a photochemical reaction. Greater amounts of light energy transmitted increase the potential of photochemical reactions causing compound degradation.

The Spectral Power Distribution (SPD) is a graphical representation of a light source that charts the level of energy present at each wavelength across the visible spectrum. So, from Figure 1, a light source may emit several wavelengths and each of those will represent energy that could be absorbed by a food photosensitizer.

Distance product is to light source

Care must be taken to prevent adding too much light to some product applications because the closer a light source is to the product, the more energy that there is available to be transmitted to any food photosensitizer. Some of these applications include:

- **Shelf lighting:** LEDs significantly reduce heat on product over fluorescents and enable longer shelf life as a result. However, adding too much light intensity (i.e. high output shelf light) could increase risks of product degradation.
- **Canopy lighting:** Most multi-deck canopy applications are far enough away from the product and require a higher light output to ensure effective merchandising of the products. However, some cases that include a swept back canopy (i.e. some seafood or sushi cases) can cause the light to be much closer to the top shelf. If a higher output canopy light is requested, this could introduce potential degradation.
- **Overstocking:** Overstocking decreases distance product is to light source which increases light intensity on the product.

Exposure Time

Time is a key influencer to product discoloration. Studies show that the longer a product sits on the shelf in a refrigerated case, the potential for noticeable discoloration by customers increases. The same holds true if products are outside of the refrigerated case for periods of time and exposed to ambient light and/or conditions (i.e. stocking, packaging, slicing, etc). Even under optimal conditions (absence of light, vacuum/opaque packaging, and appropriate temperatures) product degradation will occur over time. The best method to maintain product stability is minimizing exposure to light or storing products completely absent of light.

Other Environmental Factors

While light energy is a key factor leading to food deterioration, there are many other factors that can lead to product discoloration and degradation. Table 4 below categorizes these into chemical, physical/mechanical, and microbial growth**.**

Causes of Product Discoloration		
Chemical	**Physical**	**Microbial Growth**
Enzymatic Reactions	Bruising/crushing	Infectious
Non-enzymatic Reactions	Temperature	Intoxicants
Oxidation	Moisture	
	Dehydration	
	Light	

Table 4. Causes of Product Discoloration

"791113.pdf." 2017. Accessed August 8. https://www.princeton.edu/~ota/disk3/1979/7911/791113.PDF.

Any one or combination of these factors will impact the product decay rate leading to decreased shelf life, negatively impacting consumer satisfaction, and potentially increasing human health risks. Some examples of how factors may lead to product degradation are as follows:

- Fresh product continues to undergo metabolic processes immediately after harvesting leading to enzymatic and non-enzymatic reactions that lead to volatile compounds, decreased shelf life, and loss of nutrients.

- Mechanical stress throughout the food supply chain can lead to microbial attacks, textural changes, and unacceptable appearance of products to consumers.

- Microbial growth can produce substrates that enhance food deterioration rate.

- Higher temperatures can also promote microbial growth and production of substrates that increase enzymatic reaction rates. Product exposure to these higher temperatures for extended periods of time can denature proteins and other vital nutrients.

Solutions to Mitigate Food Degradation

1. Environmental (Packaging, Oxygen availability, Temperature stability)
    a. Use vacuum packaging where possible over more permeable plastics to reduce oxygen transmittance and permeability below 1%. This will slow rate of photo-oxidation in some foods (i.e. cheese).
    b. Avoid packaging material allowing high oxygen permeability (i.e. deli packaging).
    c. Reduce slicing or shredding product until purchase. Slicing fresh products increases the surface area and resulting interaction between oxygen and photo-sensitizer molecules.
    d. Minimize processing and packaging time. Exposure to air and ambient lights increases the rate of degradation.
    e. Ensure food product temperatures are consistently maintained throughout the food chain.
2. Lighting (Intensity, Distance, Time)

a. Do not use high output lighting in all applications. LED lights should be application-specific and lower light levels (and lower energy) may provide excellent merchandising to see and select products just as well as high output.
    i. Overhead T8LEDs may not be the best solution for refrigerated case applications.
    ii. High Output canopy LEDs may not be the best choice within 18 inches of product. Consider standard output for these to lower intensity.
b. Store fresh products in the dark for as long as possible prior to being placed on display
c. Avoid overstocking as this could reduce distance to the light (increase light energy) and sacrifice food temperature if outside refrigerated zone.
d. Place products in lower portions of a case to increase distance from light.
e. Ensure sufficient product turnover to minimize light exposure of product (i.e. FIFO). Labels will fade over time if continually exposed to light energy.

Conclusion

Product degradation can be a complicated process with many factors. Discoloration is one result of the degradation process that could be influenced from any light source that the product encounters in the food chain. Because light is a form of energy, photo-degradation is unavoidable. Since a greater intensity of light accelerates the reactions, it is vital to optimize your lighting display.

There are also other factors that can influence food degradation to include packaging, temperature, and exposure to oxygen. The good news is that there are steps that retailers can take to mitigate food degradation and to which should be a part of their perishable product strategies. Certainly, strategies that takes into consideration factors leading to food degradation will better support enhanced product merchandising, extended shelf life, and hopefully retailer financials.

Additional Lab Tests Conducted

The following tests were conducted to better understand and validate the various factors that impact perishable product stability. The results from these tests are integrated into this paper.

- Shelf Lighting Effects on Meat Color Stability
- The Effect of Packaging and Exposure Time on Fresh Product Stability
- The Effect of Live Product Color Stability with Case and Ambient Lights Off
- Shelf Life of Fresh Meat Products Under LED or Fluorescent lighting

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