INFLUENCES OF MODIFIED ATMOSPHERE PACKAGING AND DRIP ABSORBENTS ON THE QUALITY, SAFETY, AND ACCEPTABILITY OF FRESH-CUT CANTALOUPE

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ABSTRACT

INFLUENCES OF MODIFIED ATMOSPHERE PACKAGING AND DRIP ABSORBENTS ON THE QUALITY, SAFETY, AND ACCEPTABILITY OF FRESH-CUT CANTALOUPE

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In a growing market for fresh-cut produce, it is important to understand the impacts of shelf-life extending technologies and how they are perceived by consumers. In this study, the quality and safety of fresh-cut cantaloupe was examined when packaged in passive, low-O_2, and high-O_2 modified atmosphere packages (MAP), with and without drip-absorbent pads. To evaluate safety, growth of *Listeria monocytogenes* was examined over 9 days at 5°C, as well as package weight loss, pad weight gain, and headspace O_2 and CO_2. To evaluate quality, key physicochemical properties, the growth of spoilage microorganisms, and headspace O_2 and CO_2 were monitored over 15 days at 3°C. Also, consumer perception of absorbent sachets in packages of fresh-cut cantaloupe was examined through a hedonic sensory evaluation of package and product and asking their opinions of the sachets, change in fresh produce packaging, and willingness to pay for extra use life. The results show that high-O_2 MAP held *L. monocytogenes* populations on fresh-cut melon significantly lower than passive or low-O_2 MAP, while increasing redness and lowering pH. The combination of low-O_2 MAP and drip-absorbent pads led to more drip, higher aerobic bacterial populations, and lower populations of yeasts and molds. For retaining quality attributes at beneficial O_2 levels, the passive MAP atmosphere proved best, while drip-absorbent pads proved unnecessary. In addition, panelists in the sensory evaluation rated that they liked packages with absorbent sachets significantly less than packages without, but this judgment did not pass on to melon attributes. Still, most panelists were willing to pay for extra use life, showing that active compounds may be well received if delivered without sachets.

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1. INTRODUCTION

One of the most critical roles played by fresh produce packaging is extending shelf life, the amount of time the produce remains of salable quality. Water activity (A_w) of fresh produce is central to maintaining quality; most fresh produce loses market value when water losses are between 3% and 10%, while some only require 1% or 2% water loss to become unmarketable (Ben-Yehoshua and Rodov, 2003). Fundamental components of postharvest practice, such as forced-air cooling, washing and sanitizing, drying, and ventilated containers play key roles here. On the packaging front, waxed corrugated fiberboard boxes or reusable plastic crates are often used. Vents in these packages permit airflow, which mitigates respiration-driven temperature and RH fluctuations. If correctly implemented, these practices suppress decay, but may not sufficiently control for water loss. With this in mind, the major driver towards using plastic packaging for fresh produce was to extend shelf life by reducing water loss during distribution and retailing (Hardenburg, 1956). The relatively high water vapor barrier properties provided by continuous polyolefin films, combined with their low costs, make for an efficient package to prevent weight loss. However, the RH within a sealed plastic pouch of fruits or vegetables will quickly rise to near saturation conditions. While high RH prevents high-A_w fruits and vegetables from losing weight, condensation encourages the proliferation of decay microorganisms (Scott *et al.*, 1964; Kader, Zagory and Kerbel, 1989; Shirazi and Cameron, 1992; Powers and Calvo, 2003; Rodov *et al.*, 2010; Linke and Geyer, 2013; Mahajan *et al.*, 2014; Mir and Beaudry, 2014). Thus, the ideal RH is between 90 and 95% for most fresh fruits and vegetables. Maintaining those levels of RH is a multifaceted challenge (Labuza and Breene, 1989), as explained below.

RH and air temperature are closely linked through the concept of saturation vapor pressure, where RH is the ratio of the vapor pressure in the air to the saturation vapor pressure.

As temperature increases, the saturation vapor pressure in air rises exponentially, meaning that a discrete change in the actual amount of water vapor in the air will have a greater impact on RH at lower temperatures (Rodov *et al.*, 2010). For example, note the relationship between RH and temperature in Figure 1. Temperature variation of less that 2°C led to swings of 17% RH! Therefore, to maintain ideal in-package RH for fresh produce applications, tight temperature management is fundamental (Rodov *et al.*, 2010; Bovi *et al.*, 2016).

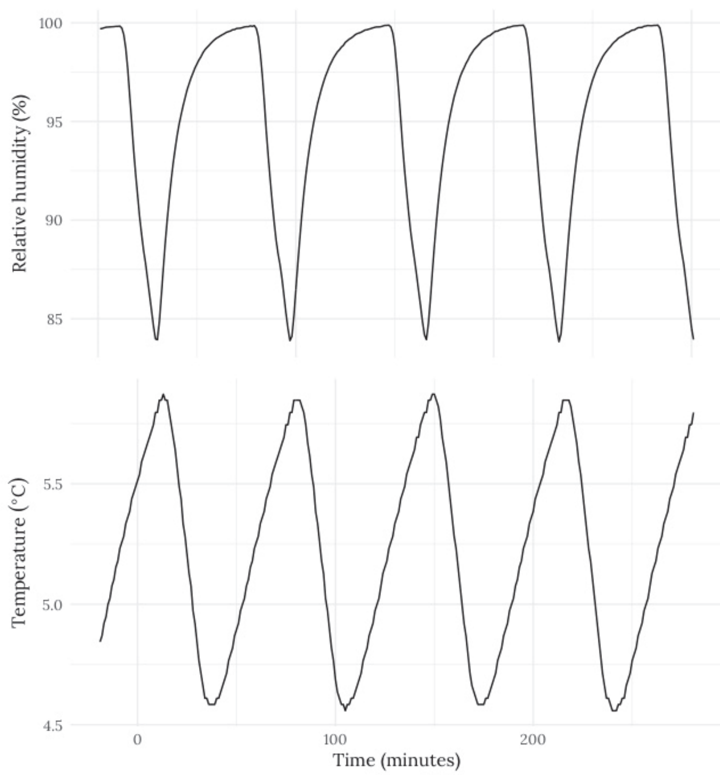

Figure 1. Temperature and RH variations in a walk-in cooler due to refrigerator cycling. Data collected by the author at Michigan State University.

Dancing between the perils of decay and weight loss, researchers and commercial firms have studied a great number of ways to manage moisture in fresh produce packages. Three traditional packaging approaches (macroperforations, films with poor water vapor barrier properties, and individual shrink packaging) see broad commercial use. These methods, collectively referred to as passive modified humidity packaging (P-MHP), provide a means for adjusting in-package RH. Macroperforations and low water vapor barrier films allow in-package RH, typically high for fresh produce, to move closer to the environmental RH, while individual shrink packaging minimizes the headspace volume to inhibit condensation while reducing moisture loss.

Good temperature management is fundamental to fresh and fresh-cut produce distribution, and certainly the most important factor in extending shelf life. P-MHP is effective in tightly controlled supply chains, but will not optimally extend shelf life under more dynamic storage conditions. Large traditional retailers have worked hard to remove breaks in their cold chains, but growth of fresh and fresh-cut produce into new formats, such as convenience stores, gas stations, and e-commerce platforms, has created more opportunities for temperature abuse. Even in complete cold chains, variability in airflow and tightly packed cases can prevent passive packaging approaches from performing as desired. Therefore, to better adapt to cold chain breaks and ensure performance in typical ones, active packaging technologies may offer a way to manage moisture with less dependence on the external environment.

Active packaging can be defined as a packaging technology where certain additives, known as "active compounds" are incorporated into the packaging material or placed within the packaging container in order to interact directly with the perishable product and/or its environment to extend its quality and/or safety (Almenar, 2017). For moisture management, this can involve incorporating hydrophilic – or water-loving – additives into the package to take up excess water in either the liquid or gaseous state. One such approach, active modified humidity packaging (A-MHP), seeks to adjust in-package RH to a favorable level for the packaged product using hygroscopic additives. A-MHP additives may buffer the in-package RH at a stable level, or not, depending upon the interactions between the sorption kinetics of the additive and the moisture in the package headspace. Conceptually, this idea originated in the 1950s, with the term coined in a 1987 poster presented by Michigan State University researchers (Shirazi and Cameron, 1987).

A-MHP remains a largely academic pursuit, where a slow but steady stream of researchers have investigated the capacities and applications of such technologies. In contrast, two active packaging approaches to controlling in-package liquid water are well-established commercially. These include anti-fogging techniques, which prevent condensation on a packaging film from obscuring the view of a product, and drip-absorbent pads. Ubiquitous in meats, poultry, and seafood, drip-absorbent pads utilize hygroscopic compounds, such as superabsorbent polymers and paper fluff, to remove excess liquids from the sight of a consumer. Commercially, some firms have expressed interest in packaging fresh and fresh-cut produce with drip-absorbent products, to extend shelf life. In principle, this derives from the idea that microbial growth is attributed to the accumulation of leaked juice rich in nutrients in the bottom of containers (Brecht, 2006). However, in the fresh produce sector, independent academic work has not been published regarding whether drip-absorbent pads have any impact on the quality or safety of fresh or fresh-cut produce.

Postharvest operations, such as processing, packaging, and storage, have been studied for most horticultural commodities and general recommendations published. These recommendations vary between types of produce, which have different sensitivities to temperature (heat or cold), RH, oxygen and carbon dioxide in the surrounding atmosphere, ethylene, and other such environmental factors. Additionally, a great deal of work has been done investigating the use of various treatments to better retain quality and safety when the produce reaches retail. One of these treatments is MAP, which has been researched and commercially implemented over the past 50+ years (Kader, Zagory and Kerbel, 1989). The premise of MAP is to control the headspace gas composition (i.e., the nitrogen, oxygen, and carbon dioxide concentrations) within a package in order to extend shelf life. Generally, MAP designs use low levels of oxygen and elevated carbon dioxide (Gorny, 1997). Lowered oxygen availability decreases respiration rate, ethylene production, enzymatic browning, and microbial growth, while elevated levels of carbon dioxide further suppress microorganisms (Gorny, 1997). However, excessively low levels of oxygen (typically below 1%) promote fermentation and may permit the growth of human pathogens such as *Listeria monocytogenes* (Farber *et al.*, 2003a). While low oxygen/elevated carbon dioxide MAP is the most common and has the longest history, alternative atmospheres composed of superatmospheric levels of oxygen, often >70% O_2, have also received academic interest (Brody, 1997; Kader and Ben-Yehoshua, 2000; Jacxsens *et al.*, 2001; Oms-Oliu, Soliva-Fortuny and Martín-Belloso, 2008; Gonzalez-Buesa *et al.*, 2014; Page *et al.*, 2016).

Fresh produce packaging systems often combine multiple technologies to improve quality and safety; it is useful to know whether such technologies perform synergistically, antagonistically, or have no interactions with each other. A major motivation for this study is to investigate the interactions between moisture absorbent pads and MAP compositions on various quality and safety aspects of a fresh-cut produce. The target produce chosen for this study needs to have potential to gain from MHP and MAP treatments. Fresh-cut cantaloupe is a complex product that satisfied these criteria.

Fresh-cut cantaloupe is delicate. Cutting wounds the melon, increasing the susceptibility of the fruit to degradation. However, the cutting process improves convenience for consumers (Ahvenainen, 1996). Amaro et al. (2012) reviewed the various attributes that are changed by cutting, including color and firmness (Portela and Cantwell, 1998; Aguayo, Allende and Artes, 2003; Aguayo, Escalona and Artes, 2004), sweetness (Portela and Cantwell, 1998), respiration rate (Aguayo, Escalona and Artés, 2007), microbial growth (Aguayo, Allende and Artes, 2003), and aroma volatiles (Beaulieu, 2006a, 2006b). In addition, methods of cutting, including blade sharpness (Portela and Cantwell, 2001) and shape of the cut product (Aguayo, Escalona and Artes, 2004), create further variances in cantaloupe quality attributes. Those studies found that trapezoidal pieces cut with sharp blades have the best quality retention and ratio of usable product to waste.

Widely-cited recommendations for modified atmosphere storage state that 3-6% oxygen and 6-15% carbon dioxide at a storage temperature of 0-5°C will best maintain the quality of fresh-cut cantaloupe (Gorny, 1997). While purportedly for modified atmospheres, this recommendation was generated solely on studies from controlled atmosphere storage, not MAP. Later work investigated those recommendations through passive and low-oxygen active MAP approaches, finding that both were effective in extending shelf life compared to melon in non-MAP perforated packages (Bai *et al.*, 2001). Another study challenges the atmosphere recommended by Gorny (1997), finding that cantaloupe respiration rates do not appreciably drop until oxygen levels dip below the fermentative threshold of the fruit (Gomes, Beaudry and Almeida, 2012). Those authors posit that the MAP benefits for fresh-cut cantaloupe lie in the elevated levels of carbon dioxide, rather than lowered levels of oxygen.

MAP compositions involving superatmospheric oxygen levels have not been explored for cantaloupe. While other melons, e.g., 'Piel de Sapo' (Oms-Oliu, Soliva-Fortuny and Martín-Belloso, 2008), have shown positive responses to superatmospheric oxygen atmospheres, responses to MAP or controlled atmosphere treatments vary between melon varieties (Portela and Cantwell, 1998; Bai *et al.*, 2001; Bai, Saftner and Watada, 2003; Aguayo, Escalona and Artes, 2004). Therefore, there is a knowledge gap regarding the effectiveness of active MAP compositions with superatmospheric oxygen levels to extend the shelf life of fresh-cut cantaloupe. Additionally, studies of fresh-cut cantaloupe have incorporated drip-absorbent pads, but incorporated them in all packages and did not evaluate their effects on safety or physicochemical properties of the melon in MAP (Bai *et al.*, 2001) and non-MAP containers (Zainal Abidin *et al.*, 2013).

The hazards of food safety are the greatest challenge facing the fresh produce industry today. In the late 1990s, thinking in the fresh-cut industry was that improved food safety knowledge and controls would decrease concerns about food pathogens (Brody, 1997). Unfortunately, the specter of pathogenic contamination has only become greater in recent years. In 2011 alone, the CDC estimates that 31 known food pathogens caused 9.4 million illnesses, leading to 288,744 hospitalizations and 2,612 deaths (Scallan *et al.*, 2011). In that year, a multistate outbreak of listeriosis, traced to cantaloupes from a single farm contaminated with *L. monocytogenes*, resulted in 143 known hospitalizations and 33 deaths (McCollum *et al.*, 2013a). Due to these terrible events, as well as intense litigious pressure, companies are taking greater measures than ever to control their supply chains and production facilities. Additionally, the U.S. Food and Drug Administration's (FDA) Food Safety Modernization Act (FSMA) of 2011, and specifically the FSMA Produce Safety Rule are providing new federal guidance on "science-based minimum standards for safe growing, harvesting, packing, and holding of fruits and vegetables grown for human consumption" (FDA, 2015).

Food safety in the fresh-cut produce industry is especially challenging. As ready-to-eat products are consumed raw, the producer must take all actions to remove the risk of pathogenic contamination. The common treatments to remove microbes from fresh produce, washing and sanitizing, can reduce microbial load but are inadequate to guarantee safety; heat treatments (for surface treatment of produce with durable exteriors), irradiation (legal only for certain products), and high-pressure pasteurization (few data for fresh-cut produce) are more potent, but limited in scope (Gombas *et al.*, 2013). As a low-acid fruit, cantaloupe is particularly vulnerable to pathogen growth (Penteado and Leitão, 2004).

While most food pathogens are generally unacceptable in fresh produce at any level, it is useful to know how different packaging technologies affect the growth and survival of such pathogens. A risk of MAP generally is that the abnormal atmosphere will suppress the growth of spoilage microorganisms and create an opportunity for food pathogens to grow with reduced competition, as many are facultative anaerobes (e.g., *Escherichia coli* O157:H7, *L. monocytogenes*) (O'Beirne and Francis, 2003). Therefore, this study will investigate the role of MAP compositions and moisture-absorbing pads on the growth of a pertinent food pathogen, *L. monocytogenes*, inoculated onto fresh-cut cantaloupe.

From another perspective, consumer acceptability of active packaging remains a key concern. As active packaging grows as a commercially-viable opportunity for fresh-cut produce, it is important to understand how consumers perceive these technologies. Existing studies that investigate consumer perception of active packaging have generally taken the form of surveys, relying upon verbal descriptions of active packaging to convey the intents, forms, and benefits of such technologies (Van Wezemael, Ueland and Verbeke, 2011; Aday and Yener, 2015; Barska and Wyrwa, 2016; O' Callaghan and Kerry, 2016). These studies have generally found that consumer unfamiliarity with active packaging plays an important role in its acceptance. Academia and industry have created and studied the capabilities of many types of active packaging for fresh-cut produce, but have never probed into consumer perception. Baselice *et al.* (2017) recently noted that perception of innovative techniques for improving food quality and safety remains a critically understudied area when compared with technology development. Our study investigates sachets among the different active compound delivery mechanisms because of their current widespread use by the produce industry, including sachets that scavenge ethylene (http://www.itsfresh.com/), absorb juice on the package bottom (https://www.maxwellchase.com/), control microbial growth (https://iotech.io/iofresh/), etc.

To fill some of the identified knowledge gaps so we can better understand consumer attitudes and perceptions towards active packaging, this study set out to determine whether the presence of a visible sachet inside of a package containing food affects consumer acceptance of active packaging and consumer perception of the packaged product. This was approached through a consumer sensory evaluation of packages of fresh-cut cantaloupe, with or without a sachet, first using a Likert scale to evaluate consumer liking of both package and organoleptic product attributes, followed by directly asking consumers about their opinions of packaging technologies, innovation, and cost. In contrast with existing survey work, consumer acceptance of active packaging was assessed by exposing consumers to the actual packaging technology. Presenting packaged food containing a visible sachet gets closer to how the product would be perceived in the store, as we did not provide consumers with information about the role or potential benefits of the sachet. We placed the sachet in the package and filled this with the product immediately before presenting the package to consumers in order to ensure no effect of the sachet on the quality of the product. Consequently, the only differences in ratings were due to how the consumers perceived the sachet. Following sensory evaluation of those packages, direct questions were asked to learn consumer opinions of the absorbent sachets, packaging changes, and willingness to pay for additional use life. This provides a lens to compare with previous work with other food products (e.g., meat and bakery products, studied by Mikkola *et al.*, 1997).

The objectives of this thesis are to assess function and consumer perception of drip-absorbent pads and sachets in MAP-packed fresh-cut cantaloupe. Chapter 2 reviews the literature exploring fresh-cut produce quality and safety, then examines key MAP, MHP, and liquid water-controlling technologies. The experimental results are presented in Chapters 3 and 4. In Chapter 3, we investigate the performance of drip-absorbent pads when combined with MAP for shelf-life extension and safety implications. This includes three MAP treatments – passive (21% O_2, 78% N_2, 0.03% CO_2), low-oxygen active (5% O_2, 80% N_2, 15% CO_2), and high-oxygen active (95% O_2, 5% N_2) – with or without a commercial drip-absorbent pad. These treatments are assessed in two studies.

1. *L. monocytogenes*-inoculated fresh-cut cantaloupe were packed and monitored over 9 days of storage at 5°C.
2. Critical horticultural quality attributes of fresh-cut cantaloupe were studied over 15 days of storage at 3°C.

Chapter 4 contains a consumer sensory evaluation investigating perception of absorbent sachets for fresh-cut cantaloupe. The questionnaire was comprised of:

1. A consumer sensory evaluation of fresh-cut cantaloupe packages and product quality attributes, examining the role of:
    a. A visible absorbent sachet, that had no interaction with the melon.
    b. A drip-absorbent pad, packed with the melon for a week, but unseen.
2. Direct questions about consumer opinions of the absorbent sachet, fresh produce packaging changes, and willingness to pay for additional use life.

2. LITERATURE REVIEW

2.1. Fresh-cut produce

Fresh-cut, or value-added, fruits and vegetables are made to be ready to use, meaning that they have been washed, inedible parts removed, and cut into a product that can be completely consumed (Beaulieu and Gorny, 2002). With a compound annual growth rate (CAGR) of more than 8% between 2011 and 2015, fresh-cut fruit sales have blossomed to over $2.2 billion annually, while fresh-cut vegetable sales grew at a CAGR of 10% over that same period, to total sales of over $1.7 billion in 2015 (Nielsen Perishables Group, 2016).

2.1.1. Fresh-cut produce quality

When undergoing the cutting process, the produce is wounded and becomes more delicate, as cutting removes protective outer tissues. This accelerates degradation processes, such as respiration rate, ethylene production, moisture loss, color changes, tissue softening, microbiological decay, loss of nutritional value, and decline in sensory quality (Hodges and Toivonen, 2008). In addition, while the natural, protective coatings of whole fruits and vegetables restrict microbial growth, cutting releases moisture and nutrients that create a hospitable environment for harmful pathogen growth (Harris *et al.*, 2003). To maintain quality, proper storage conditions (such as temperature, relative humidity, and atmospheric oxygen and carbon dioxide) should be optimized for each fresh-cut produce (Rojas-Graü *et al.*, 2009; Francis *et al.*, 2012). Thus, strict controls from farm through processing and retail environments are necessary to ensure fresh-cut produce quality and safety are retained (Suslow *et al.*, 2003; Gorny, 2006).

2.1.1.1. Fresh-cut cantaloupe quality

Quality attributes key to the shelf life and salability of fresh-cut cantaloupe as discussed by Amaro et al. (2012) include color and firmness (Portela and Cantwell, 1998; Aguayo, Allende and Artes, 2003; Aguayo, Escalona and Artes, 2004), sweetness (Portela and Cantwell, 1998), respiration rate (Aguayo, Escalona and Artés, 2007), microbial growth (Aguayo, Allende and Artes, 2003), and aroma volatiles (Beaulieu, 2006a, 2006b). To measure changes in the aforementioned quality attributes, various methods have been reported in the literature.

2.1.1.1.1. Texture

Texture-related attributes of fresh-cut cantaloupe include hardness (or firmness), density, and cohesiveness of a compressed sample (Beaulieu *et al.*, 2004). Instrumental texture measurements are conducted using machines that compress and/or shear fresh-cut cantaloupe pieces. One method is to use a Kramer shear cell, which applies a combination of compression and shear to emulate chewing between molars (Bai *et al.*, 2001). Another method involves compressing melon pieces with a flat probe, using either a two-cycle test (Lamikanra *et al.*, 2006) or trimming prior to compression (Beaulieu *et al.*, 2004; Beaulieu, 2006b) to standardize samples.

Firmness decline of fresh-cut cantaloupe during storage has been reported by multiple authors (Aguayo, Escalona and Artes, 2004; Gil, Aguayo and Kader, 2006; Amaro *et al.*, 2012; Zainal Abidin *et al.*, 2013). Softening of fresh-cut fruits and vegetables is expected over time due to a decline in the strength of the cell wall, a natural development in ripening that is accelerated by the cutting process (Toivonen and Brummell, 2008).

2.1.1.1.2. Color

Fresh-cut cantaloupe color is most often described in the L* a* b* color space, defined by the International Commission on Illumination, commonly known by its French acronym, CIE. Colorimeters are used to instrumentally measure color. L*, a*, and b* are Cartesian coordinates that encompass the full spectrum of colors in a three-dimensional representation. L* refers to lightness (0 = black, 100 = white), a* goes from green (-) to red (+), and b* from blue (-) to yellow (+). Instead of a* and b*, hue angle (h°, perpendicular to the L* axis) and chroma (C*, or color saturation) may be used. Converting a* and b* to hue angle and chroma is accomplished through the following relationships:

$$h^{\circ} = \arctan\left(\frac{b^*}{a^*}\right)$$

$$C^* = \sqrt{(a^*)^2 + (b^*)^2}$$

Color changes in fresh-cut cantaloupe occur as quality declines. Authors have reported declines in L* (Portela and Cantwell, 2001; Beaulieu, 2005; Amaro *et al.*, 2012; Martiñon *et al.*, 2014), C* (Portela and Cantwell, 2001; Amaro *et al.*, 2012), a* (Beaulieu, 2005), and b* (Gil, Aguayo and Kader, 2006; Martiñon *et al.*, 2014), while h° remains constant (Amaro *et al.*, 2012) or slightly increases (Portela and Cantwell, 2001) over storage. These changes indicate darkening of tissues and an increase in translucency of cut surfaces, which limits marketability to approximately 9 days (Bai *et al.*, 2001; Portela and Cantwell, 2001; Aguayo, Escalona and Artes, 2004; Beaulieu, 2005; Gil, Aguayo and Kader, 2006). These color changes are more evident when dull cutting blades are used (Portela and Cantwell, 2001).

2.1.1.1.3. Sweetness

Sweetness has been shown to be the most important aspect of consumer acceptability of cantaloupe melons (Bianco and Pratt, 1977; Beaulieu *et al.*, 2004). Although sugar content increases as melons mature on the vine, early picking is common to yield a firmer product that is less vulnerable to distribution hazards (Beaulieu and Grimm, 2001; Beaulieu *et al.*, 2004). Therefore, sugar retention is important for maintaining the acceptability of fresh-cut cantaloupe. Sugars are often reported as soluble solids content (SSC), which is measured with a refractometer in the unit °Brix. A minimum level of 9°Brix is necessary to meet the U.S. No. 1 standard for cantaloupe. Sugar content in fresh-cut cantaloupe can remain constant (Bai *et al.*, 2001; Gil, Aguayo and Kader, 2006) or decline over storage (Lamikanra *et al.*, 2000; Portela and Cantwell, 2001; Beaulieu, 2005; Amaro *et al.*, 2012). This decline occurs faster at higher temperatures (Lamikanra *et al.*, 2000).

2.1.1.1.4. Titratable acidity and pH

Titratable acidity (TA) and pH are two measures of the acidity of a fruit, although there are key differences between them. Although both represent the concentration of hydrogen ions, pH is tied to free hydrogen ions, that is, the protons that dissociate from the organic acids in a fruit. A pH of 7 is neutral, with lower values indicating increasing acidity (more free hydrogen ions), while higher values correspond to increasing alkalinity (more free hydroxyl ions). In fruits, organic acids are a major contributor to sour tastes. However, humans perceive different acids to vary in sourness even if they have the same pH (Neta, Johanningsmeier and McFeeters, 2007). Electronic meters are typically used to measure pH.

TA measures both free and bound hydrogen ions. This has been reported to better reflect the way acids are tasted (Neta, Johanningsmeier and McFeeters, 2007). TA is measured by neutralizing the acids in the fruit with a base (e.g., 0.1 N NaOH) to a pH of 8.2, often using a pH-sensitive dye like phenolphthalein as an indicator (Wills *et al.*, 2007). The amount of base used, relative to the amount of the fruit sample and the predominant acid in the fruit (e.g., citric acid, malic acid, tartaric acid), can be used to calculate the percentage of acid in the fruit.

Cantaloupe is a low-acid fruit, meaning that it is slightly acidic, with a pH just below neutral. This has consequences for its microbiological quality, as discussed in the following sections. Lamikanra *et al.* (2000) reported relatively steady pH in fresh-cut cantaloupe stored at 4°C, although at 20°C they found that pH quickly declined. Those authors stated that citric and malic acids were the dominant acids in fresh-cut cantaloupe. In contrast, Gil, Aguayo and Kader (2006) considered citric acid to be the predominant acid. Those authors found that TA increased near the limit of marketability, while pH decreased, although both remained stable during the earlier time in storage. Initial pH in that study was 6.79, decreasing to 6.11 after 9 days of storage.

2.1.1.1.5. Spoilage microorganisms

Low acidity and high water activity (a_w) make the surfaces of fresh-cut cantaloupe an excellent medium for the growth of spoilage microorganisms, especially bacteria (Lamikanra *et al.*, 2000; Beaulieu and Gorny, 2002). Most spoilage bacteria require a_w of above 0.9 to grow, while spoilage yeasts tend to grow as low as an a_w of 0.88 (with osmophilic yeasts growing as low as 0.65), and molds lower still (approximately 0.8, with xerophilic molds growing as low as 0.61), with variation depending on temperature and nutrient availability (Jay, 2012). The types of spoilage microorganisms that grow on a fruit or vegetable are also influenced by pH; high acid produce, with a pH below 4.5, favors the growth of fungi, while low acid produce (e.g., cantaloupe), with a pH above 4.5, is predominantly spoiled by bacteria (Wills *et al.*, 2007). Environmental factors, such as temperature and time, also play key roles in produce spoilage and safety (Bari *et al.*, 2005). Modified atmosphere packaging and other packaging technologies further influence the growth rate of spoilage microorganisms (Varoquaux and Ozdemir, 2005; Page *et al.*, 2016).

2.1.2. Fresh-cut produce safety

Foodborne illness outbreaks traced to fresh and fresh-cut produce are a major concern to consumers, governments, and the fresh produce industry. Fresh and fresh-cut produce are often consumed raw, meaning that there is no "kill" step where heat, pressure, or other means are used to drastically reduce the microbial load of a food product (Gorny, 2006). The increase in reports and attention to outbreaks of foodborne illness linked to fresh produce is due to many factors, including increased consumption of fresh fruits and vegetables, centralized processing of fruits and vegetables followed by long distance shipping, growth of global trade, and greater awareness and surveillance of pathogenic contamination of fresh produce (Harris *et al.*, 2003; Gorny, 2006). To reduce the risk of foodborne outbreaks, the fresh produce industry is taking many steps to minimize the potential of contamination at all stages of production. This includes improved sanitation in fields and packinghouses, tighter temperature control in distribution, and more stringent quality assurance testing for microbiological hazards. To address these and other risk factors, the United States Food and Drug Administration (FDA) has implemented the Produce Rule of the Food Safety Modernization Act of 2011 (FSMA), with the Final Rule in effect as of January 2016. In recent years, one of the most devastating foodborne pathogens for the fresh produce industry has been *L. monocytogenes*.

2.1.2.1. Listeria monocytogenes

High-profile foodborne outbreaks and recalls due to *L. monocytogenes* have been tied to several fresh and fresh-cut produce commodities in recent years (Gorny, 2015). *L. monocytogenes* has proven particularly challenging to control due to its innate characteristics. It is widely present in the environment (Wiedmann and Sauders, 2007; Adams and Moss, 2008), capable of forming persistent biofilms in processing environments (Yousef and Lado, 2007), grows at temperatures as low as 0°C (Yousef and Lado, 2007), and is a facultative anaerobe (Rocourt and Buchrieser, 2007). *L. monocytogenes* causes the rare, difficult to diagnose, and very serious foodborne illness, listeriosis (Painter and Slutsker, 2007). With a mortality rate of nearly 20%, this illness affects the most vulnerable populations of society: older or immunocompromised adults, pregnant women, and newborns (Painter and Slutsker, 2007; Scallan *et al.*, 2011). This group is expanding as the US population ages, prompting greater action into the understanding and control of *L. monocytogenes*. A brief policy history relating to *L. monocytogenes* was presented by the FDA Center for Food Safety and Applied Nutrition (CFSAN, 2015), and current discussions revolve around government policy (e.g., FSMA), research needs, and information sharing of educational resources (Produce Marketing Association and United Fresh Produce Association, 2016).

2.1.2.1.1. *Listeria monocytogenes* and cantaloupe melons

Cantaloupe melons have been implicated as a vector for foodborne illnesses caused by *L. monocytogenes*. In 2011, a particularly grave outbreak led to 147 reported illnesses and 33 deaths, across 28 states, with the contamination traced to a single Colorado farm using unsanitary processing practices (McCollum *et al.*, 2013b). The responsible farm recalled at least 1.5 million cantaloupes (Flynn, 2011). Here in Michigan, Heeren Brothers Produce, of Grand Rapids, recalled 5,400 lbs. of cantaloupe due to samples testing positive for *Listeria* (Food Safety News, 2013). Cutting melons to make a fresh-cut product introduces issues of cross contamination. A Kansas food processor opted to recall packages of fresh-cut cantaloupe due to the risk that they were produced from melons connected to that 2011 outbreak (Food Safety News, 2011).

2.2. Packaging technologies to extend fresh-cut produce shelf life

A wide variety of packaging technologies have been investigated for their ability to extend the shelf life of fresh-cut produce. This review examines modified atmosphere packaging (MAP), and three approaches to dealing with in-package moisture: modified humidity packaging (MHP), liquid-absorbing packaging, and antifogging additives.

2.2.1. Modified atmosphere packaging

MAP is a packaging technology based on the replacement of ambient air (78.09% nitrogen (N_2), 20.95% oxygen (O_2), 0.03% carbon dioxide (CO_2), and 0.93% Argon (Ar) plus others) inside the package with a single gas or a specific mixture of gases that can lead to produce shelf-life extension (Almenar and Wilson, 2016). A headspace containing low O_2 (1-5%), high CO_2 (10-20%), with N_2 as make-up gas is normally desired. Low O_2 slows down respiration rate, ethylene production, enzymatic browning, and growth of aerobic microorganisms (Gorny, 1997). However, the amount of O_2 needs to be carefully controlled since concentrations below 1% can lead to produce fermentation and create a friendlier environment for the growth of anaerobic or facultative anaerobic pathogens, such as *Clostridium botulinum* and *L. monocytogenes* (Farber *et al.*, 2003b). CO_2 is used due to its direct antimicrobial capacity, but excessive levels of CO_2 can cause a reduction in pH, flavor tainting, and drip loss. N_2 is used as a make-up gas to avoid the collapse of the package and, by displacing O_2, has an indirect antimicrobial capacity. The most adequate gas or mixture of gases is selected based on the type of produce to be packaged, due to differences in respiration rate, ethylene production and/or sensitivity, etc., between different fruits and vegetables. Tight temperature management is essential for maintaining the proper balance between the produce respiration rate, package barrier properties, and headspace volume (Almenar and Wilson, 2016).

Depending on how the ambient air inside the package is replaced with a desired gas composition, MAP is classified into two types: active MAP (AMAP) and passive MAP (PMAP). In AMAP, the ambient air in the package is replaced with a desired gas or mixture of gases by direct flushing prior to package sealing. In PMAP, air free of contaminants, such as medical air, replaces the ambient air inside a package by direct flushing. After package sealing, the composition of the headspace is modified due to the interplay between produce respiration (which consumes O_2 and replaces it with CO_2), packaging characteristics (including film permeability and headspace volume), and the storage conditions (namely, temperature and relative humidity) (Almenar and Wilson, 2016). Some examples of the oxygen permeability of petroleum-based and bio-based plastic packaging materials are presented in Table 1 (Almenar and Wilson, 2019). Both continuous and microperforated films can be used in PMAP to control gas exchange. Microperforated films allow a faster entrance of O_2 into the package, mitigating the high and low concentrations of CO_2 and O_2, respectively, that are developed in continuous film packages containing produce. A desired gas composition can easily be obtained with microperforated films by varying the number, area, and length of the microperforations and thereby optimizing the gas exchange (Koutsimanis, Harte and Almenar, 2015). In either case, produce is sanitized prior to AMAP or PMAP application. Page *et al.* (2016) showed that careful selection of the sanitizer type and the in-package atmosphere is necessary for produce, since interactions between sanitizers and gas compositions affect microbial growth and quality.

Retail chains in the United States use AMAP to extend the shelf life of many types of fresh-cut produce, including leafy greens, vegetable salads, sliced apples, and sliced peaches, among others. Similarly, PMAP with microperforations has been commercially used for baby spinach and ready-to-eat blueberries. In the United States, AMAP is widely used to extend the shelf life of bulk produce including strawberries, blueberries, and cherries during warehouse storage and transportation (Almenar and Wilson, 2016).

Table 1. Comparison of barrier properties of assorted petroleum-based and bio-based packaging plastics

Plastic	Processing method	Thickness (µm)	Permeability: Water vapor at 38 °C and 90% RH (10^{-15} kg m m^{-2} s^{-1} Pa^{-1})	Permeability: Oxygen at 23 °C and 0% RH (10^{-22} kg m m^{-2} s^{-1} Pa^{-1})
LDPE[a]	Extrusion/ chill roll	32	11.5	281,612
PP[b]	Extrusion/ chill roll	30	11.7	406,065
PET[c]	Extrusion/ chill roll	12.5	21.9	8,421
Saran-coated nylon	Extrusion/ chill roll	20	13.6	504
EVOH[d]	Extrusion/ chill roll			
32 mol % ethylene		20 – 30	3.5	8.2
44 mol % ethylene			1.5	39.2
PLA[e]	Extrusion/ chill roll	44	21.9[f]	56,700[f]
Chitosan[h]	Casting	54	600	14,300
Egg white protein[i]	Extrusion/ calendering	106	381	26,304
Whey protein isolate	Casting	71	425[g]	-

[a] Low-density polyethylene, [b] polypropylene, [c] polyethylene terephthalate,
[d] ethylene vinyl alcohol copolymer (http://www.eval.eu/media/15492/technical%20brochure_english.pdf),
[e] polylactic acid, [f] Gonzalez-Buesa et al. (2014), [g] measured at the School of Packaging, Michigan State University, MI, USA,
[h] Adzaly, Jackson, Villalobos-Carvajal, Kang, & Almenar (2015), [i] Pranata (2014).
Table data source: (Almenar and Wilson, 2019)

2.2.1.1. Superatmospheric oxygen MAP

While traditional MAP compositions focus on reduced O_2 and elevated levels of CO_2, the abilities of alternative gas compositions to improve safety and quality have also been examined. A review summarizing different superatmospheric oxygen atmospheres as a means to extend the shelf life of fresh produce was presented by Kader and Ben-Yehoshua (2000), who found limited research and many unanswered questions. One benefit of a superatmospheric oxygen MAP design is to reduce the risks of harmful anaerobic bacterial growth, which can occur in MAP designs where very low levels of O_2 are present (Kader and Ben-Yehoshua, 2000; Harris *et al.*, 2003). Through an in-vitro study, Jacxsens *et al.* (2001) showed that atmospheres of 95% O_2 extend the lag phase of *L. monocytogenes*, although the maximum population was unchanged.

Recent work has shown AMAP with 95% O_2 suppressed the growth of *L. monocytogenes* on fresh-cut celery during 10 days of storage (Gonzalez-Buesa *et al.*, 2014). In a study of fresh-cut onions, superatmospheric oxygen atmospheres, in combination with peroxyacetic acid sanitizer, outperformed other packages in suppressing the growth of *Salmonella* Typhimurium, another human pathogen known to contaminate foods (Page *et al.*, 2016). However, superatmospheric oxygen AMAP with other sanitizers active against aerobic bacteria, yeasts, and molds was no more effective than conventional AMAP, PMAP, or a snap fit container that did not create a modified atmosphere. By flushing with 95% O_2, Jacxsens *et al.* (2001) found AMAP compositions were capable of extending the shelf life of grated celeriac, sliced mushrooms, and shredded chicory, relative to conventional MAP, particularly by decreasing enzymatic browning. In fresh-cut 'Piel de Sapo' melon, Oms-Oliu, Soliva-Fortuny and Martín-Belloso (2008) found AMAP designs with 70% O_2 effective in preventing fermentation and maintaining melon texture, although soluble solids content (SSC) dropped far faster than when other modified atmospheres were employed.

2.2.1.2. MAP for fresh-cut cantaloupe

Gas compositions of 3-6% O_2 and 6-15% CO_2 at a storage temperature of 0-5°C are widely recommended for maintaining quality of fresh-cut cantaloupe (Gorny, 1997). However, these recommendations were generated solely from controlled atmosphere storage data, not the dynamic environment of MAP. When these recommendations were subsequently investigated using PMAP and AMAP (4% O_2, 10% CO_2), both atmospheres effectively extended the shelf life of fresh-cut cantaloupe when compared with perforated packages (Bai *et al.*, 2001). In that study AMAP outperformed PMAP in reducing translucency and microbial load (total aerobic bacteria and yeasts and molds). However, those authors noted that the MAP treatments had no effect on firmness decline. A later study challenged the recommendations of Gorny (1997), finding that cantaloupe respiration rates do not appreciably drop until O_2 levels dip below the fermentative threshold of the fruit (Gomes, Beaudry and Almeida, 2012). Those authors posit that the MAP benefits for fresh-cut cantaloupe lie in the elevated levels of CO_2, rather than lowered levels of O_2. AMAP compositions involving superatmospheric oxygen levels have not been explored for cantaloupe. While other melons, e.g., 'Piel de Sapo' (Oms-Oliu, Soliva-Fortuny and Martín-Belloso, 2008), have shown positive responses to superatmospheric oxygen atmospheres, responses to MAP or controlled atmosphere treatments vary between melon varieties (Portela and Cantwell, 1998; Bai *et al.*, 2001; Bai, Saftner and Watada, 2003; Aguayo, Escalona and Artes, 2004).

While MAP in combination with refrigeration can delay produce deterioration and pathogen growth, this packaging technology is not always sufficient to maintain produce quality and safety for a desirable marketing period (Almenar and Wilson, 2016). Therefore, combining MAP with other technologies to improve quality and safety is necessary, and the interactions between such technologies are of crucial importance to their success. For instance, for fresh-cut cantaloupe, combining MAP and irradiation has shown to greatly reduce microbial load, and additionally to lower produce respiration rate, reduce off-flavors, and enhance sensory evaluations of sweetness (Boynton *et al.*, 2006). Two studies of MAP-packed fresh-cut cantaloupe have incorporated moisture-absorbent pads into the package, although neither study investigated the impact of such pads on the shelf life of the melon (Bai *et al.*, 2001; Zainal Abidin *et al.*, 2013). Studies on such impacts from moisture modification are on the rise in recent years for other fresh and fresh-cut produce, as explored in the following section.

2.2.2. Modified humidity packaging

Water and fresh produce quality are inextricably linked. Fresh fruits and vegetables are typically composed of 80–90% water and may shrivel or wilt if they lose 3-10% of it (Ben-Yehoshua and Rodov, 2003; Wills *et al.*, 2007). The process of transpiration – water vapor release from plant tissue – continues in fresh produce after harvest. Low levels of RH surrounding the product lead to weight losses, shriveling, and other detriments (Wills *et al.*, 2007). At saturation, water vapor will condense onto the product, impacting respiration rates and fostering microbial growth (Scott *et al.*, 1964; Kader, Zagory and Kerbel, 1989; Shirazi and Cameron, 1992; Powers and Calvo, 2003; Rodov *et al.*, 2010; Linke and Geyer, 2013; Mahajan *et al.*, 2014; Mir and Beaudry, 2014). Numerous methods to favorably modify the moisture dynamics in a package have been studied, broadly categorized by whether the technology interacts with water in the vapor or liquid phase. These are explored in the following sections.

Modifying in-package RH to reduce the risk of condensation-driven rot and decay can be done in many ways. The term modified humidity packaging (MHP) was originally coined to refer to the use of hygroscopic additives – compounds that sorb moisture from the air – to control in-package RH (Shirazi and Cameron, 1987, 1992; Rodov *et al.*, 1995). Usage has since broadened the definition to capture other mechanisms of changing in-package RH (Aharoni *et al.*, 2008; Porat *et al.*, 2009; Rodov *et al.*, 2010; Bovi *et al.*, 2016). Hence, for the purposes of this review, MHP will refer to any packaging technologies that serve to change in-package RH. The goal of MHP is to generate and maintain optimal in-package RH conditions to preserve the quality of fresh fruits and vegetables (Rodov *et al.*, 2010). Strategies to accomplish this include tailoring water vapor barrier properties of the package to the produce, through material decisions or modifications (e.g., perforations), and adding hygroscopic compounds to the package.

2.2.2.1. Passive modified humidity packaging

When the RH differs from the inside to the outside of a package, water vapor permeates through the film towards the side of lower RH until attaining equilibrium. The water vapor permeation process, like other types of mass transfer, is governed by well-studied scientific principles such as sorption, diffusion, and desorption. The barrier properties of the packaging film, resisting this mass transfer, are most usefully recorded as a water vapor permeability coefficient (WVPC) at a given temperature:

$$WVPC = \frac{q\ L}{A\ t\ \Delta p}$$

Where q, L, A, t, and Δp represent the mass of water vapor, film thickness, film area, time, and water vapor partial pressure differential, respectively. Utilizing a film with a WVPC that prevents condensing humidity without promoting too much weight loss will achieve the goal of passive MHP, to extend produce shelf life. The rest of this section will examine the effects of films with high and low barrier properties on passive MHP systems, as well as the use of additives to modify the barrier properties of a film.

2.2.2.1.1. In-package humidity and high water vapor barrier films

Polyolefins, such as low-density polyethylene (LDPE) and polypropylene (PP), are the most widely used plastics in the fresh produce industry, due to their low cost, easy converting, and good optical and printing properties. However, due to their low WVPC, such materials promote rapid condensation because transpired water cannot escape the package, without modifications such as perforations. Based on the film's barrier properties to oxygen and carbon dioxide, as well as the respiration rate of the produce, a sealed package comprised of a continuous film will also generate a modified atmosphere, which can be beneficial to shelf life. Examples of the water vapor and oxygen barrier properties provided by various plastic films are presented in Table 1 (Almenar and Wilson, 2019). For products such as fresh-cut salad, that are highly vulnerable to weight loss and can benefit from a modified atmosphere, sealed packages of polyolefin materials are used.

An alternative and effective technique using high barrier films to create a MHP for fresh produce is individual shrink packaging. This process takes a thin, biaxially-stretched film and heat-shrinks it over a single piece of produce, forming a tight-fitting package. Theoretically, individual shrink packaging minimizes the headspace volume and heat differentials between the package and produce surface, preventing condensation on the produce while providing an enhanced water vapor barrier (Rodov *et al.*, 2010). The produce must have sufficiently uniform geometry to permit a well-fitted shrink package and prevent condensation in the voids (Rodov *et al.*, 2010). Initial studies of individual shrink packaging for fresh produce were conducted in the 1970s, and continue to attract research interest today. Studies have shown shelf life extension for products such as cucumber (Dhall, Sharma and Mahajan, 2012), bell pepper (Ben-Yehoshua *et al.*, 1983; Bar-Yosef *et al.*, 2009; Fallik *et al.*, 2009; Ilić *et al.*, 2012), various citrus (Ben-Yehoshua, Kobiler and Shapiro, 1981; Ben-Yehoshua *et al.*, 1983; Rodov *et al.*, 2000), zucchini (Megías *et al.*, 2015), sweet corn (Deak *et al.*, 1987), pomegranate (Nanda, Sudhakar Rao and Krishnamurthy, 2001; D'Aquino *et al.*, 2010), guava (Pal *et al.*, 2004), mango (Sudhakar Rao and Shivashankara, 2014), and honeydew melon (Rij and Ross, 1988). However, the studies listed above should be viewed with caution, as the details of the shrink-wrapping process (e.g., film type and thickness, temperature), storage conditions, and variety or cultivar of the commodity have a major impact on the success of the treatment. In some climacteric fruits, individual shrink packaging was shown to inhibit ripening and contribute to off-flavors as a result of creating inappropriate modified atmospheres (Rodov *et al.*, 2010).

2.2.2.1.2. In-package humidity and low water vapor barrier films

One strategy to reduce in-package humidity is to utilize high-WVPC continuous films. Like in the previous section, continuous film packages with high WVPC can create beneficial modified atmospheres, based on their barrier properties to oxygen and carbon dioxide. If the correct environmental conditions are maintained outside of the package, high-WVPC films can additionally permit enough transpired water vapor to escape the package to minimize condensation and extend shelf life. Films employed for this purpose are traditionally described as "poor water vapor barriers," although in this case, their water vapor barrier properties are superior for shelf life extension. Plastics such as nylon-6 and polylactic acid (PLA) have been explored in this context.

Under the brand name Xtend® (Johnson Matthey, Royston, UK), proprietary polyamide-based blended films with high WVPC have been marketed internationally with the explicit goal of extending produce shelf life by reducing in-package RH (Aharoni *et al.*, 2008; Rodov *et al.*, 2010). These films have predominantly been used as case liners for long-distance shipping of bulk produce, such as melons from South America to Europe, and bell peppers, eggplant, squash, and cucumbers from Mexico to the United States or Canada (Leighton, 2015). Microperforated Xtend® films have also been used to extend the shelf life of broccoli, green onions and leeks, topped radishes and carrots, snap beans, nectarines, and strawberries (Aharoni *et al.*, 2008), while continuous films have been successfully applied to mangoes (Pesis *et al.*, 2000) and pomegranates (Porat *et al.*, 2009). Generally, these films produce both a MAP and a MHP, the combination of which enables the films to reduce decay, color changes, and other factors discussed in those studies.

Pallet-scale MAP is commercially employed for long-distance shipment of certain produce. Kim *et al.* (2016) explored various materials to reduce condensation in a pallet-scale MAP, studying bags made from LDPE, oriented PP with an antifogging additive, Mosspack® (a commercial linear low-density polyethylene film with humidity absorbing additives), nylon-6, and PLA. All three polyolefin bags contained significant condensation. PLA maintained high (>98%) RH over one week of storage, with minimal condensation, although the film was prone to tearing and judged mechanically insufficient for pallet bag applications. The nylon-6 bags prevented condensation by reducing in-bag RH to 94.5-97% over one week. Those authors later bagged a pallet load of tomatoes with the nylon-6 film, although they did not conduct any quality analysis by which to judge the effectiveness of the treatment. For reference, comparisons of the differences in selected barrier properties of bio-based and petroleum-based films are presented in Table 1 (Almenar and Wilson, 2019).

More successful applications of PLA to create passive MHP have been accomplished with retail-size packages. Koide and Shi (2007) compared the quality of bell peppers over time in bio-based film packages made from PLA to continuous and perforated LDPE packages. Those authors found that total aerobic bacterial load was 1 log CFU/g lower in PLA packages than in continuous LDPE packages after 1 week of storage, while weight loss increased from 0.38% in LDPE packages to 2.46% in PLA packages.

The high WVPC of PLA packages has been shown to outperform some commercial packages, like vented containers, which permit greater weight loss. In a study of blueberries packaged in either PLA snap-fit containers, without vents, or in polyethylene terephthalate (PET) clamshell containers, with vents, MHP principles were indirectly examined (Almenar *et al.*, 2008). Their results showed greater weight loss in the vented clamshell containers, while fungal growth in the PLA containers outpaced that in the clamshells. However, the shelf life-limiting weight loss was met after only three days of storage in the clamshells, while fungal growth only became visible on the twelfth day of storage at 10°C, resulting in an increased shelf life in the non-vented PLA containers, partially due to the superior MHP design.

2.2.2.1.3. Modifying water vapor barrier properties with additives

When the properties of a film are insufficient to meet the needs of a specific application, additives may be compounded into the film to overcome that deficiency. Drivers such as cost, product requirements, and a greater desire for sustainable materials are pushing the development of new packaging materials, often accomplished through additives. Creation of nanocomposites (composites containing distributed additives with a dimension below 100 nm) to improve the properties of packaging plastics is a rapidly growing field. Research on additives such as nanoclays has explored their ability to improve the barrier properties of packaging materials

(Duncan, 2011). Lightweighting, or source reduction, has been one of the strongest trends in the packaging industry over the past few years (Robertson, 2015), and nanocomposites can be formed from fewer raw materials while providing similar or superior performance to conventional plastics (Silvestre, Duraccio and Cimmino, 2011). Additionally, nano-scale additives have been targeted as a means to bring bio-based polymers into more direct competition with the performance of their petroleum-derived counterparts (Azeredo, 2009). In the context of MHP, use of additives to modify barrier properties is another method to attain a desirable package, balancing the many aspects of produce shelf life and marketability.

2.2.2.1.4. Perforation-mediated modified humidity packaging

Perforations are one of the simplest ways to modify the in-package RH, as well as oxygen and carbon dioxide levels in MAP. In principle, perforations have a greater effect on oxygen and carbon dioxide permeability than on water vapor permeability (Bovi *et al.*, 2016). Therefore, the perforated area (i.e., the size and number of perforations) determines whether the perforations regulate MAP or MHP.

When a package has a small perforated area, the perforations will modify the barrier properties of the material to oxygen and carbon dioxide, but have minimal effect on the movement of water vapor into or out of the package. For MAP purposes, these microperforations have a diameter between 50 and 200 μm (Gonzalez-Buesa *et al.*, 2009). Microperforations have a key role in developing equilibrium modified atmosphere packaging (e.g., Almenar *et al.*, 2007), but do not noticeably affect the MHP properties that would be provided by a continuous material of the same substrate (Rodov *et al.*, 2010).

In contrast, larger perforated areas are widely used to regulate in-package RH. Fresh produce packages utilizing macroperforations or vents are common, although due to their size they prevent the formation of a modified atmosphere (Shirazi and Cameron, 1992). By increasing the perforated area, in-package RH is brought closer to equilibrium with the outside environment. Models to assist in the prediction of such behavior for mango fruit packaging were presented by Fishman, Rodov and Ben-Yehoshua (1996), although the model could be applied to other types of produce by changing the transpiration coefficients (Bovi *et al.*, 2016). More recently, Techavises and Hikida (2008) developed a model for the permeation of atmospheric gases and water vapor through macroperforations in thin films. As that model did not include the role of material thickness, Mahajan, Rodrigues and Leflaive (2008) developed a model to relate the impact of perforation diameter, material thickness, number of perforations, and temperature on the water vapor transmission rate.

2.2.2.1.5. Weaknesses of passive modified humidity packaging

Packaging approaches to maintain proper moisture levels inside of a package must operate effectively in the environmental conditions expected during distribution, retailing, and consumer storage. However, it is well known that temperature and RH vary in fresh produce supply chains (Linke and Geyer, 2013; Koutsimanis, Harte and Almenar, 2015). Transpiration, respiration, condensation dynamics, and material permeability are dependent upon temperature; unless the outside temperature and RH are stable, the package will not function correctly to maintain in-package RH for shelf-life extension.

Good temperature management is fundamental to fresh and fresh-cut produce distribution, and easily the most important factor in extending shelf life. While large traditional retailers have worked hard to remove breaks in their cold chains, growth of fresh and fresh-cut produce into new formats, such as convenience stores, gas stations, and e-commerce platforms, has created more opportunities for temperature abuse. RH management during distribution and retailing, tightly tied to temperature management, is crucial to the performance of passive MHP systems. However, even in complete cold chains, variability in airflow and tightly packed cases can prevent passive MHP technologies from performing as desired. In order to adapt to cold chain breaks and ensure performance in typical ones, active MHP technologies offer a way to manage moisture with less dependence on the external environment.

2.2.2.2. Active modified humidity packaging

Reviews of active packaging have generally included a section on moisture control, dating back to Labuza and Breene (1989). Designed uses of hygroscopic compounds to modify RH in fresh produce packages date back a half century (Scott *et al.*, 1964), far predating terminology like *active packaging* and *modified humidity packaging*. Following the seminal paper by Shirazi and Cameron (1992), active packaging for moisture control was split into two groups: liquid water control and humidity buffering (Rooney, 1995). Since then, this split has remained constant through numerous reviews of active packaging technologies covering food in general or meat products (Vermeiren *et al.*, 1999; Suppakul *et al.*, 2003; Ozdemir and Floros, 2004; Kerry, O'Grady and Hogan, 2006; Singh, Wani and Saengerlaub, 2011; de Abreu, Cruz and Losada, 2012; Biji *et al.*, 2015).

Reviews that focus on moisture modification technologies are relatively scarce when compared to other types of active packaging. Many include mention of fresh produce with respect to moisture modification, which is often a direct reference to the Rooney (1995) book's reference to the Shirazi and Cameron (1992) paper. However, two recent reviews have specifically targeted fresh produce applications of active packaging for moisture control. Rodov *et al.* (2010) broadly reviewed postharvest interactions between produce and water, with a focus on the abilities of different MHP approaches to extend shelf life. Those authors reviewed both academic and commercial work in active MHP, although the latest reviewed studies were published in 2007, and most of the commercial technologies had been presented in earlier active packaging reviews (Rooney, 1995; Suppakul *et al.*, 2003). Recently, a review of moisture dynamics in fresh produce packaging summarized knowledge of integrative models to predict in-package RH with and without active compounds, while adding some of the recent work in active MHP (Bovi *et al.*, 2016).

These reviews have always included liquid absorbing materials as a type of MHP. However, the effect of liquid absorbing technologies on in-package RH has not been proven, so it seems misleading to classify them as a type of MHP. Likewise, antifogging additives, which interact with liquid water but do not affect in-package RH, should not be considered as a type of MHP. For the purposes of this review, active MHP consists of the addition of hygroscopic additives to the package. The key distinction in active MHP approaches is whether they generate and maintain a distinct in-package RH, known as humidity buffering, or simply sorb water vapor from the headspace without maintaining a consistent in-package RH. This section will discuss the development of active MHP, the goals of humidity buffering and the challenges of doing so, as well as recent approaches that are changing the future direction of MHP research.

2.2.2.2.1. Water vapor sorption

Desiccants, or drying agents, are commonly used to prevent moisture from degrading dry foods. As hygroscopic compounds, they utilize sorption processes to take in and retain water vapor from the package headspace. Other hygroscopic compounds, called humectants, are added to relatively wet food products to retain moisture. For the purposes of MHP for produce, compounds classified in either category can be employed to lower moisture content in the package headspace. Maintaining a very high in-package RH is necessary for fresh and fresh-cut produce as discussed in section 2.2.2. Therefore, only a slight drying action is desirable to prevent condensation while avoiding dehydration. A few factors determine the behavior of hygroscopic compounds, such as the rate at which they adsorb or absorb water vapor, their maximum water holding capacity, and the temperature and RH of the surrounding atmosphere. Additionally, the package and produce characteristics that dictate the success or failure of passive MHP are still in play. Therefore, hygroscopic compounds serve to further modify the in-package RH created by the existing passive systems. Generally, a major advantage of utilizing active MHP over passive MHP is that the former can cushion in-package RH when temperature fluctuations or other improper environmental conditions are present.

2.2.2.2.2. Humidity-buffering active packaging

The fundamental idea behind humidity-buffering packaging is that the package can generate and maintain the ideal RH for optimizing the shelf life of any given commodity. The breakthrough in creating humidity-buffering packaging came in the late 1980s, when Michigan State University researchers assessed the ability of a group of hygroscopic compounds to maintain stable in-package RH levels (Shirazi and Cameron, 1987, 1992). Applying the principles of RH maintenance with saturated salt solutions (Greenspan, 1977) and humectant sugar alcohols to the microenvironment inside of a package, Shirazi and Cameron (1987, 1992) investigated five hygroscopic compounds: sorbitol, xylitol, sodium chloride (NaCl), potassium chloride (KCl), and calcium chloride ($CaCl_2$). Placing a spun-bonded polyethylene (Dupont Tyvek®) sachet containing 10 g of hygroscopic compound into a low-density polyethylene (LDPE) pouch containing one tomato, the authors monitored RH at 20°C over 48 days of storage. Additionally, the same packages were loaded with sachets containing 0.1, 0.5, 1, 5, 10, and 25 g of hygroscopic compound and a tomato, sealed, and then RH was measured over three days. The authors found that incorporating 10 g of NaCl, to maintain an in-package RH of ~80%, extended the shelf life of the tomato from 5 days to between two and three weeks (Shirazi and Cameron, 1992). Core to their results for future humidity-buffering applications were a) that $CaCl_2$ did not effectively buffer humidity at a stable level, b) that very small amounts of hygroscopic compound may not properly buffer humidity, and c) xylitol, KCl, sorbitol, and NaCl can each provide a range of in-package RH levels, depending on the amount of hygroscopic compound in the package.

In a further study, Rodov *et al.* (1995) packaged red bell peppers in LDPE pouches containing sachets of 5, 10, or 15 g of NaCl, finding that the addition of 10 g of desiccant best reduced decay after three weeks of storage at 17°C. In-package RH was maintained at approximately 92% with this combination, while the control packages approached saturated levels of RH. Weight losses of 3% over that time period were triple that of packages without the active compound, but far lower than the 10% weight lost by unpackaged peppers.

In the subsequent decade, studies seeking to buffer humidity fell short of the dramatic shelf-life extension that seemed possible from earlier work. In fact, many of these studies failed to extend shelf life at all. A group of studies published between 1995 and 1996 investigated the ability of various hygroscopic compounds to extend the shelf life of mushrooms. Two of those hygroscopic compounds – sorbitol and NaCl – were previously shown to have humidity buffering properties. An initial study placed Tyvek® sachets filled with sorbitol in commercially used mushroom packages – polyvinyl chloride (PVC) film with two macroperforations overwrapping a polystyrene (PS) tray – and evaluated the effects of varying sorbitol quantities on mushroom quality (Roy, Anantheswaran and Beelman, 1995). The authors found that the best color retention and lowest microbial load were achieved in packages containing 15 g of sorbitol, following 6 days of storage at 12°C. However, addition of the hygroscopic compound led to weight losses of 13% in that same period, far above the 2-6% limit that other authors have quoted for mushrooms (Villaescusa and Gil, 2003). While color retention was improved, nearly tripling the weight loss from control packages combined with a paltry 0.5 log CFU/g reduction in microbial load seems less beneficial for shelf life than the authors claim. In-package RH was not reported, although continuing work by those same authors did present such data. Studying sorbitol as well as NaCl, Roy, Anantheswaran and Beelman (1996) showed that 5, 10, and 15 g of sorbitol in the package proved incapable of maintaining a steady in-package RH over 7 days of storage. Changing the active compound to NaCl retained a more constant level of in-package RH, around 84%, although minor, cyclical variances were evident as in previously discussed studies (Shirazi and Cameron, 1992; Rodov *et al.*, 1995). The lower in-package RH generated by the NaCl led to greater weight losses; packages containing 5 g of NaCl had greater weight losses than the same packages containing 15 g of sorbitol. The most effective packages, containing 10 or 15 g of sorbitol, had an in-package RH that rose from 80% to 85-90% over 9 days of storage at 12°C, although high levels of weight loss preclude the conclusion that those treatments truly extended shelf life.

In contrast with earlier studies, Villaescusa and Gil (2003) found that adding sorbitol to MAP packages of mushrooms decreased quality, promoting texture degradation and exudates. In-package RH was not reported by those authors, so it is uncertain if the addition of sorbitol developed a buffered humidity level. This is a great challenge in evaluating the success of humidity buffering – some studies do not record in-package RH. As evidenced by comparing the studies of Shirazi and Cameron (1992) and Roy, Anantheswaran and Beelman (1996), compounds that served as a humidity buffer in one context may fail to do so when a different produce is packed. Therefore, if studies do not continually record in-package RH, it is difficult to tell whether humidity was buffered at a useful level, as shown by Yahia and Rivera (1992) and Villaescusa and Gil (2003).

2.2.2.2.3. Non-buffering active MHP

Where humidity-buffering approaches use specific sorption properties of certain hygroscopic compounds to generate and keep a stable in-package RH, compounds with different sorption properties have also been explored for produce shelf-life extension. With commercially available desiccants such as silica gel and montmorillonite clay, mushroom studies have shown unremarkable results; one found better color retention at the expense of weight loss (Anantheswaran and Sunkara, 1996), while another with silica gel alone found that the compound reduced condensation and increased weight loss, but did not improve mushroom quality (Villaescusa and Gil, 2003).

As previously mentioned, the two sets of studies [Roy, Anantheswaran and Beelman, (1995, 1996) and Anantheswaran and Sunkara (1996); and Villaescusa and Gil (2003)], used different varieties of mushrooms, finding different results with the same hygroscopic compounds. A study of three raspberry cultivars, packaged with finely ground zeolites to adsorb water and volatiles, found reduced levels of decay, improved firmness, and reductions of in-package condensation (Toivonen, Kempler and Stan, 2002). Those authors further reported that one of the three cultivars studied failed to respond to the zeolite treatment in terms of color, darkening to a past-ripe stage, while the other two cultivars remained significantly brighter when the zeolite was present. With cultivar and variety both showing importance in the success or failure of MHP designs, recent work has turned to greater customization of MHP systems.

2.2.2.2.4. Incorporation mechanisms and blending of active compounds

Considering the challenge of matching individual produce commodities to appropriate humidity modification technologies, blending different active compounds may be the appropriate strategy. Mahajan *et al.* (2008) demonstrated a process for designing an optimized mixture of hygroscopic compounds for mushrooms, citing the failure of individual desiccants to extend shelf life. Observing sorption rates and maximum capacities of various desiccants under different temperature and RH conditions, those authors built a combination desiccant that satisfied both key sorption parameters: rate and maximum capacity. Validating the effectiveness of their designed mixture in mushroom packages, those authors found that condensation was greatly reduced in packages containing desiccant. While the authors describe "excessive moisture loss" in their packages that lost 5% weight over 5 days of storage, these weight loss values are far below those seen in other mushroom MHP studies.

Like other studies presented in this review, Mahajan *et al.* (2008) incorporated their active compounds into a sachet, or small bag, which was then placed inside the package. This is the simplest way to add active compounds to a package. Active sachets are constructed of a permeable material, such as spunbonded HDPE (Tyvek®, DuPont) or cloth. As the addition of an extra piece to a package is problematic for manufacturers (another piece of inventory to track) and undesirable for consumers (can be confusing, could be eaten accidentally) incorporating active compounds into the main packaging substrates is preferable.

Recent studies have created active MHP through coating (Kim *et al.*, 2006) and coextrusion processes. In some such studies, a humidity buffering compound, NaCl, was coextruded into polyolefin films (Sängerlaub, Böhmer and Stramm, 2013) and multilayer rigid trays (Geyer *et al.*, 2015; Rux *et al.*, 2015, 2016). Using mushrooms to assess the tray's effectiveness, Rux *et al.* (2015) found that the tray adequately buffered humidity at 93%, with these mushrooms having superior quality after 6 days of storage, compared with packages not containing NaCl. Due to some in-package condensation, those authors decided to conduct further studies on slower-respiring produce, although the trays were curiously unable to buffer in-package humidity for strawberries or tomatoes (Rux *et al.*, 2016). In any case, those studies show the challenges and great potential for future developments in active MHP.

2.2.2.2.5. Modeling active MHP systems

Development of models to assist in the design of active MHP for fresh produce has followed a similar timeline to the above studies. A history of such models was presented by Song, Lee and Yam (2001), with more recent studies reviewed by Bovi *et al.* (2016). Generally, these models rely upon balancing the produce transpiration rate, the amount of water permeating through the package film, and the amount of water vapor sorbed by the active compound in the package, at a given environmental temperature and RH.

2.2.2.3. Closing remarks on MHP

Many viable strategies to modify in-package moisture are available to the fresh produce industry. Additionally, consumer trends continue to indicate preference for “clean labels,” indicating that successful shelf life extension strategies utilizing minimal strange-sounding additives may be better received. Even so, when compared with the bustle around other active packaging technologies, strategies to optimize in-package water content seem relatively unstudied. Recent research has turned strongly to antimicrobial additives, which will likely face greater FDA and consumer acceptability challenges as they transition to becoming marketable products. As the relatively basic and safe shelf-life extension provided by proper water management has not been fully explored, further work to develop MHP shows a bright future.

2.2.3. Liquid absorbing pads for fresh produce packages

Intercepting water directly from the liquid phase is common in commercial settings. Pads or sheets used for this purpose are ubiquitous in meat, poultry, and fish packages and have been in use for over half a century. Limited suppliers, such as Paper Pak Industries (USA) and Maxwell Chase Technologies (USA), market similar products for fresh and fresh-cut produce applications. The rationale is the same as for the other perishable products: pooling liquids are unsightly to consumers and free water in fresh produce packages encourages microbial decay (Wills *et al.*, 2007; Rodov *et al.*, 2010). Liquids in the package include drippings from the (cut) produce and accumulated condensate.

Commercial pads used for liquid absorption alone have remained relatively unchanged over the years. The basic construction of such pads is a polyolefin top layer (to prevent direct desiccation the food), and a porous bottom layer, with an absorbent material filling the sealed space between. The absorbent materials inside include fluff pulps, which are made from long softwood fibers, superabsorbent polymers (such as sodium polyacrylate), and various combinations (Novipax, 2016). The development of materials for food-grade absorbent pads parallels those used in consumer products such as diapers, sanitary napkins, and adult incontinence products. New innovations in the area of absorbent pads have focused on incorporating other active compounds, such as carbon dioxide emitters, antimicrobials, and oxygen scavengers into the pads, which are often activated by water entering the pad (Kerry, O'Grady and Hogan, 2006; Otoni *et al.*, 2016). Commercial products, such as the UltraZapXtendaPak line (Paper Pak Industries, USA) have targeted fresh-cut tomatoes and onions with their carbon dioxide emitter-loaded moisture absorbent pads.

Few data are available in the literature about the effectiveness of liquid-absorbing pads and sheets on microbial load, and less still when incorporated in fresh produce packaging. A study of multiple types of absorbent pads used with packaged chicken breast found that microbial load remained similar between the treatments throughout the study (Charles, Williams and Rodrick, 2006). Additional studies have incorporated absorbent pads and collected microbiological data, but no control treatments without pads were reported (Bai *et al.*, 2001; Bai, Saftner and Watada, 2003; Zainal Abidin *et al.*, 2013), while others have used absorbent pads as a control when treatments incorporated active compounds into the pads (Oral *et al.*, 2009; Fernández, Picouet and Lloret, 2010).

2.2.4. Antifogging additives

Rather than functionally reducing free water in a package, as done by MHP or liquid absorbing technologies, antifogging additives serve a cosmetic purpose (Rooney, 1995). When water condenses on a surface, it forms a network of tiny droplets, based on the surface tension of the packaging material. Antifogging additives increase this surface energy, producing a continuous film of water instead of droplets (Selke, Culter and Hernandez, 2004). Where the small droplets of condensation scatter light, a continuous layer of water does not, meaning that consumers can clearly view the product even with very high in-package RH. Common additives used for this purpose include glycerol, sorbitol stearate, and fatty alcohols (Selke, Culter and Hernandez, 2004), which are distributed in the polymer matrix during extrusion. While removing the appearance of condensation on the package, antifogging additives do not inhibit the spoilage mechanisms promoted by condensation on the food product.

2.2.5. Consumer perception of active packaging

Although the commercial success of any packaging technology lies in the hands of consumers, research on either consumer acceptance of active packaging or consumer preference for a specific delivery mechanism of the active compound is scarce and rather incomplete.

2.2.5.1. Consumer acceptance of active packaging

Mikkola *et al.* (1997) investigated the acceptability of oxygen absorbers using a take-home type survey questionnaire given out with two food samples (pizza and sliced bread), packaged with or without an oxygen absorber sachet, to Finnish consumers in several supermarkets. The authors found that ~ 50% of the consumers preferred the two packaged foods with oxygen absorbers due to improved sensory attributes, ~ 40% found no difference, and ~ 10% preferred both food samples packaged without the oxygen absorbers. Those consumers accepted the application of oxygen absorbers in food packaging differently depending on the type of food, with fresh meats having the lowest level of acceptance from a list of selected foodstuffs. Targeting beef safety, Van Wezemael, Ueland and Verbeke (2011) used an online questionnaire to study European consumers' acceptance of different beef packaging technologies aimed at improved safety, including packaging with added antimicrobials (natural agents, protective bacteria, and releasing preservative additives). The study showed high rejection of packages with added antimicrobials, which the authors justified with the consumers' lack of familiarity with this packaging technology compared to modified atmosphere packaging and vacuum packaging. Similarly, O' Callaghan and Kerry (2016) conducted a consumer survey through the online network of University College Cork (Ireland) to assess acceptance of cheese products packaged with different technologies, including active packaging. The authors reported a general lack of knowledge regarding the assessed packaging technologies; 76% of the respondents had not heard about the term active packaging, and only 6% of the respondents were willing to purchase cheese commercialized in active packaging. In agreement, Barska and Wyrwa (2016) found that consumer unfamiliarity with active packaging plays a key role in its acceptability when the authors surveyed Polish consumers for their opinions of active and intelligent packaging. The authors found that the term active packaging was known by only 4% of responders. Consumers were more familiar with scavengers than emitters (42% vs. 16% of respondents, respectively). Also not targeting any specific food product and exploring preferences for specific attributes of active and intelligent packaging, Aday and Yener (2015) surveyed Turkish consumers about "innovative" food packaging technologies. In this study, consumers preferred that active compounds not be incorporated in sachets (only ~33% in favor of sachets) due to the possibility of accidental swallowing or product contamination because of sachet breakage. This finding agrees with Ahvenainen and Hurme (1997) who reported that consumers are not fond of active sachets for food products because of risks of accidental ingestion or broken inserts causing the active compound to contaminate the food.

2.2.5.2. Lack of work investigating perception of active compound delivery mechanism

As discussed earlier, common methods to add an active compound to a package include placing it in a visible device, such as a sachet, pad, or label, or utilizing a process that hides the active compound, such as direct incorporation into a polymer matrix or package coating (Lopez-Rubio *et al.*, 2004; Lee, 2016; Otoni *et al.*, 2016). Due to their simplicity, sachets and pads have remained a popular delivery mechanism in research and commercial practice (de Abreu, Cruz and Losada, 2012; Almenar, 2017).

All of the previous studies aside from the one by Aday and Yener (2015) cover consumer acceptance of active packaging but not consumer preference for the delivery mechanism of the active compound. Except for Mikkola *et al.* (1997), consumer acceptance of active packaging was assessed using a verbal description of the packaging technology, rather than exposing consumers to the actual packaging technology, which might have affected consumer response based on idea conception. A similar limitation exists in the only study in the literature that includes consumer preferences for the delivery mechanism of the active compound (Aday and Yener, 2015). The authors' choice of defining sachet as "an inedible capsule usually found inside drug bottles," seems odd in a food packaging survey, and might have negatively biased consumer responses. Of the previous studies, only the one by Mikkola *et al.* (1997) evaluated consumer perception of packaged food. Although the packages used in this study contained a sachet, the study solely assessed the consumer acceptance of the active compound inside the sachet, but not of the actual sachet.

3. IMPACTS OF MODIFIED ATMOSPHERE PACKAGING CONTAINING DRIP-ABSORBENT PADS ON QUALITY AND SAFETY OF FRESH-CUT CANTALOUPE

3.1. Overview

In this chapter, we examine the impacts of drip-absorbent pads and three different MAP compositions on safety and quality attributes of fresh-cut cantaloupe. This was completed through two independent studies. For the first, fresh-cut cantaloupe was inoculated with *Listeria monocytogenes*, packaged, and stored at approximately 5°C for 9 days. Beyond monitoring *L. monocytogenes* populations, weight changes of the package and drip-absorbent pad and headspace O_2 and CO_2 were recorded. In the second study, fresh-cut cantaloupe exposed to the same package treatments was stored at 3°C for 15 days. Key quality attributes were measured over time, including weight changes of the package and drip-absorbent pad, color, firmness, populations of spoilage microorganisms, pH, soluble solids content, and titratable acidity.

Many components of the materials and methods are shared by the studies, with differences noted where present. Critically, storage temperature differed between the trials. This was to ensure adequate growth of *L. monocytogenes* to assess differences in the safety study, while the quality study was conducted at a lower temperature to conform with best commercial practices.

3.2. Materials and methods

3.2.1. Cantaloupe (plant material)

Cantaloupe melons were purchased from a local produce wholesaler (Stan Setas Produce, Lansing, MI, USA) and transported under refrigerated conditions to the MSU Trout Food Science Building, where they were stored at 5°C and processed within 24 hours of delivery.

Melons were visually inspected for ripeness and decay; selected fruits were all at ¾- to full-slip maturity (Figure 2), free of pitting and soft spots, and showed no visible decay or physical damage. All melons were commercial 9's, meaning that a 40-lb. case contained nine melons weighing approximately 2 kg each.

Figure 2. Whole cantaloupe showing full-slip stem scar

3.2.2. Sanitizing and cutting

Selected melons were rinsed with cold water while being scrubbed with a brush. Melons were then immersed for 1 minute in a sodium hypochlorite solution containing 150 ppm available chlorine at pH ~6.6 and 17°C, then rinsed thoroughly with cool tap water. Available chlorine concentration was measured by titration using a test kit (FAS-DPD Chlorine Test Kit, LaMotte, Chestertown, MD), while pH and temperature were recorded with a handheld pH meter (Waterproof Double Junction pHTestr® 30, Oakton, Vernon Hills, IL). Cutting was performed in a cold room, 3-6.5°C, with all cutting tools, cutting boards, spoons, surfaces, and baskets for storing cut pieces sanitized prior to use. First, the stem end and flower end of the melons were removed with a sharp knife. One of the flat ends was placed on the cutting board, and the rest of the rind was removed in downward, arcing strokes. Then, the melon was halved and the seeds removed with a spoon. Melons halves were then cut into wedges, 2-3 cm wide, which were then cut into trapezoidal pieces, 2-3 cm long. A piece of melon, equidistant from the stem and flower ends, was taken and analyzed for soluble solids content. Melons meeting U.S. No. 1 standards of minimum 9 °Brix were retained, others discarded. For the safety study, initial SSC (Average ± SD) for cantaloupe cubes was 11.75 ± 1.57 °Brix in the first replicate, 10.74 ± 1.50 °Brix in the second, and 10.27 ± 1.88 °Brix in the third replicate of the experiment. In the quality study, initial SSC for cantaloupe cubes was 9.80 ± 1.95 °Brix in the first replicate and 10.19 ± 0.77 °Brix in the second replicate. Qualified cubes were collected in metal wireframe baskets and mixed to homogenize the trial. Melon intended for *Listeria monocytogenes* inoculation was treated as described in the following subsection.

3.2.3. *Listeria monocytogenes* inoculation

3.2.3.1. Inoculum

Stock cultures of three attenuated strains of *Listeria monocytogenes* (J22F, J29H, M3) were maintained at -80°C in trypticase soy broth (Becton Dickinson, Sparks, MD) containing 0.6% (w/v) yeast extract (Neogen, Lansing, MI) (TSB-YE) with 10% (v/v) glycerol added. Working cultures were prepared by streaking a stock culture onto trypticase soy agar (Neogen) containing 0.6% (w/v) yeast extract (Neogen) (TSA-YE), followed by incubation at 37°C for 24 hours. A single colony from each strain was transferred into 9 mL of TSB-YE, and incubated for 24 hours at 37°C. A sterile loopful was transferred again into 9 mL of TSB-YE and incubated for

24 hours at 37°C. A cocktail was obtained by combining equal volumes of the three cultures, and used immediately.

3.2.3.2. Inoculation

In a biosafety cabinet, cocktail cultures were diluted in tap water to approximately 10^7 CFU/mL. Cantaloupe cubes were immersed in the mixture for three minutes in batches of approximately 2.5 kg. Once removed from the inoculum, samples were drained and dried at room temperature in the biosafety cabinet for a few minutes before being placed in a large wire basket in an ice-loaded cooler. This procedure ensured an even inoculation level across packaged samples.

3.2.4. Packaging materials

Thermoformed polypropylene (PP) trays (Sealed Air, Charlotte, NC), polyethylene terephthalate (PET) film (Clear Lam, Elk Grove Village, IL), and drip-absorbent pads (Novipax, Oak Brook, IL) were used as packaging materials. The PP trays had external dimensions of 246 mm × 178 mm × 44.5 mm, a wall thickness of 0.5 mm, and weighed 26.7 ± 0.26 g. The PET films had a thickness of 25 µm, including a sealing layer of ethylene vinyl acetate (EVA). The drip-absorbent pads, commercially sold as Pad-Loc® PLSA 100, have a stated maximum absorbency of 100 g of water per pad. The pads are constructed of a polyolefin top layer and a permeable, non-woven bottom layer, with an absorbent core of fluff pulp and granules of a superabsorbent polymer. Three cylinder gases were used for modified atmosphere packaging (MAP): oxygen (Airgas, Radnor, PA), medical air (Airgas), and a commercial produce mixture (5% O_2, 15% CO_2, 80% N_2) (for *L. monocytogenes* trials: Purity Cylinder Gases, Wyoming, MI; for quality trials: Airgas). Six packaging treatments – each of the three MAP compositions, with and without a drip-absorbent pad – were assessed. The different MAP treatments are abbreviated throughout the chapter as follows:

HO-AMAP: High-oxygen active modified atmosphere packaging

LO-AMAP: Low-oxygen active modified atmosphere packaging

PMAP: Passive modified atmosphere packaging

3.2.5. Packaging method

Baskets of inoculated melon were transferred from the ice-loaded cooler into a small polystyrene cooler with a cut window, with gel ice packs loaded in the bottom to lessen heat gain. This cooler was placed in a biosafety cabinet, along with trays, pads, and an analytical balance. Approximately 410 g of cantaloupe cubes were placed inside of each tray, with the pad placed in the bottom of the tray for only the treatments with pads. Two trays at a time were loaded into a commercial MAP tray-sealing machine (T200, Multivac Inc., Kansas City, MO). Atmosphere was evacuated from the headspace of the trays and replaced by a flush of oxygen (HO-AMAP), medical air (PMAP), or the commercial produce mixture (LO-AMAP). Trays were then lidded with the PET film and sealed for 2 seconds at 140°C. A filled package is shown in Figure 3. Packages were labeled by treatment and then stored at 4°C until all packages were ready for distribution simulation (less than 1 hour).

Figure 3. Package of fresh-cut cantaloupe, with adhesive septum for headspace gas extraction

3.2.6. Distribution simulation

Vibration testing was conducted on a single-axis, vertical vibration test system (Model 10000-10, Lansmont Corp., Monterrey, CA, USA). High-pressure hydraulic fluid drives the table of the vibration test system up and down, with an electric servo valve controlling the motion of the fluid. This motion was generated to simulate the frequencies and intensities of vibration during transportation at a compressed time scale. Six coolers made of 1” thick expanded polystyrene (EPS) were affixed to the aforementioned table with nuts (Figure 4). In each cooler, ice was loaded into a separation made of corrugated fiberboard, capable of maintaining approximately 8°C in the coolers without directly contacting the packages. Packages were loaded into the coolers in a double layer. The vibration simulation was conducted according to ASTM D4728, a frequency spectrum for over-the-road truck vibration, with a 30-minute test cycle, in order to simulate 125-150 miles of truck transportation.

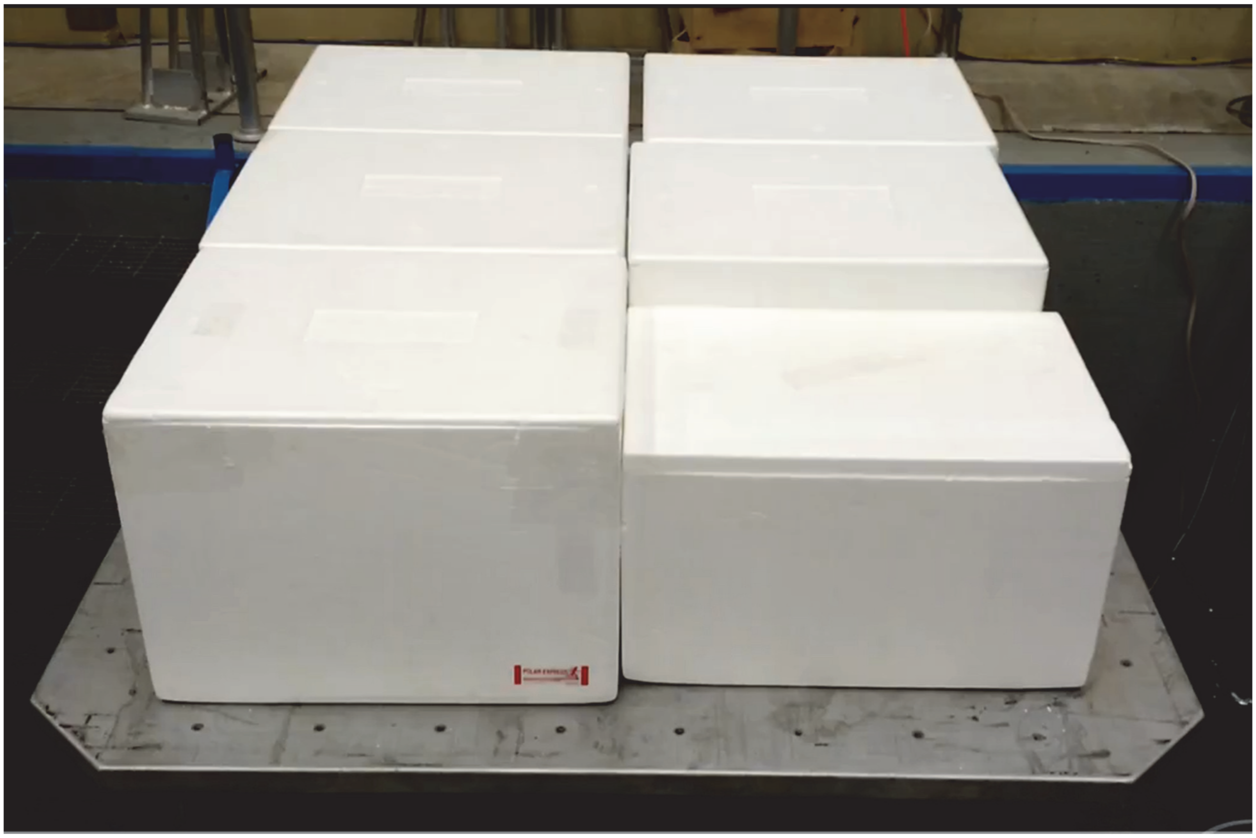

Figure 4. Vibration table with attached EPS coolers.

3.2.7. Storage

Following the distribution simulation, packages were quickly moved in a cooler to a secure cold storage location in Trout Food Science Building. In these studies, “0” days refers to the condition of the melon following processing, packaging, and the distribution simulation, which took approximately 2 hours.

3.2.7.1. Safety study

Packages containing fresh-cut cantaloupe inoculated with *L. monocytogenes* were stored in the dark at 5.25 ± 0.75°C for up to 9 days, with samples taken after 0, 3, 6, and 9 days. On each sampling day, destructive analyses were performed on one package per treatment, to measure headspace gas composition, weight changes of the packages and pads, and growth of *L. monocytogenes*.

3.2.7.2. Quality study

Packages were then stored in the dark at 3.3 ± 0.2°C for up to 15 days, with samples taken after 0, 3, 6, 9, 12, and 15 days. On each sampling day, destructive analyses were performed on one package per treatment, to measure headspace gas composition, weight changes of the packages and pads, color, firmness, microbiological quality, titratable acidity (TA), pH, and soluble solids content (SSC) of the cantaloupe cubes.

3.2.8. Headspace atmosphere analysis

Changes in O_2, CO_2, and N_2 in the packages were measured over the course of the study. Samples were transported in an ice-loaded cooler to a refrigerator in the Packaging Building. 50 µL of headspace was manually removed from the package with a 100 µL gastight syringe (SGE, Austin, TX, USA) through an adhesive silicone septum, then injected into a gas chromatograph (Thermo Scientific Trace GC Ultra, Thermo Electron S.p.A., Rodano, Italy) fitted with a thermal conductivity detector and a Carboxen 1010 Plot capillary column with a length of 30 m, internal diameter of 0.53 mm, and 30 µm film thickness (Supelco, Bellefonte, PA). Helium was used as a carrier gas (3 mL min^{-1}). The integrated area under the peaks for oxygen, nitrogen, and carbon dioxide were measured. Due to partially overlapping peaks, the first and second halves of the oxygen and nitrogen peaks, respectively, were recorded, while the entire area under the carbon dioxide peak was taken. Calibration curves were created by injecting various quantities of pure and mixed gases, measuring peak area, and assessing the relationship between the injections by linear regression. For O_2, three injections each containing 1.25, 2.5, 5, 5.25, 10.5, 21, or 50 µL of oxygen were considered. For N_2, three injections each of 19.75, 20, 25, 39.5, 50, 79, or 100 µL were considered. For CO_2, three injections each of 3.75, 7.5, 15, 50, or 100 µL were considered. Utilizing the slope of these calibration curves and the integrated area of the headspace gas sample, the number of μL of each gas in the sample could be determined. These values were normalized to 100% to give the percent concentrations of each gas in the package headspace.

3.2.9. Weight changes

3.2.9.1. Whole package

Prior to being placed in cold storage, packages were weighed on an analytical balance. After headspace analysis on each sampling day, the packages were weighed inside a biosafety cabinet with the change from the initial weight recorded. The weight change of the package was calculated as follows:

$$\Delta W_{package}\,(\%) = \frac{W_{\mathrm{f}} - W_0}{W_0 - W_{0(pad)} - W_{tray}} * 100$$

where:

W_0 = Initial weight of the filled package (g)

W_f = Final weight of the filled package (g)

$W_{0(pad)}$ = Average initial weight of the pad (g)

W_{tray} = Average initial weight of the tray (g)

3.2.9.2. Drip-absorbent pads and accumulated liquid

After the packages were opened, the drip-absorbent pad was removed and weighed for samples with pads or accumulated liquid was collected with a burette and measured for samples without a pad. The weight change of the drip-absorbent pad was calculated as a percentage of initial melon weight, to better determine how much of the total initial melon weight the pad was absorbing. This was calculated as follows:

$$\Delta W_{pad}(\%) = \frac{W_{\mathrm{f}(pad)} - W_{0(pad)}}{W_0 - W_{0(pad)} - W_{tray}}$$

where:

$W_{f(pad)}$ = Final weight of the pad (g)

3.2.10. Package breakdown for analyses

3.2.10.1. Safety study

A 50 ± 1.5 g melon sample from each package was placed in a Whirl Pak sample bag and promptly processed as described in section 3.2.11.

3.2.10.2. Quality study

Fresh-cut melon from each package was divided into three samples: (1) 100 ± 1.5 g of cubes were placed inside a Whirl Pak sample bag for microbiological analyses, (2) 10 cubes were placed inside a reclosable plastic bag for color and firmness analysis, and (3) the remaining cubes were placed inside a reclosable plastic bag for pH, SSC, and TA analysis.

3.2.11. *L. monocytogenes* analysis

The cantaloupe cubes in the Whirl Pak bag were combined with 100 mL of 0.1% phosphate buffered saline (PBS) solution. Samples were vigorously shaken for two minutes, after which 1 mL of the liquid was serially diluted in 9 mL of PBS, then 100 µL of each dilution was spread plated in duplicate on Modified Oxford Agar (MOX, Neogen, Lansing, MI, USA). All *Listeria*-like colonies were counted after 24 hours of incubation at 37°C, and plate counts taken. For early samples, 100 µL of the liquid was directly plated from the Whirl Pak bag. Enumeration was performed per the conventional plate count methods in the FDA Bacteriological Analytical Manual. To do this, plates with 25-250 CFU were counted, calculations performed based on the dilution factor, then recorded as the first two significant digits. For statistical analyses and figures, these were logarithmically transformed. As such, results were expressed as log CFU/g cantaloupe.

3.2.12. Firmness and color analysis

The color of ten randomly selected melon pieces was measured using a handheld colorimeter (CR-400, Konica Minolta Sensing Americas, Ramsey, NJ), previously calibrated with a white tile. Only the color of one side of each piece was measured, excluding the original rind-side and inside of the melon. The L* (lightness), a* (+red/-green), and b* (+yellow/-blue) color components were recorded automatically, utilizing the D65 illuminant and 2° observer.

Of the ten pieces used for color measurements, seven were used for firmness measurements. The following method was a modified version of that used by Beaulieu *et al.* (2004). A texture analyzer (XT2, Texture Technologies, South Hamilton, MA, USA), fitted with a cylindrical aluminum probe (50 mm dia.) compressed the samples. To form even samples, a sharp steel cylindrical punch was pressed through each piece of melon, starting from the inside and exiting on the rind-side, to form a cylinder with a diameter of 1.11 cm. Using a wooden guide, the edges of the cylinder were trimmed off with a sharp knife to a final length of 1.0 cm. These evenly sized pieces were always placed with the original rind side down, to mitigate variances from the orientation of the piece, as reported in Beaulieu *et al.* (2004). The probe moved at a pre-test speed of 10.0 mm/s, then a test speed of 0.5 mm/s, compressing samples to 25% strain (75% of their original height). Results are expressed in grams force.

3.2.13. Soluble solids content (SSC), pH, and titratable acidity (TA) analysis

For each package on each sample day, cantaloupe pieces were processed through a garlic press to obtain a juice, which was kept in a beaker in an ice bath and quickly analyzed for pH, SSC, and TA. To measure TA, 1.0 gram of the juice was measured into a small flask, diluted with 10 mL of water, and mixed with two drops of 1% phenolphthalein. Using a pipette, 10 μL of 0.1 N NaOH were added at a time, mixing between additions, until the titration was complete, indicated by the characteristic color change of the phenolphthalein. %TA was calculated with citric acid as the predominant acid in the melon.

Three small samples of juice from the beaker were removed to determine SSC content. A handheld electronic Brix meter (ATAGO, U.S.A., Bellevue, WA) was calibrated with distilled water at the beginning of each analysis day. Each of the three samples was placed on the scanner of the Brix meter and a measurement taken, with results expressed in °Brix.

The remainder of the juice in the beaker was tested for pH using an electronic pH meter (SevenCompact™, Mettler-Toledo, Columbus, OH, USA). The probe was inserted into the juice until a stable reading was achieved, removed, rinsed with distilled water and dried with a lint-free tissue, and the measurement repeated two more times. Results are expressed in units of pH.

3.2.14. Spoilage microorganisms analysis

3.2.14.1. Common method

From every package on each measurement day, 100 g of melon cubes were randomly selected. The cubes were combined with 100 mL 0.1% phosphate buffered saline solution (PBS), shaken vigorously for two minutes, then 1 mL of the liquid was serially diluted in 9 mL of PBS.

3.2.14.2. Mesophilic total aerobic bacteria

A 100 µL sample of each dilution, or aliquot directly from the Whirl Pak bag, was spread plated in duplicate on trypticase soy agar (Neogen) with 0.6% yeast extract (Neogen) (TSA-YE). Plates were incubated for 48 hours at 35°C. Enumeration was performed per the conventional plate count method in the FDA Bacteriological Analytical Manual, as described previously. Results are expressed as log CFU/g cantaloupe.

3.2.14.3. Psychrotrophic total aerobic bacteria

A 100 µL sample of each dilution, or aliquot directly from the Whirl Pak bag, was spread plated in duplicate on TSA-YE. Plates were incubated for 10 days at 7°C. Enumeration was performed per the conventional plate count method in the FDA Bacteriological Analytical Manual, as described previously. Results are expressed as log CFU/g cantaloupe.

3.2.14.4. Yeasts and molds

A 100 µL sample of each dilution, or aliquot directly from the Whirl Pak bag, was spread plated in duplicate on potato dextrose agar (Neogen), acidified to pH 3.5 with tartaric acid. Plates were incubated in the dark at 25°C for 5 days. Enumeration was performed per the conventional plate count method in the FDA Bacteriological Analytical Manual, as described previously. Results are expressed as log CFU/g cantaloupe.

3.2.15. Statistical analysis

3.2.15.1. Safety study

A repeated-measures mixed-model analysis of variance (ANOVA) (PROC MIXED in SAS version 9.4) was used to compare *L. monocytogenes* populations on the fresh-cut cantaloupe from the six packaging treatments at four timepoints (0, 3, 6, and 9 days). The entire experiment was replicated three times with independent batches of cantaloupe; batch was included as a random effect. Day was included in the model as a repeated measure. Due to the even spacing between timepoints, a Toeplitz covariance structure was chosen. Two-way and three-way interactions of factors were removed from the final model if $P > 0.05$ by manual backward selection, highest order interactions first. Differences in *L. monocytogenes* populations were assessed by comparing least-squares means; post-hoc pairwise comparisons further utilized the

Bonferroni adjustment to reduce the likelihood of type I error. To meet model assumptions, *L. monocytogenes* populations were log-transformed prior to analysis.

A separate repeated-measures mixed-model ANOVA was fitted to the weight gains of the drip-absorbent pad, using the day and atmosphere fixed effects, as well as the atmosphere × pad two-way interaction. Day was included as a repeated measure with an unstructured covariance matrix. Initially, batch was included as a random effect, although it was removed from the model as it was estimated to have no effect. Differences and post-hoc analyses were conducted as above.

3.2.15.2. Quality study

A repeated-measures mixed-model analysis of variance (ANOVA) (PROC MIXED in SAS version 9.4) was used to compare each quality parameter of the fresh-cut cantaloupe from the six packaging treatments at six timepoints (0, 3, 6, 9, 12, 15 days). The entire experiment was replicated twice with independent batches of cantaloupe. Day was included in the model as a repeated measure, with a first-order autoregressive covariance structure, to acknowledge the greater similarity between quality parameters at consecutive timepoints. A separate linear model was fitted to each quality parameter. Two-way and three-way interactions between atmosphere, day, and pad fixed effects were evaluated, starting with the highest-order interactions. Differences were assessed by comparing least-squares means, with post-hoc pairwise comparisons adjusted with the Bonferroni procedure to reduce the likelihood of type I error. To meet model assumptions, microbiological populations were log-transformed prior to analysis.

A separate repeated-measures mixed-model ANOVA was fitted to the weight gains of the drip-absorbent pad, using the day and atmosphere fixed effects, as well as the atmosphere × pad two-way interaction. Day was included as a repeated measure with a first-order autoregressive covariance matrix. Initially, batch was included as a random effect, although it was removed from the model as it was estimated to have no effect. Differences and post-hoc analyses were conducted as above.

Some quality parameters were measured on multiple samples per package to account for inherent variability in those attributes (10 for each color component, 7 for firmness, 3 for pH, and 3 for SSC). These were averaged prior to statistical analysis.

3.3. Results and discussion

3.3.1. Headspace atmosphere composition

The tray and film of the package form a sealed environment, in which the cantaloupe and microorganisms respire (consuming O_2 and emitting CO_2), thus modifying the original composition of the headspace. Packages for the safety study were stored at a slightly higher temperature than in the quality study, accelerating the rate of change of the headspace makeup due to increased respiration. In each study, the three MAP treatments started with defined O_2 and CO_2 concentrations in the package headspace.

3.3.1.1. Safety study

Overall, O_2 concentrations tended to decline over the course of the study regardless of treatment, due to respiration of the fresh-cut cantaloupe (Figure 5). HO-AMAP samples fell from initial O_2 concentrations of 92.8 ± 1.8% to 56.4 ± 5.8% on day 9, never reaching an equilibrium state. LO-AMAP samples had initial O_2 concentrations of 5.8 ± 0.7%, declining to 1.5 ± 0.5% after 9 days. PMAP samples were initially flushed with atmospheric O_2 levels (20.9 ± 0.8%), falling to 3.0 ± 0.2% after 9 days.

CO_2 concentrations rose over time for all treatments, due to respiration of the fresh-cut cantaloupe (Figure 5). Initial CO_2 concentrations were 9.6 ± 0.8% in the LO-AMAP samples, below the expected 15%. This may have been due to CO_2 rapidly dissolving into the water present in the package, as vapor, condensate, or on the surface of the melon. PMAP and HO-AMAP treatments were not flushed with initial levels of CO_2, however, they reached CO_2 concentrations similar to those in LO-AMAP by day 6 and beyond. Final CO_2 concentrations were 31.3 ± 4.9% for PMAP, 35.7 ± 3.5% for LO-AMAP, and 35.2 ± 5.6% for HO-AMAP. The drip-absorbent pad did not have an effect on headspace O_2 or CO_2 levels ($P > 0.05$).

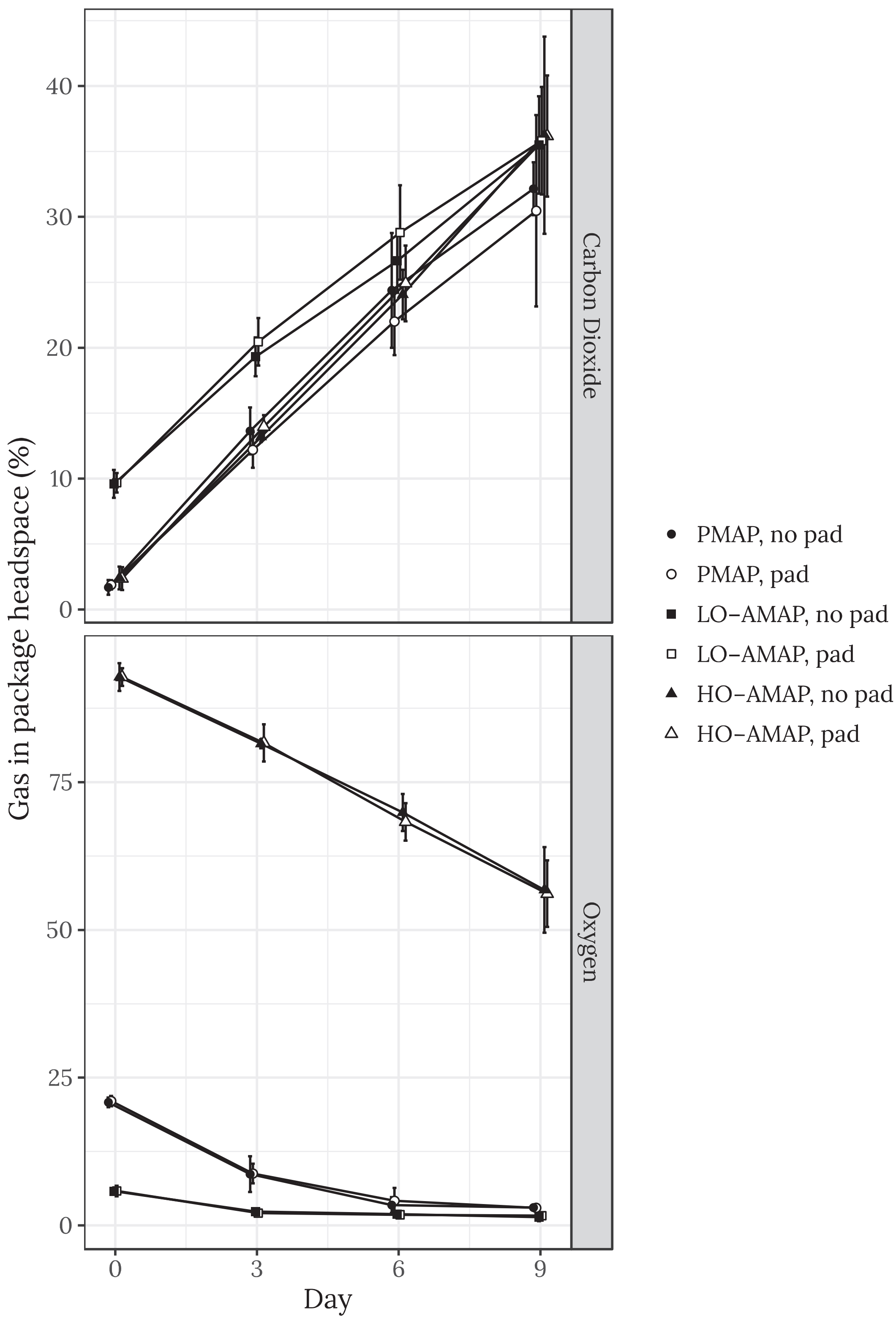

Figure 5. Headspace carbon dioxide and oxygen levels in packages of *L. monocytogenes*-inoculated fresh-cut cantaloupe stored at 5°C for 9 days. Plots presented as means ± standard deviation.

3.3.1.2. Quality study

Like in the safety study, O_2 levels declined over the course of the quality study in all treatments (Figure 6), while CO_2 levels steadily rose (Figure 7). Presence of the drip-absorbent pad did not significantly affect the initial atmosphere flush or the changes over time ($P > 0.05$).

PMAP treatments started with atmospheric levels of oxygen, falling to a stable level of approximately 3% on day 9, within literature recommendations (3-6%, per Gorny 1997). HO-AMAP treatments, initially flushed to contain 91% oxygen, fell gradually to approximately 70% oxygen over 15 days. LO-AMAP treatments were flushed with the lowest initial levels of oxygen (6.7 ± 1.4%), closest to the recommended oxygen levels from Gorny (1997). Consequently, by day 6, LO-AMAP packages approached very low levels of oxygen (~1%), due to the strong oxygen barrier properties of the film. While the GC-TCD used to measure O_2 concentrations did not have the sensitivity to determine if the package dropped below the anaerobic threshold, this treatment would likely have benefitted from a more permeable lidding film. The drip-absorbent pad did not have an effect on headspace O_2 levels ($P > 0.05$).

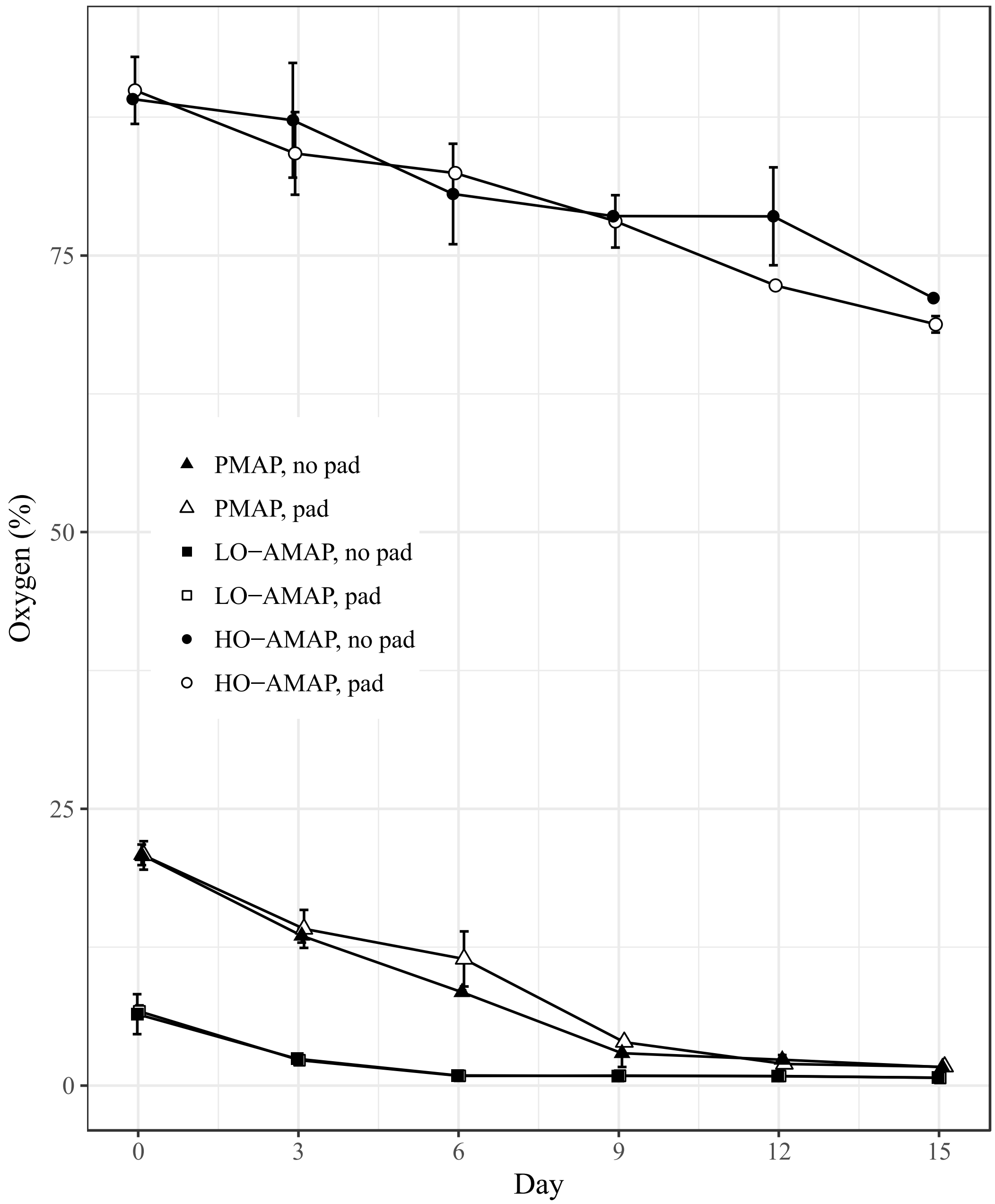

Figure 6. Headspace oxygen levels in packages of fresh-cut cantaloupe stored at 3°C for 15 days. Plots presented as means ± standard deviation.

PMAP and HO-AMAP treatments initially contained no CO_2, rising to 21-25% over 15 days of storage. CO_2 levels did not reach steady state. LO-AMAP treatments were initially flushed to contain 8.3 ± 0.7% CO_2, which rose to 26.8 ± 2.7% over 15 days of storage. These CO_2 levels are above those commonly recommended (6-15%, per Gorny 1997, or near 10% per

Bai *et al.* 2001), indicating that a film that is more permeable to CO_2 may be more appropriate to meet accepted horticultural recommendations. The HO-AMAP treatment did not accumulate more CO_2 than the other treatments. This follows Gomes, Beaudry and Almeida (2012), who found that fresh-cut cantaloupe respiration rates are minimally affected by reductions in O_2 until the fermentation threshold (0.7 kPa O_2 at 0°C), concluding that reduced O_2 levels provide minimal shelf-life extension for fresh-cut cantaloupe. The drip-absorbent pad did not impact headspace CO_2 levels ($P > 0.05$).

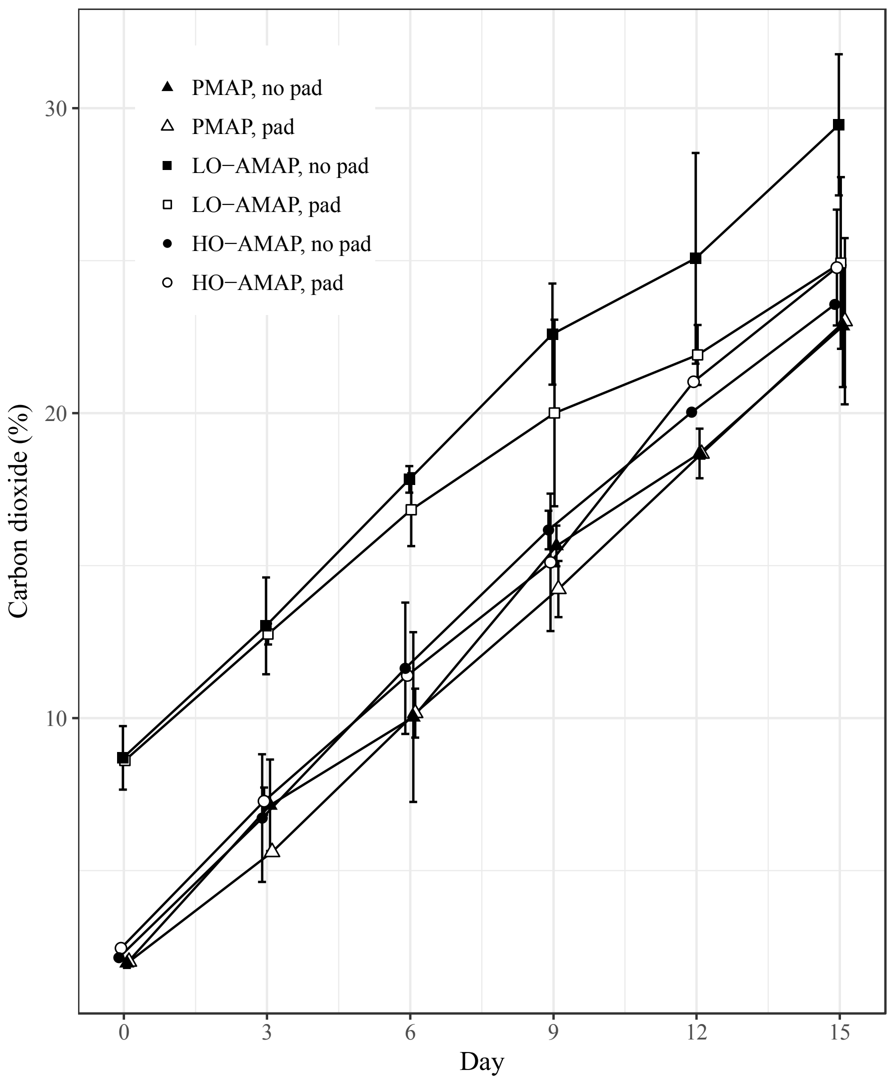

Figure 7. Headspace carbon dioxide in packages of fresh-cut cantaloupe stored at 3°C for 15 days. Plots presented as means ± standard deviation.

3.3.2. Package weight loss

3.3.2.1. Safety study

All packages lost weight over the course of the study. However, due to the good water vapor barrier properties of the packages, weight changes remained small for all treatments, with losses < 0.25% of the initial melon weight over 9 days of storage. This follows the finding of Aguayo, Allende and Artes (2003), that fresh-cut melon in MAP loses minimal weight, due to the enclosed system combined with the use of water barrier materials. Package weight losses were not affected by the inclusion of the drip-absorbent pad, indicating that the water vapor partial pressure differential between the inside and the outside of the package was similar between packages with and without pads.

3.3.2.2. Quality study

Similar to the safety study, weight losses from the package were minimal due to the strong water vapor barrier properties of the sealed package. This was expected for MAP packages of fresh-cut melon (Aguayo, Allende and Artes, 2003).

3.3.3. Drip-absorbent pad weight gain

3.3.3.1. Safety study

Drip-absorbent pads consistently gained weight over the course of the study, to upwards of 2.3% of the initial total melon weight after 9 days of storage. In packages without a drip-absorbent pad, there was no noticeable accumulation of liquids in the package over the duration of the study, other than condensation on the film that was present for all treatments. Since there was no noticeable accumulation of liquids in packages without a drip-absorbent pad and condensation on the film that was present for all treatments, the weight gained in the drip-absorbent pads indicates direct absorption of juice from the fresh-cut cantaloupe.

The results also show that pad weight gain was time dependent, independent of headspace O_2 levels, and slightly affected by CO_2 levels. In this study, differences in headspace CO_2 between atmosphere treatments were too minor to note a significant effect of CO_2 levels on pad weight gain. While a previous MAP study of fresh-cut cantaloupe incorporated drip-absorbent pads (Bai *et al.*, 2001), no weight changes in the product, pad, or package were reported. While CO_2 levels may synergize with drip-absorbent pads to encourage product drip, drip was not noticeable in samples without the drip-absorbent pad, regardless of O_2 or CO_2 levels in the headspace.

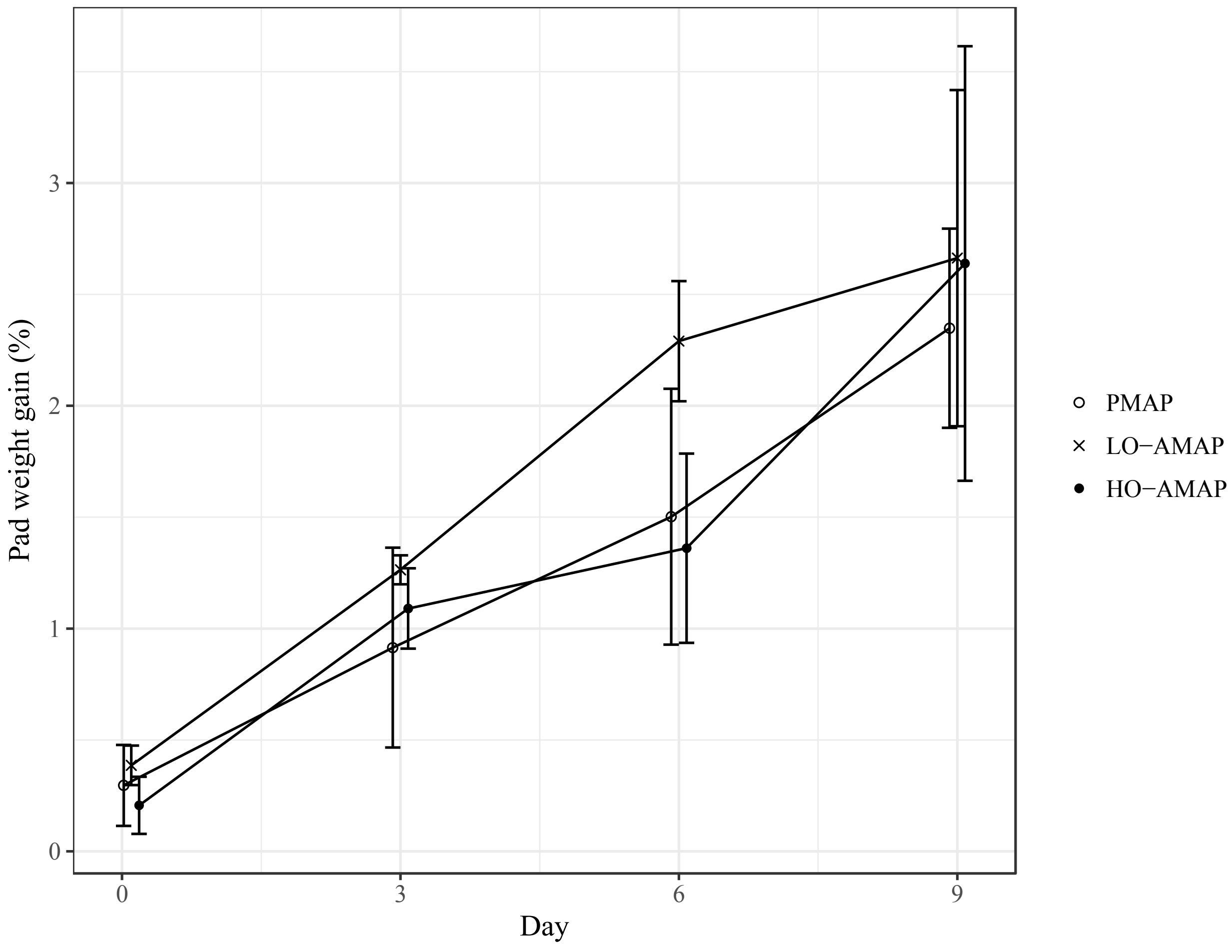

Figure 8. Weight gain in drip-absorbent pads in packages of *L. monocytogenes*-inoculated fresh-cut cantaloupe stored at 5°C for 9 days. Values are expressed as a percentage of initial melon weight. Plot presented as means ± standard deviation.

3.3.3.2. Quality study

Drip-absorbent pads in the quality study gained weight throughout storage in all treatments (Figure 9). By day 15, the pads had absorbed between 3 and 6% of the initial total melon weight. Evaluating differences in least-squares means, many pairwise comparisons showed significant differences. Of interest, on days 12 and 15, pads in LO-AMAP packages had absorbed significantly more weight than pads in HO-AMAP and PMAP packages ($P < 0.05$). This shows that the combination of LO-AMAP atmosphere and a drip-absorbent pad encourages seepage from fresh-cut cantaloupe. This difference only becomes relevant following nine days of storage, indicating that it may be due to either high exposure to CO_2 or a lack of O_2 in the headspace. Future analyses will be needed to determine which of these drives seepage. As with the safety study, there was no significant accumulation of drippings in packages that did not contain an absorbent pad.

While practical limits of fresh-cut melon weight loss have not been established in previous work, weight loss caused by drip-absorbent pads was compared to that resulting from no packaging or packaging designs reported in the literature. Aguayo, Allende and Artes (2003) showed that unpackaged fresh-cut melon lost nearly 16% of initial weight after 14 days of storage at 5°C. Bett-Garber *et al.* (2011) showed a weight loss of about 2.5% for fresh-cut cantaloupe packaged in snap-fit containers over 7 days of storage at 4°C. These weight losses are in line with our packages if we consider the weight gained in the drip-absorbent pads as weight lost from the fresh-cut melon.

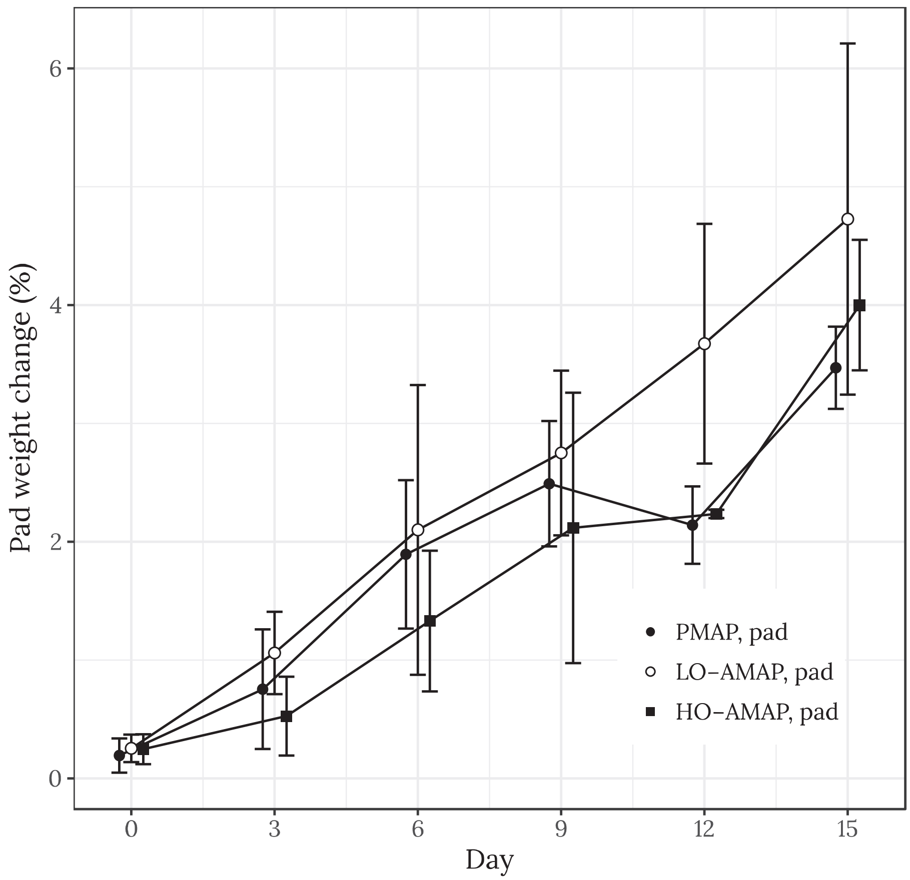

Figure 9. Weight gain in drip-absorbent pads in packages of fresh-cut cantaloupe stored at 3°C for 15 days. Values are expressed as a % of initial melon weight. Plot presented as means ± standard deviation.

3.3.4. *L. monocytogenes* growth

L. monocytogenes populations rose over the duration of the study in all atmosphere and pad treatment combinations, as shown in Figure 10. Overall, *L. monocytogenes* populations varied significantly ($P < 0.05$) with atmosphere treatments, time, and the atmosphere × day interaction, but were not significantly affected by the drip-absorbent pad.

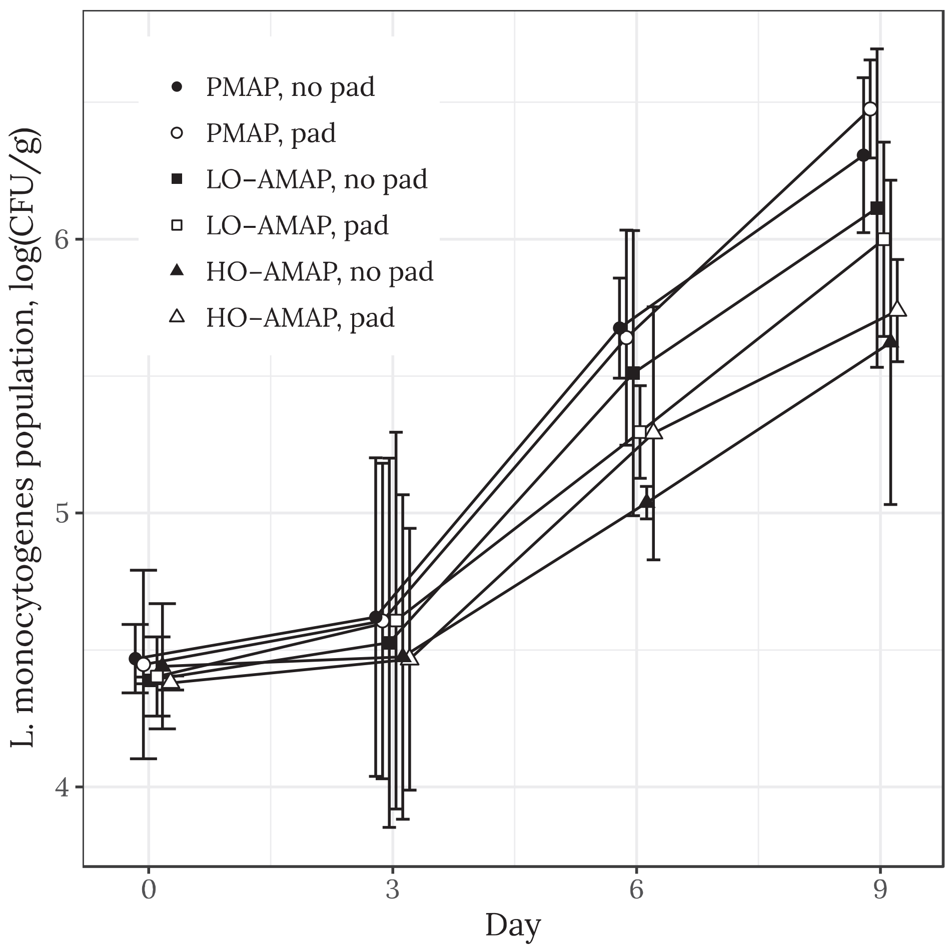

Figure 10. *L. monocytogenes* growth on fresh-cut cantaloupe in six package designs. Plot presented as means ± standard deviation.

Specifically, HO-AMAP yielded *L. monocytogenes* populations lower than PMAP (P<0.0001), and LO-AMAP (P=0.0128), while LO-AMAP was similarly better than PMAP (P=0.0308). The effect of atmosphere against time as modeled by the interactions "Atmosphere × Day" and "Pad × Day" is shown in Figure 11. *L. monocytogenes* on fresh-cut cantaloupe in HO-AMAP had lower populations than in the other atmospheres. This behavior follows the pattern of in-vitro studies in the literature, where high-oxygen atmospheres have contributed to an elongated lag phase of *L. monocytogenes*. One study conducted by Amanatidou, Smid and Gorris (1999) investigated the growth of *L. monocytogenes* on Palcam Listeria Selective Medium under controlled-atmosphere conditions at 8°C. Those authors found that the lag phase of the bacterium was extended in an atmosphere of 90% O_2 when compared to 20% O_2. Another study by Jacxsens *et al.* (2001) spread an *L. monocytogenes* culture on plates of Brain Heart Infusion agar, packaged the plates in a sealed barrier film flushed with one of four gas combinations (70% O_2, 80% O_2, 95% O_2 and 5% O_2, each balanced with N_2), and stored the packages at 4°C. Those researchers found 95% O_2 atmosphere extended the lag phase compared to the other atmospheres, although the maximum bacterial load was eventually similar for all atmospheres.

Despite differences in MAP performance, *L. monocytogenes* continued to multiply in fresh-cut cantaloupe regardless of the treatment. Other studies investigating *L. monocytogenes*-inoculated fresh-cut celery (Gonzalez-Buesa *et al.*, 2014), salad greens (Allende *et al.*, 2003), diced onions, and diced celery (Jayeola, 2015) packaged using high-oxygen AMAP designs have shown much longer lag phases, and slower growth (or bacteriostatic conditions) compared with this study, often despite being stored at elevated temperatures. Higher nutrient availability, especially sugars, in fresh-cut cantaloupe is likely responsible for the observed differences in growth.

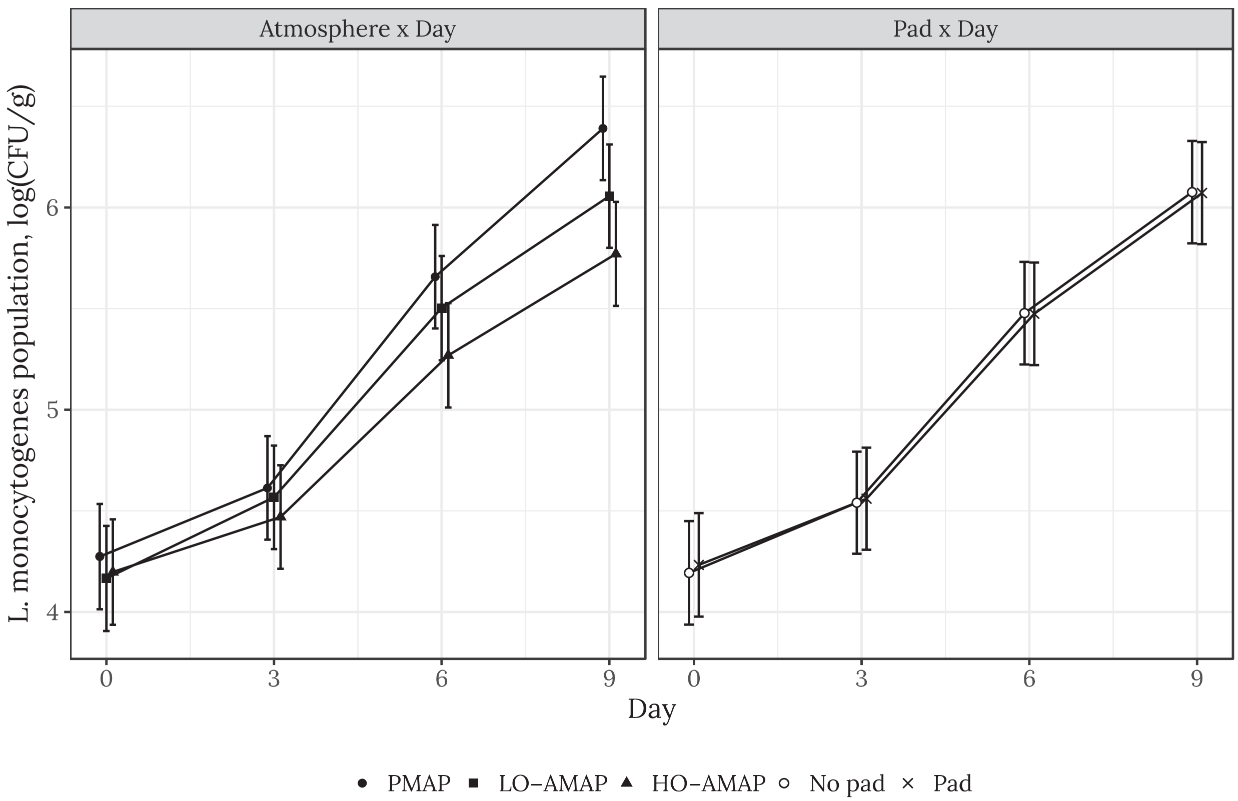

Figure 11. *L. monocytogenes* growth as modeled by the interactions "Atmosphere × Day" and "Pad × Day". Plots presented as lsmeans ± standard error.

Inclusion of the drip-absorbent pad did not significantly impact the growth of *L. monocytogenes*. To analyze this, it is worth reflecting on the earlier results of how the drip-absorbent pad contributed to weight change since high water activity is critical to the growth of bacteria. Over 9 days of storage, the drip-absorbent pads took up 2.3% of the weight of the fresh-cut melon, which was insufficient to affect microbial growth, as shown in Figure 11.

While the effect of drip-absorbent pads on *L. monocytogenes* has not been previously studied, other packaging techniques can create similar water deficits. Gonzalez-Buesa *et al.* (2014) packaged *L. monocytogenes*-inoculated celery sticks in 95% O_2 AMAP packages made from either PLA or PP/PE. Over 21 days of storage at 7°C, celery packaged in the PP/PE pouches lost less than 1% of their weight, while those packaged in PLA lost approximately 4.5%

weight over that same period. These differences are comparable to those seen in the present study between packages with and without drip-absorbent pads. Similarly, Gonzalez-Buesa *et al.* (2014) also found that *L. monocytogenes* growth was unaffected by minor differences in product-headspace water vapor deficit between treatments.

3.3.5. Color

*3.3.5.1. L**

A two-way interaction was seen between atmosphere and day ($P < 0.05$), particularly for HO-AMAP treatments, which dramatically lightened between day 0 and day 3 (Table 2). Over the full fifteen-day period, L* increased in the HO-AMAP treatments, but remained relatively stable in the PMAP and LO-AMAP treatments. Previous studies have shown that declines in L* are a sign of quality loss (Portela and Cantwell, 2001; Beaulieu, 2005; Amaro *et al.*, 2012; Martiñon *et al.*, 2014) and that low-oxygen MAP better retains lightness in fresh-cut cantaloupe compared with perforated packaging (Bai *et al.*, 2001). Fresh-cut cantaloupe packaged in HO-AMAP tended to have higher lightness than the other treatments on most sample days, although these differences were not significant. In general, these results show that MAP retains lightness of fresh-cut cantaloupe over 15 days of storage. This could be due to elevated CO_2 content in the headspace or by the maintenance of high in-package RH. Interactions considering the pad were not significant, indicating that presence of the drip-absorbent pad did not affect L* over time.

*3.3.5.2. a**

More dramatic effects were seen in a* than the other color components. This was indicated by a significant interaction between atmosphere and day ($P = 0.0193$). In HO-AMAP packages, a* declined over the course of study, while remaining steady in the other atmosphere treatments (Table 2). This was significant between day 0 and 12, 3 and 12, 0 and 15, and 3 and

15. Additionally, differences were noted between the atmosphere treatments in later days; on day 15, a* in HO-AMAP treatments was significantly lower than a* in PMAP or LO-AMAP treatments ($P < 0.05$). Changes in a* have been less frequently reported for fresh-cut cantaloupe, with only one study noting declines in a* over time when packaged in snap-fit containers (Beaulieu, 2005). That study attributed the differences in a*, accompanied by decreasing L*, as reflections of tissue darkening. In our study, since fresh-cut cantaloupe lightened in HO-AMAP over time, the changes in a* can be attributed to oxidation of carotenoids, which serve as a key orange pigment, in the high O_2 atmospheres. Others have also reported color effects resulting from HO-AMAP atmospheres, both beneficial and harmful [e.g., improved color retention in celeriac (Jacxsens *et al.*, 2001), vs. intense yellowing of celery sticks (Gonzalez-Buesa *et al.*, 2014)]. Our PMAP and LO-AMAP treatments showed good retention of a* over time. The pad did not significantly affect a* over the period of study.

*3.3.5.3. b**

Unlike the other color components, b* did not show a consistent pattern over time between treatments (Table 2). Curiously, significant two-way interactions were found in b* between atmosphere and day, as well as between day and pad presence ($P < 0.05$). Neither significant two-way interaction satisfied the Bonferroni adjustment when comparing factor levels, so it is difficult to claim where these interactions are meaningful. In general, previous studies of fresh-cut cantaloupe have reported minimal variance in b*, with the exception of Gil, Aguayo and Kader (2006), who saw dramatic drops in b* over the period of study in snap-fit containers. As with the other color components, b* was not significantly affected by inclusion of the drip-absorbent pad. Overall, all treatments studied here retained b* over the period of study.

Color forms one element of the visual perception of fresh-cut cantaloupe quality. Another element discussed by other authors and seen here, to some extent, is the development of translucency as melon ages (Bai *et al.*, 2001; Aguayo, Allende and Artes, 2003). While L* can reflect translucency to some degree, L* is not all-encompassing. Descriptive sensory evaluations can measure translucency, although improved rapid instrumental measures could prove useful for future studies.

Table 2. Effects of atmosphere*time interaction on color of fresh-cut cantaloupe during 15 days storage at 3°C

Color component	**Time (days)**	**Treatment**		
		HO-AMAP	**LO-AMAP**	**PMAP**
L*	0	56.10±0.69 aA*	58.19±0.69 aA	58.05±0.69 aA
	3	59.12±0.69 bA	58.79±0.69 aA	58.33±0.69 aA
	6	59.50±0.75 bA	57.42±0.69 aA	58.11±0.69 aA
	9	57.99±0.69 abA	57.93±0.69 aA	57.46±0.69 aA
	12	58.21±0.75 abA	57.89±0.69 aA	57.33±0.69 aA
	15	58.73±0.78 abA	58.46±0.69 aA	57.85±0.69 aA
a*	0	11.08±0.25 aA	11.53±0.25 aA	11.45±0.25 aA
	3	10.97±0.25 aA	11.68±0.25 aA	11.39±0.25 aA
	6	10.43±0.28 abA	11.05±0.25 aA	11.68±0.25 aA
	9	10.15±0.25 abA	11.05±0.25 aA	11.09±0.25 aA
	12	9.46±0.28 bA	10.88±0.25 aAB	11.28±0.25 aB
	15	9.49±0.29 bA	11.12±0.25 aB	11.54±0.25 aB
b*	0	34.25±0.41 aA	35.57±0.41 aA	35.80±0.41 aA
	3	35.46±0.41 aA	36.26±0.41 aA	35.68±0.41 aA
	6	35.53±0.46 aA	34.79±0.41 aA	36.00±0.41 aA
	9	35.45±0.41 aA	35.16±0.41 aA	34.58±0.41 aA
	12	34.82±0.46 aA	34.90±0.41 aA	35.30±0.41 aA
	15	36.04±0.47 aA	35.25±0.41 aA	35.71±0.41 aA

*Results presented as means ± standard error. Within each color component, sharing the same lower-case letter indicates no significant difference ($P < 0.05$) between days. Across, sharing the same upper-case letter indicates no significant difference ($P < 0.05$) between atmosphere treatments on a given day.

3.3.6. Firmness

Fresh-cut cantaloupe firmness declined (on average) by 30% during the 15 days of study, based on measurements under compression at 25% strain (Figure 12). This amounted to a significant difference in firmness between day 0 and day 15 (P=0.0218). This decline was not significantly impacted by atmosphere, pad, or their interactions. Under the objectives of the study, it is important to note that pad presence, or interactions including the pad effect, were not significant. Despite the drip-absorbent pads taking up appreciable amounts of liquid from the fresh-cut cantaloupe, firmness decline was unaffected. This was unexpected, since removing water from the cantaloupe cellular structure would be expected to affect resistance to compression.

Previous work has shown that firmness declines in fresh-cut cantaloupe during storage (Aguayo, Escalona and Artes, 2004; Gil, Aguayo and Kader, 2006; Amaro *et al.*, 2012; Zainal Abidin *et al.*, 2013), including in MAP-packaged fresh-cut cantaloupe (Bai *et al.*, 2001). In particular, Bai *et al.* (2001) noted no significant differences between firmness decline in MAP containers and perforated packages, despite the much higher weight losses expected in a perforated container, as compared to a MAP. This finding, that a high-weight-loss package has similar firmness decline to a low-weight-loss package, is reflected in our results, where the drip-absorbent pad did not impact firmness decline. Reduced cell wall strength has been identified as the major cause of softening in fresh and fresh-cut produce (Toivonen and Brummell, 2008). In this study, neither MAP nor drip-absorbent pad treatments could significantly reduce softening during storage.

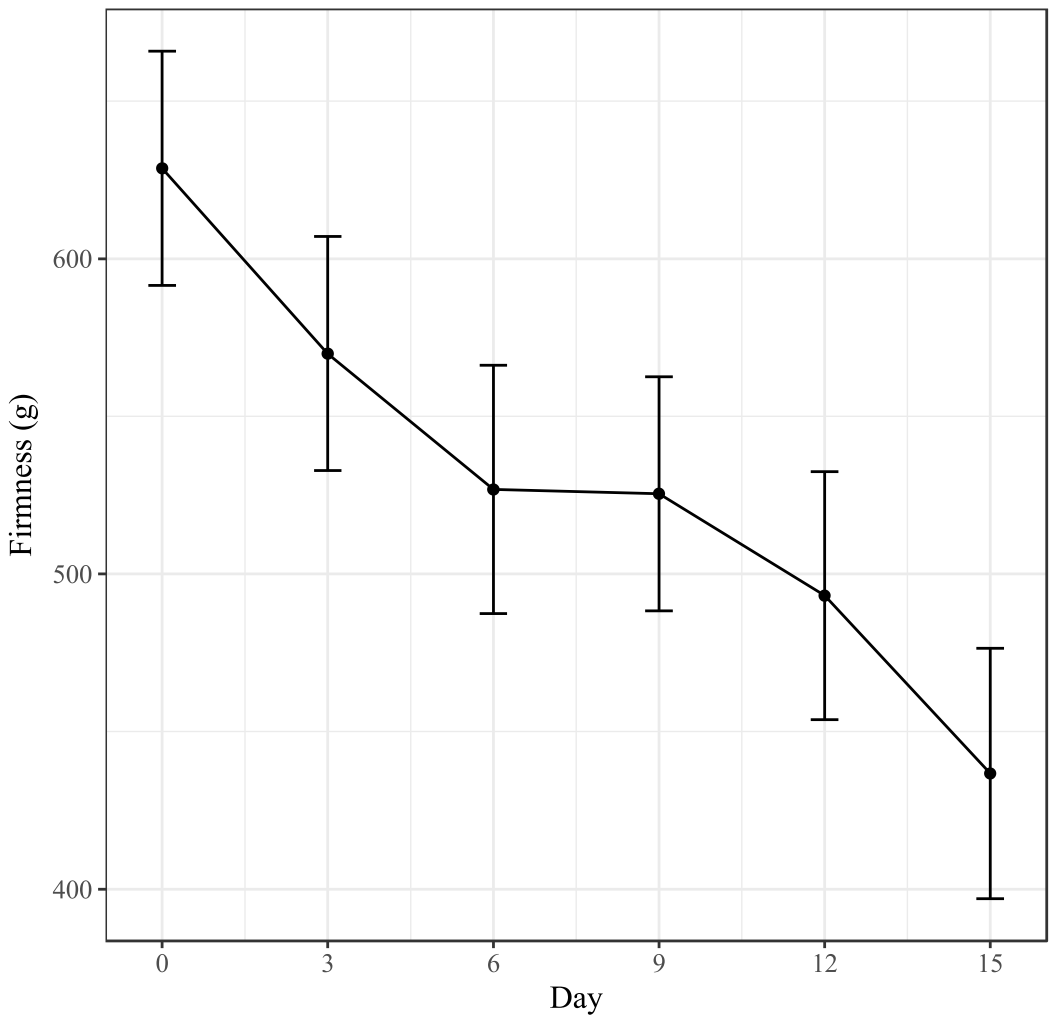

Figure 12. Decline in firmness of packaged fresh-cut cantaloupe during 15 days of storage at 3°C, presented as lsmeans ± standard error

3.3.7. Microbiological quality

3.3.7.1. Mesophilic aerobic bacteria

Due to an incubator error, most mesophilic bacteria data from the first two timepoints were lost. The remaining data show continued mesophilic bacterial growth, rising from initial levels of ~3 log CFU/g to between 6.5 and 7.5 log CFU/g after 15 days of storage at 3°C (Figure 13). Significant interactions (day*atmosphere, day*pad) were observed ($P < 0.05$), with these primarily being driven by storage time. The combination of LO-AMAP with a drip-absorbent pad yielded bacterial loads approximately 1 log CFU/g higher than other treatments between day 6 and 9, with populations similar across all treatments by day 15.

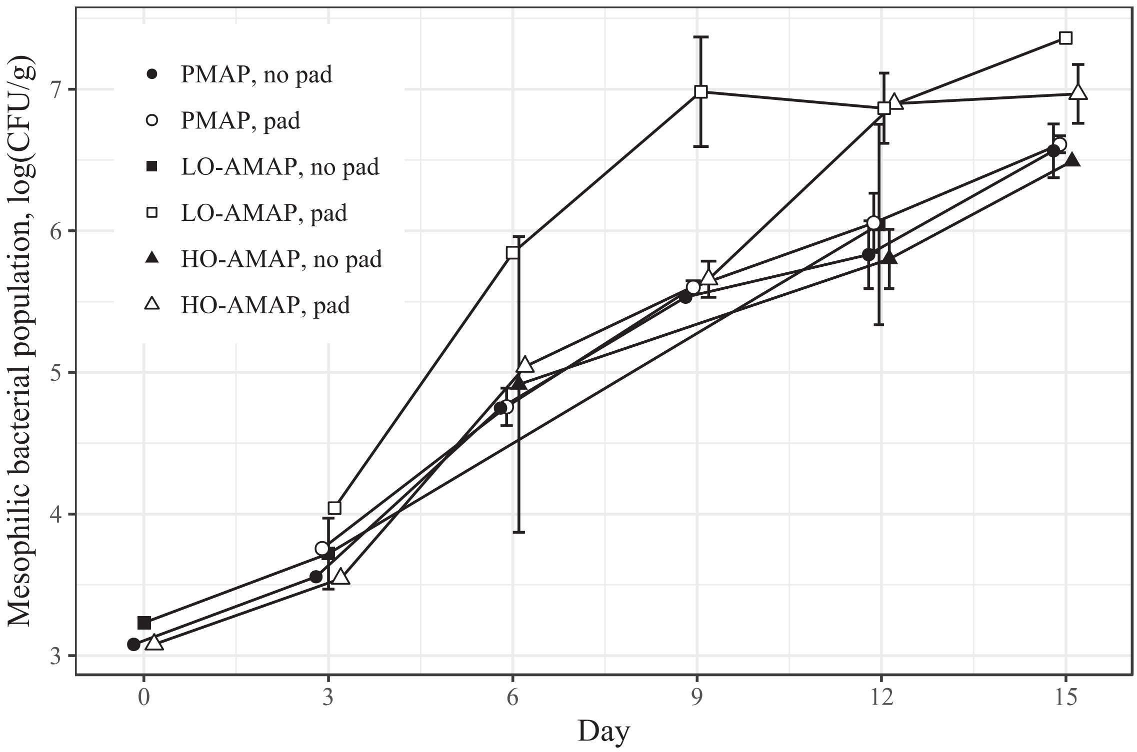

Figure 13. Mesophilic bacterial populations on fresh-cut cantaloupe, stored at 3°C for 15 days. Data presented as means ± standard deviation

3.3.7.2. Psychrotrophic aerobic bacteria

As with the mesophiles, psychrotrophic aerobic bacterial counts increased significantly during 15 days of storage ($P < 0.05$), from initial populations averaging slightly below 3 log CFU/g to between 6.5 and 7 log CFU/g on day 15. A significant three-way interaction was identified ($P < 0.05$) between atmosphere, day, and pad. Differences in least-squares means were primarily due to the day effect. Additionally, as seen in the mesophilic results, the combination of LO-AMAP with the drip-absorbent pad led to an approximately 1 log CFU/g increase in bacterial populations, largely between day 6 and 9. This treatment influenced the statistical model, showing differences between that combination of atmosphere and pad and the others, particularly on day 9. In any case, aerobic bacterial populations remained in the range expected on other types of fresh-cut produce (Qadri *et al.*, 2015) during 15 days of storage at 3°C.

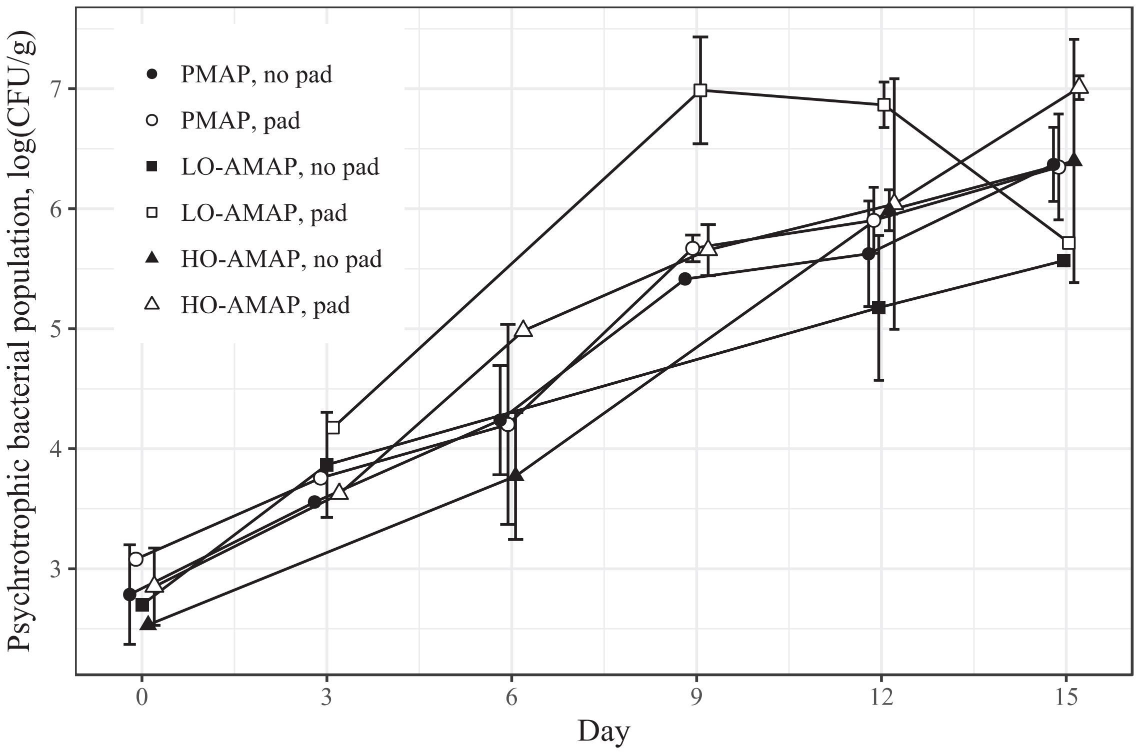

Figure 14. Psychrotrophic bacterial populations on fresh-cut cantaloupe, stored at 3°C for 15 days. Data presented as means ± standard deviation

3.3.7.3. Yeasts and molds

As with bacteria, yeast and mold counts increased during the study, particularly yeasts (growth was significantly different with time, $P < 0.05$). Populations increased from approximately 1 log CFU/g to an average of 2 log CFU/g after 15 days of storage, with most growth occurring between day 6 and 12. Additionally, a significant interaction between atmosphere and pad was found (P=0.0381), identifying the LO-AMAP treatment with a pad to contain a significantly lower yeast and mold populations than PMAP treatments with or without a drip-absorbent pad (Figure 15). These findings were expected since LO-AMAP with pad contained the highest bacterial counts, which would displace the growth of other microorganisms. Oddly, this implies a higher water activity on the melon surface, despite the finding that the pad in LO-AMAP packages absorbed more water than the other treatments. Perhaps this also reflects greater melon drip delivering nutrients to bacteria on the surface of the fresh-cut melon.

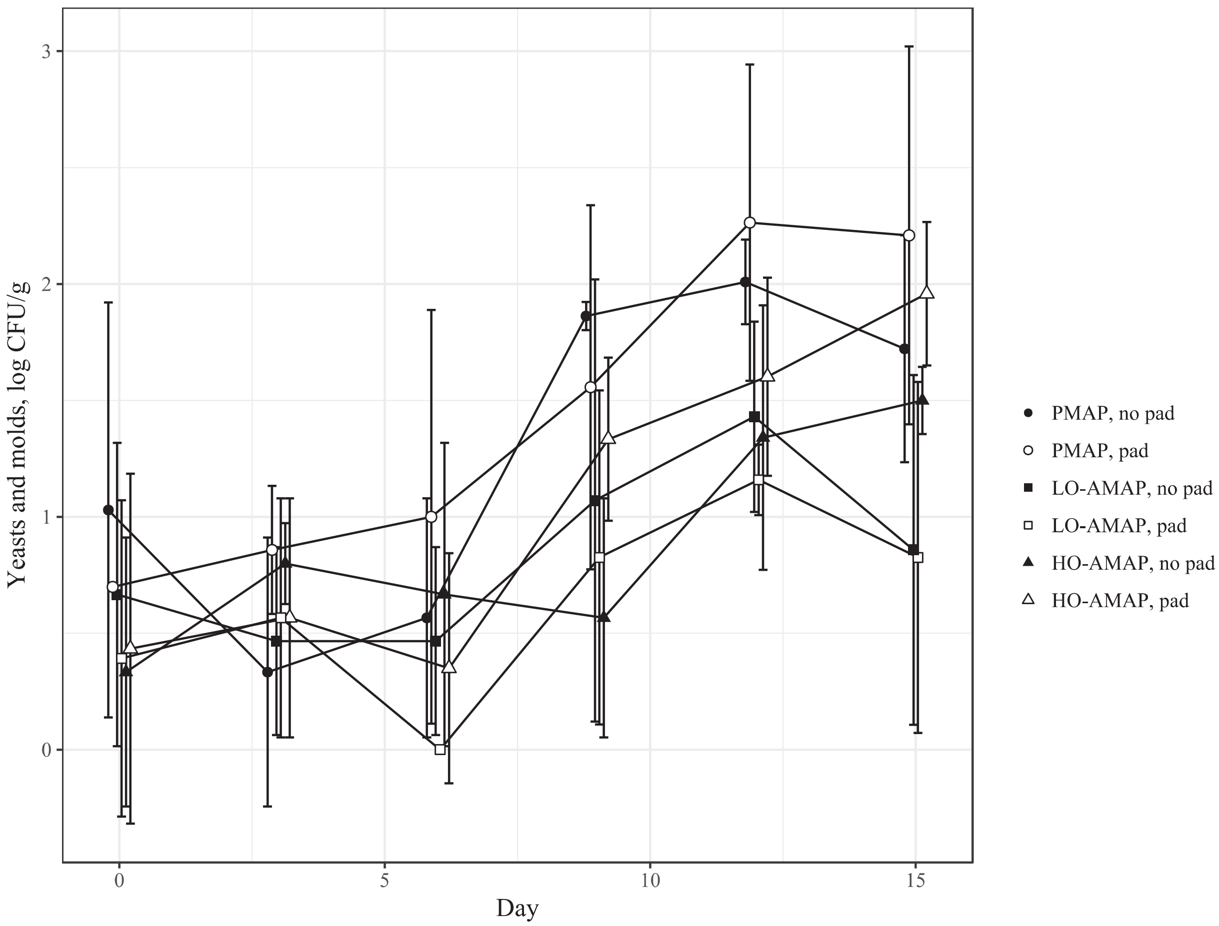

Figure 15. Yeast and mold populations on fresh-cut cantaloupe stored at 3°C for 15 days. Data presented as means ± standard deviation

3.3.8. SSC

Significant two-way interactions between atmosphere*day and pad*day were found (*P* < 0.05) (Table 3). The SSC content in packages with pads declined, while remaining constant in packages without pads. Atmosphere tended to have a less structured effect over time, with some inconsistency on day 12 due to missing measurements biasing the remaining trend. While all melons met the minimum U.S. No. 1 standard of 9°Brix prior to packaging, some variation between melons and within melons is unavoidable (Beaulieu, 2011). The trend of decreasing SSC in fresh-cut melon over time when exposed to the pads could be explained by dissolved sugars leaving the melon as drip into the pads. In general, other studies have found that SSC either remains stable (Bai *et al.*, 2001; Gil, Aguayo and Kader, 2006) or declines during storage (Portela and Cantwell, 2001; Beaulieu, 2005; Amaro *et al.*, 2012), with better retention in refrigeration than at higher temperatures (Lamikanra *et al.*, 2000). Overall, good retention of soluble solids was achieved across all treatments.

Table 3. Effects of interactions between atmosphere and day, and between pad and day, on SSC content of fresh-cut cantaloupe stored at 3°C

	Interaction				
	atmosphere*day			**pad*day**	
Time (days)	**PMAP**	**LO-AMAP**	**HO-AMAP**	**No pad**	**Pad**
0	9.73±0.19 ab *	9.58±0.19 ab	9.88±0.19 a	9.34±0.15 a	10.12±0.15 a
3	10.08±0.19 a	9.68±0.19 ab	9.83±0.19 a	9.67±0.15 a	10.06±0.15 a
6	9.16±0.19 b	9.89±0.19 ab	9.76±0.21 a	9.34±0.15 a	9.86±0.17 a
9	9.64±0.19 ab	9.77±0.19 ab	9.79±0.19 a	9.78±0.15 a	9.69±0.15 a
12	9.99±0.23 ab	10.63±0.23a	**	10.16±0.19 a	**
15	9.78±0.19 ab	9.67±0.19b	9.06±0.23 a	9.46±0.17 a	9.54±0.15 a

* Data presented as lsmeans ± standard error. Shared lower-case letters within columns indicate no significant difference ($P < 0.05$) between days. No significant differences were observed between treatments on a given day for either two-way interaction.
** Non-estimable interaction due to dropped and uncollected datapoints.

3.3.9. Titratable acidity

Fresh-cut cantaloupe showed low TA levels throughout the study, with very few drops of NaOH required to reach the characteristic color change of phenolphthalein. Consequently, the data contained distinct “levels” of TA, depending on the number of drops required (Figure 16). On average, samples maintained a TA close to 0.05% through 12 days of storage, with a slight increase on day 15. A similar pattern was noted by Gil, Aguayo and Kader (2006), who found that TA rose during nine days of storage at 5°C, in snap-fit containers. In our study, this rise was steeper in HO-AMAP packages. While a significant three-way interaction (atmosphere*day*pad) was found ($P<0.05$), it is difficult to interpret with the levels that are seen in the data. The following section presents the trends of acidity by treatment based on pH.

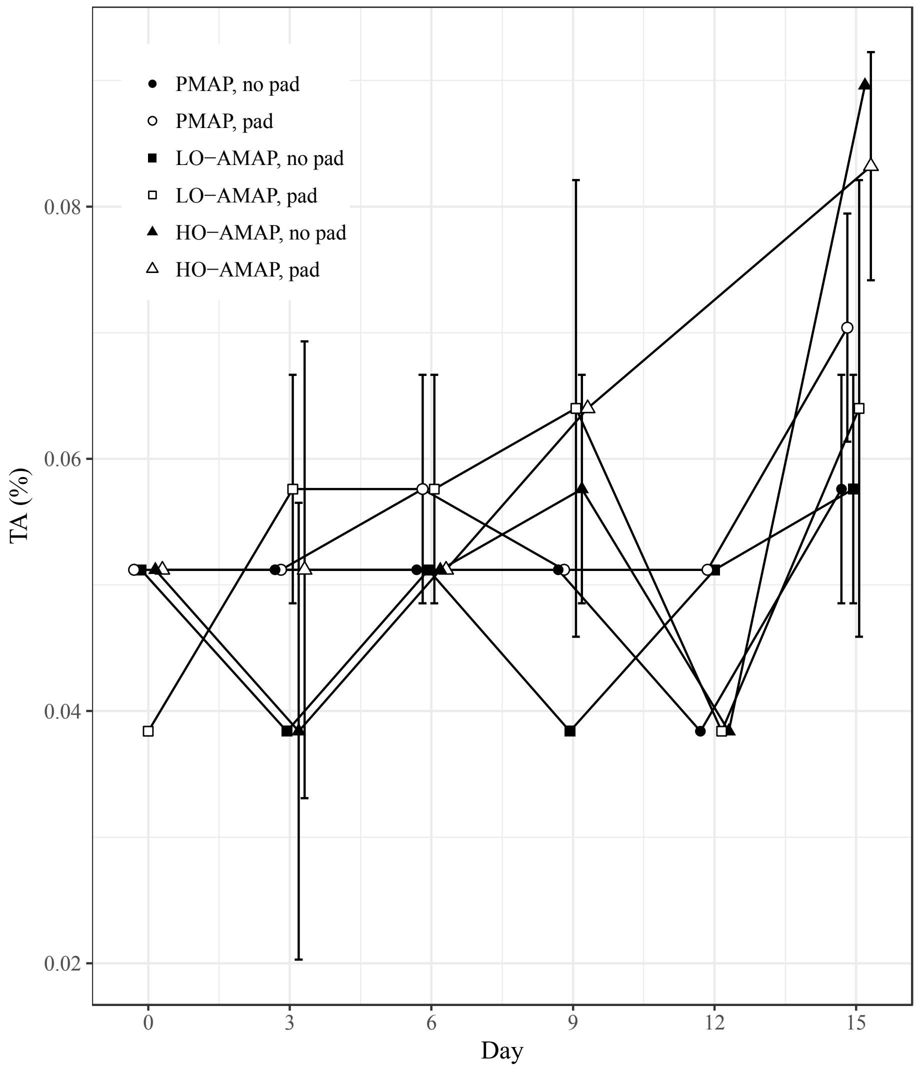

Figure 16. Titratable acidity of fresh-cut cantaloupe stored at 3°C for 15 days

3.3.10. pH

The pH of fresh-cut cantaloupe in all packages increased until day 6, with differences thereafter based on treatment (Table 4). A significant three-way interaction (atmosphere*pad*day) was found for pH ($P < 0.05$). The pH in HO-AMAP-treated packages declined after day 6, while pH in LO-AMAP- and PMAP-treated packages continued to slowly rise, leading to significant differences on day 15 ($P < 0.05$). While the interaction involved the pad, the pad alone did not impact the pH of fresh-cut melon.

Table 4. SSC of fresh-cut cantaloupe during 15 days of storage at 3°C in three MAP treatments, with or without drip-absorbent pads.

Time (days)	Treatment					
	PMAP		LO-AMAP		HO-AMAP	
	No pad	Pad	No pad	Pad	No pad	Pad
0	6.97±0.05 a*	6.85±0.05 a	6.97±0.05 a	6.98±0.05 ab	6.97±0.05 a	6.90±0.05 ab
3	6.93±0.05 a	7.08±0.05 a	7.03±0.05 a	6.97±0.05 a	6.88±0.05 a	6.92±0.05 ab
6	7.14±0.05 a	7.01±0.05 a	7.18±0.05 a	7.25±0.05 b	7.05±0.05 a	7.06±0.07 a
9	7.12±0.05 a	7.04±0.05 a	7.12±0.05 a	7.06±0.05 ab	7.00±0.05 a	6.97±0.05 a
12	7.22±0.07 a	6.96±0.07 a	7.33±0.07 a	7.28±0.07 ab	7.04±0.07 a	**
15	7.26±0.05 a	7.09±0.05 a	7.16±0.05 a	7.26±0.05 ab	6.81±0.08 a	6.61±0.05 b

* Presented as least squares means ± standard error. Different lowercase letters within a column indicate significant differences ($P < 0.05$) between days.
** Data not collected or missing.

4. EFFECTS OF SACHET PRESENCE ON CONSUMER PRODUCT PERCEPTION AND ACTIVE PACKAGING ACCEPTABILITY - A STUDY OF FRESH-CUT CANTALOUPE

4.1. Materials and methods

4.1.1. Melon processing, packaging, distribution, and storage

Cantaloupe melons meeting the U.S. No. 1 standard were acquired from a local distributor, washed, sanitized in a sodium hypochlorite solution, then peeled and diced with a sharp knife in a cold room as described in section 3.2. Approximately 420 g of fresh-cut cantaloupe was packaged in polypropylene trays (246mm x 178mm x 44.5mm, Sealed Air, Charlotte, NC, USA) lidded with polyethylene terephthalate/ethylene vinyl acetate film (Clear Lam, Elk Grove Village, IL, USA). Half of these packages were loaded with a commercial drip-absorbent pad (Novipax, Oak Brook, IL, USA) prior to their filling with melon (Figure 17). A semi-automatic commercial tray sealer (Multivac Inc., Kansas City, MO, USA) was used to flush each package with medical air (Airgas, Radnor, PA, USA) prior to sealing, creating a PMAP. Packages were placed in ice-loaded coolers (~8°C) and subjected to vibration on a table (Lansmont Corp., Monterrey, CA, USA), simulating 100-150 miles of truck transportation per ASTM standard (ASTM D4728-06, 2012). Packages were then moved to a temperature-controlled room where they were stored in the dark at 4°C for 6 days.

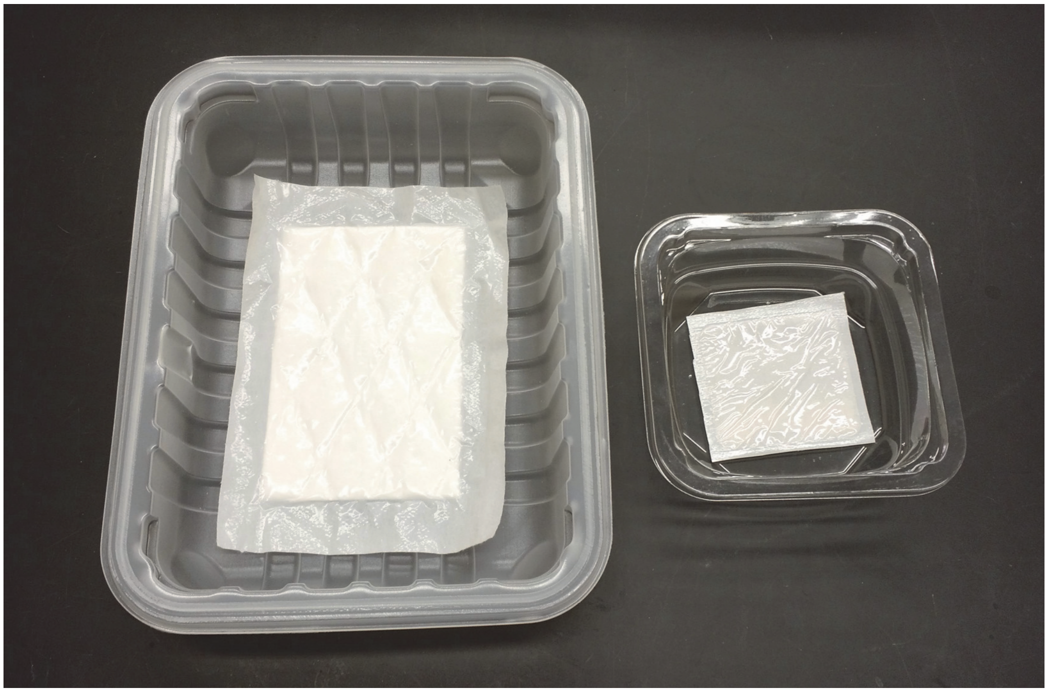

Figure 17. PP tray with drip-absorbent pad for storage (left) and PET tray with absorbent sachet for consumer evaluation (right)

4.1.2. Preparation of samples for sensory evaluation

Following 6 days of cold storage, fresh-cut cantaloupe was repacked from the PMAP trays into smaller containers immediately before the sensory evaluation. The components of this container were PET trays and snap-fit lids (95mm x 95mm x 25 mm, Clear Lam, Elk Grove Village, IL, USA), and absorbent sachets (60mm x 60 mm, Maxwell Chase Technologies, Atlanta, GA, USA) (Figure 17). Approximately 30 g of fresh-cut cantaloupe from trays with drip-absorbent pads was repacked into PET containers with and without the sachet, and the same was done for melon from trays without drip-absorbent pads. Thus, four packaging combinations were created to study the sachet (with or without) and pad (from trays with or without) factors. Finally, the packages were labeled with a three-digit code, and stored in a cooler, over ice, until serving to panelists, with a maximum of 30 minutes in the presentation package.

4.1.3. Sensory evaluation

4.1.3.1. Panelists

Ninety-four cantaloupe consumers were recruited from the university and surrounding community using an online research participation (SONA) system. Potential panelists provided demographic and other consumer information to the SONA pool. Only those who met the testing recruiting requirements were contacted via the SONA system email. Prior to registering for the study, potential panelists were provided an overview of the experimental protocol. Panelists were refreshed on the experimental protocol and a written informed consent form was obtained before the evaluation. The protocol used in this study was approved by the Institutional Review Board of Michigan State University. Each panelist received $5 cash in appreciation for his or her participation.

4.1.3.2. Testing conditions

This evaluation was conducted in a single session on one day. Panelists were seated in individual sensory booths in the Michigan State University Sensory Lab (East Lansing, MI, USA), under controlled lighting and environmental conditions. Each package (treatment) was served on a white tray containing a paper napkin, plastic fork, two unsalted saltine crackers (Nabisco, East Hanover, NJ, USA) and a cup of filtered water. The four packages were presented to each panelist sequentially and in a randomized order. Instructions, questions, and response inputs were displayed on a computer monitor using the SIMS 2000 Sensory Evaluation Testing Software (Sensory Computer Systems, Berkeley Heights, NJ USA).

4.1.3.3. Questionnaire

A two-part questionnaire was administered to each participant using the aforementioned software. The first part of the questionnaire consisted of a consumer sensory evaluation where panelists were asked to rate the acceptability of both package and melon for each of the four packages. Panelists were first asked to look at the package and then to rate their liking of it. Subsequently, panelists were asked to open the package, look at the melon to evaluate color and then to bite down on the sample to evaluate liking of the firmness, sweetness, and flavor. Finally, panelists were asked to rate their liking of the fresh-cut cantaloupe (overall acceptance). Comments were permitted following each sample. Responses of package/product evaluation were each collected using a nine-point Likert scale ranging from dislike extremely (1) to like extremely (9).

The second part of the questionnaire consisted of a list of categorical and ordinal questions to assess panelist opinions about packaging for produce including sachet presence, new packaging types, and willingness to pay for use-life extension. Questions and choose one guided-type responses presented to the panelists in this part of the questionnaire are shown in Table 5.

Table 5. Questions and choose one guided-type responses presented to the panelists in the second part of the questionnaire

Question	Choose one guided-type responses
About absorbent sachet	
How do you feel about the presence of an absorbent sachet at the bottom of the package, under the fruit?	1. I liked it 2. I did not mind that it was there 3. I did not like it 4. I would not care if I knew why it was added 5. I did not notice it
About new packaging	
How do you feel about the packaging used for fresh produce?	1. I prefer to see new packaging types 2. I prefer packaging to stay the same 3. I do not care about the packaging
About cost	
How much more would you be willing to pay for a package that will preserve the quality of the cantaloupe for multiple days after opening?	4. 0% more 5. 2% more 6. 5% more 7. 7% more 8. 10% more

4.1.4. Statistical design and analysis

Panelist data collected in SIMS 2000 was analyzed using SAS 9.4 (SAS Institute Inc., Cary, NC, USA). Responses from the first part of the questionnaire were arranged in a randomized complete block design, and analyzed using a mixed model analysis of variance (ANOVA) (PROC MIXED in SAS 9.4). Fixed effects included in the model were pad in the storage package (PAD), sachet in the sensory evaluation package (SACHET), and PAD×SACHET, while panelist blocks were included as a random effect. Differences in each independent variable (rating of the package, melon color, sweetness, firmness, flavor, and overall acceptability) were assessed by comparing least-squares means at a significance level of $P < 0.05$. Post-hoc pairwise comparisons were adjusted per the Bonferroni procedure to avoid inflation of Type-I error.

In order to further assess whether these sensory evaluation responses (based on PAD or SACHET) were specific to population segments (by demographic divisions (Table 2) or responses to choose-one guided questions (Table 1)), interactions were tested. For each question in the sensory evaluation, two-way interactions were assessed between a population segment (e.g., age) and SACHET, as well as two-way interactions between a population segment and PAD. Due to incompatibility between data sets, ethnicity was not included. Non-significant two-way interactions were removed from the model by manual backwards selection, as necessary. Any significant interactions were evaluated as previously described.

4.2. <u>Results and discussion</u>

4.2.1. Population demographics

Ninety-four participants above the age of 18 took part in the study, having responded during pre-screening that they eat cantaloupe. The demographic breakdown of the panel, as well as their frequency of cantaloupe consumption, is presented in Table 6. Dominant trends within the population show that the panelists were predominantly Caucasian, female, eat cantaloupe several times per month, and aged between 25-34. The demographic breakdown of our panel matches the sex, age, and ethnicity distributions reported in studies focused on consumer acceptance of active packaging that presented demographic data (O' Callaghan and Kerry, 2016; Aday and Yener, 2015). In fact, O' Callaghan and Kerry (2016) reported sex (67% female vs. 33% male), age (88% aged between 18-34), and ethnicity (Caucasian bulk of responders) distributions almost identical to those in this study. Those authors attributed the high female representation to more females than males being enrolled in universities.

Table 6. Demographic information and cantaloupe consumption frequency

	Panel response frequency	
	%	**N**
Age		
Under 25	20.2	19
25-34	50	47
35 and up	29.8	28
Sex		
Male	34.0	32
Female	64.9	61
Other	1.1	1
Ethnicity		
Caucasian	60.6	57
Asian	19.1	18
African-American	4.3	4
Mixed race or other	4.3	4
American Indian or Alaska native	1.1	1
Unidentified	10.6	10
Frequency of cantaloupe consumption		
Six times a year or less	14.9	14
Once a month	31.9	30
Several times a month	37.2	35
Several times a week	16.0	15

N=94

4.2.2. Package acceptability due to sachet presence

4.2.2.1. Overall response

Panelist Likert-scale responses of package acceptability showed a preference for fresh-cut produce packages without sachets (P=0.0129). The full spectrum of responses is shown in Figure 18. Approximately 73% of panelists rated the packages without sachets from like slightly to like extremely, while 65% of panelists rated the packages with sachets in the same range. On the other hand, only 13% of panelists rated the packages without sachets between dislike slightly and dislike extremely, while 22% of panelists rated the packages with sachets in the same range. The mean difference can be found in Table 7. These results indicate that a sachet in a package containing produce plays a significant role in how much panelists like the package upon visual inspection, as the packages of this study were identical except for the presence or absence of the sachet. These results also show that the presence of a sachet in a package containing produce, without any indication as to its purpose or benefits, is not well perceived. This could be attributed to consumer unfamiliarity with the role that active packaging plays, as reported by Van Wezemael, Ueland and Verbeke, 2011; Barska and Wyrwa, 2016; and O' Callaghan and Kerry, 2016). In alignment with our results, the survey by Aday and Yener (2015) found that 67% of respondents preferred active packaging to not take the form of a sachet. However, our study establishes the difference in liking through a visual, rather than a written description of what an active sachet is, which could be misunderstood by consumers. Furthermore, our study affirms that those feelings of "sachet dislike" cross into the growing fresh-cut produce market. This negative attitude towards sachets may affect fresh-cut produce purchase at retail as packaging plays a key role in consumer purchase decisions for fresh produce (Koutsimanis *et al.*, 2012).

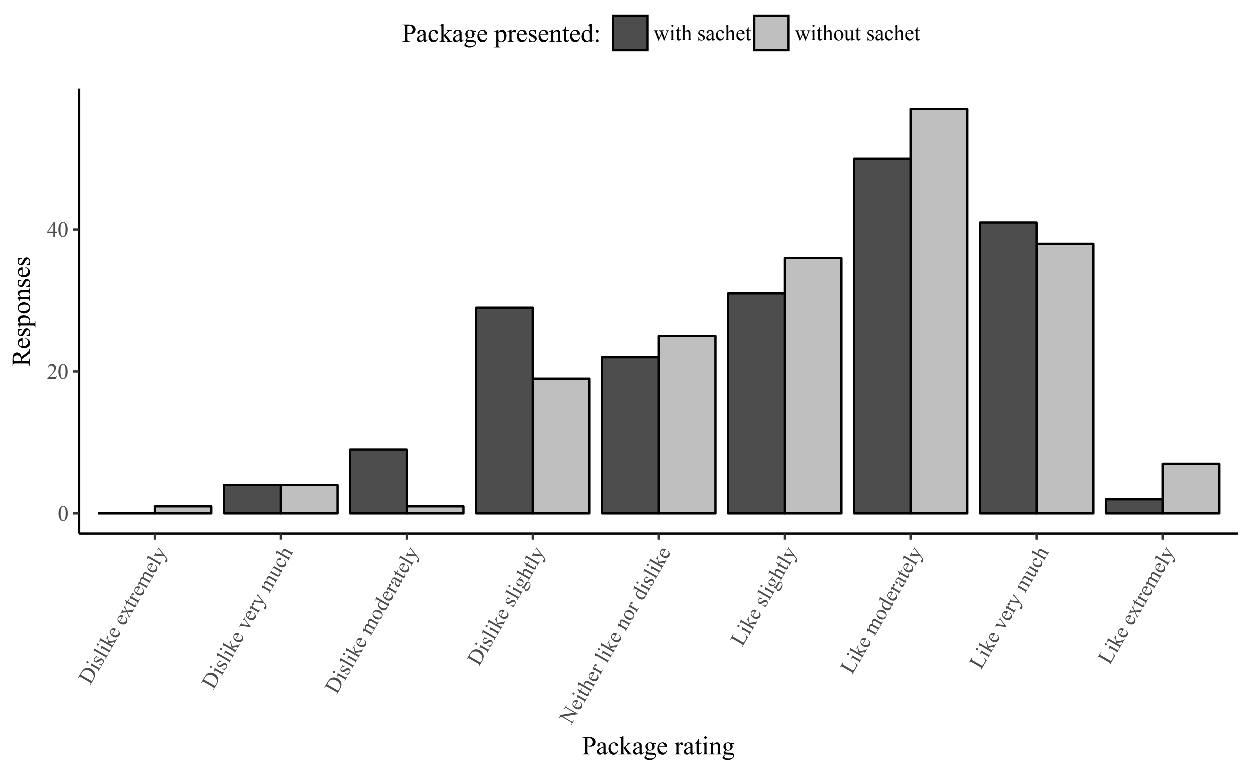

Figure 18. Package liking based on sachet presence. 1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely.

Table 7. Likert scores for presentation with sachet and storage with drip-absorbent pad of packages and fresh-cut cantaloupe attributes

	Likert scores				
Attribute	With sachet		Without sachet	From pad	From no pad
Package	6.08±0.15[a]	*	6.36±0.15	6.22±0.15	6.21±0.15
Melon					
Color	7.15±0.12		7.27±0.12	7.18±0.12	7.24±0.12
Firmness	6.79±0.14		6.98±0.14	6.80±0.14	6.96±0.14
Sweetness	6.81±0.13		7.04±0.13	6.90±0.13	6.95±0.13
Flavor	6.80±0.14		7.03±0.14	6.88±0.14	6.94±0.14
Overall acceptability	6.50±0.14		6.77±0.14	6.62±0.14	6.65±0.14

[a] Scores presented as mean ± standard error. n = 188. * Indicates significant differences ($P < 0.05$) between adjacent items.

4.2.2.2. Effects of population segments on package acceptability due to sachet presence

Following analysis of the whole panel, the impact of population segments on the package acceptability due to sachet presence was evaluated to determine if groups within the panel had differing opinions. The results show different opinions based on sex and age, but not cantaloupe consumption frequency.

A two-way interaction between sachet presence and sex was found, showing that female panelists liked packages with sachets significantly less than packages without (P=0.0171), while male panelists liked both packages equally (Figure 19). About 76% of female panelists rated the packages without sachets from like slightly to like extremely, while ~66% rated the packages with sachets in the same range. O' Callaghan and Kerry (2016) similarly found women less willing to accept shelf life-extending packaging for cheese. Aday and Yener (2015) saw that women preferred to visually evaluate the quality and freshness of a food product themselves, while men expressed interest in packaging technologies that could deliver that information. Perhaps, using this finding to interpret the results of our study, women may see the sachet as an inhibitor to gathering correct information about the freshness of a food product. Overall, the difference found in our study is important because women do most of the shopping for families and, as such, make the majority of grocery purchase decisions (Beardsworth *et al.*, 2002).

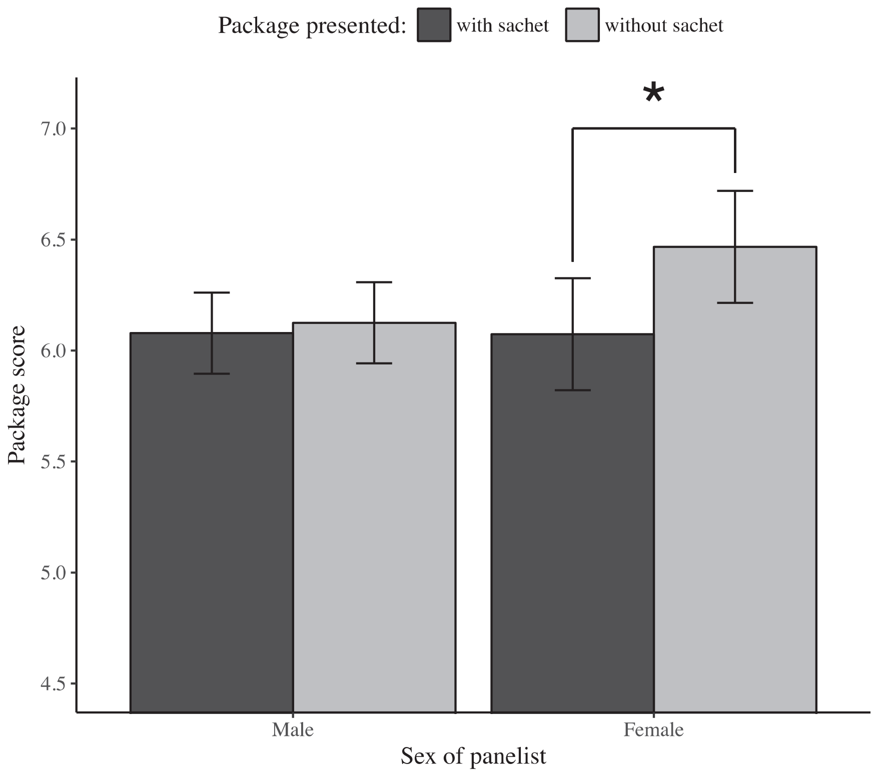

Figure 19. Comparisons of the effect of sachet presence on package acceptability score, by the sex of the panelist. The * indicates a significant difference at $P < 0.05$. Error bars represent standard error on the mean.

A two-way interaction between sachet presence and age group was also found. Panelists over the age of 35 rated packages without sachets significantly higher than panelists in the 25-34 age group rated packages with and without sachets (P=0.0014 and P=0.0372, respectively) (Figure 20). Both the 25-34 and 35 and older age groups rated packages without sachets slightly higher than packages with sachets, however, these differences were not statistically significant ($P > 0.05$). This pattern reflects the findings of O' Callaghan and Kerry (2016), who identified that consumers over 35 years of age were less likely than younger consumers to accept the use of new packaging technologies (including active packaging) for cheese. Overall, these results indicate that active sachets may be successfully implemented in products targeted towards younger consumers.

The 25-35 age group had lower scores overall than the other groups. Lower scores regardless of sachet presence suggest that this age group liked the package less than other age groups did. This could be due to several factors, such as design, size, or material. For example, Koutsimanis *et al.* (2012) noted that consumers under the age of 40 significantly preferred larger containers for fresh cherries, so perhaps our container was less desirable due to its small size. Differences between the Millennials and other generations have previously been reported. However, while Millennials are a current global force when it comes to driving packaging design, older groups are rapidly closing the gap due to their increasing numbers in developed countries (Heath, 2016).

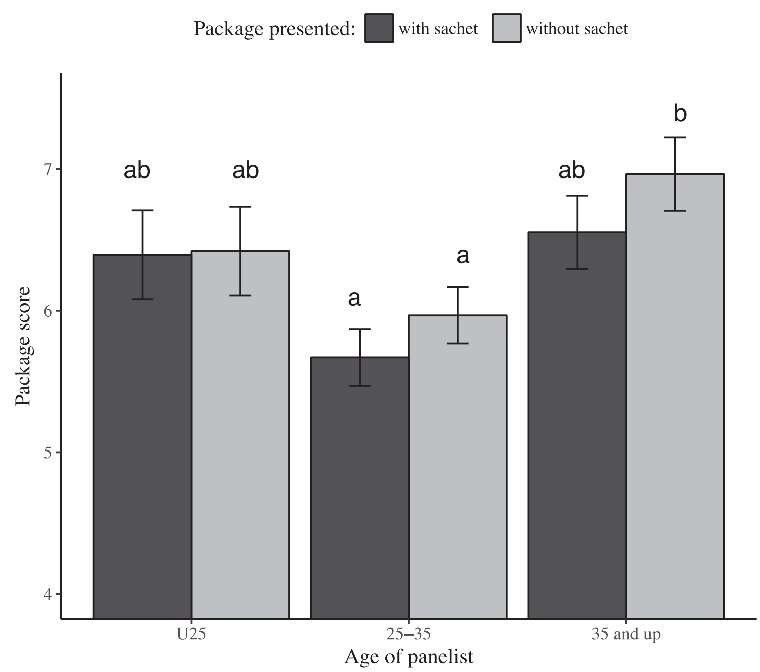

Figure 20. Effect of sachet presence on package acceptability, as affected by panelist age. Error bars represent standard error on the mean. Different letters indicate significant differences ($P < 0.05$).

4.2.2.3. *Effects of willingness to pay for use life on acceptability of packages with sachets*

Besides population segments, correlations between package liking and responses to choose-one guided questions were evaluated. A two-way interaction (*P*=0.0034) was observed between sachet presence and how much panelists were willing to pay for a package that would give a few more days of use life (0, 2, 5, 7, and 10% more, or, "it depends," as responses). The effect was found at the "0%" level, where consumers preferred packages without sachets, with the mean rating over 1 point higher, as shown in Figure 21. This could reflect that some consumers reject the idea of paying for packaging that extends use life altogether, and so are not in favor of packages that contain sachets. A similar idea was forwarded by O' Callaghan and Kerry (2016), who proposed that data regarding willingness to pay for "smart packaging" would always be skewed by consumers who reject the technology altogether. Furthermore, Aday and Yener (2015) reported that when consumers were asked about their willingness to try "innovative packaging," 7% responded, "I absolutely don't take it."

Additionally, a trend shown here is rising package (with sachet) scores with higher responses to the willingness to pay question, while packages without sachets scored consistently across the question. This shows that consumers who were less averse to sachet presence were also more likely to pay for packages that extend use life. This corresponds with the idea that familiarity with novel packaging technologies correlates positively with consumer acceptability, as reported by Van Wezemael, Ueland and Verbeke, 2011; Barska and Wyrwa, 2016; O' Callaghan and Kerry, 2016.

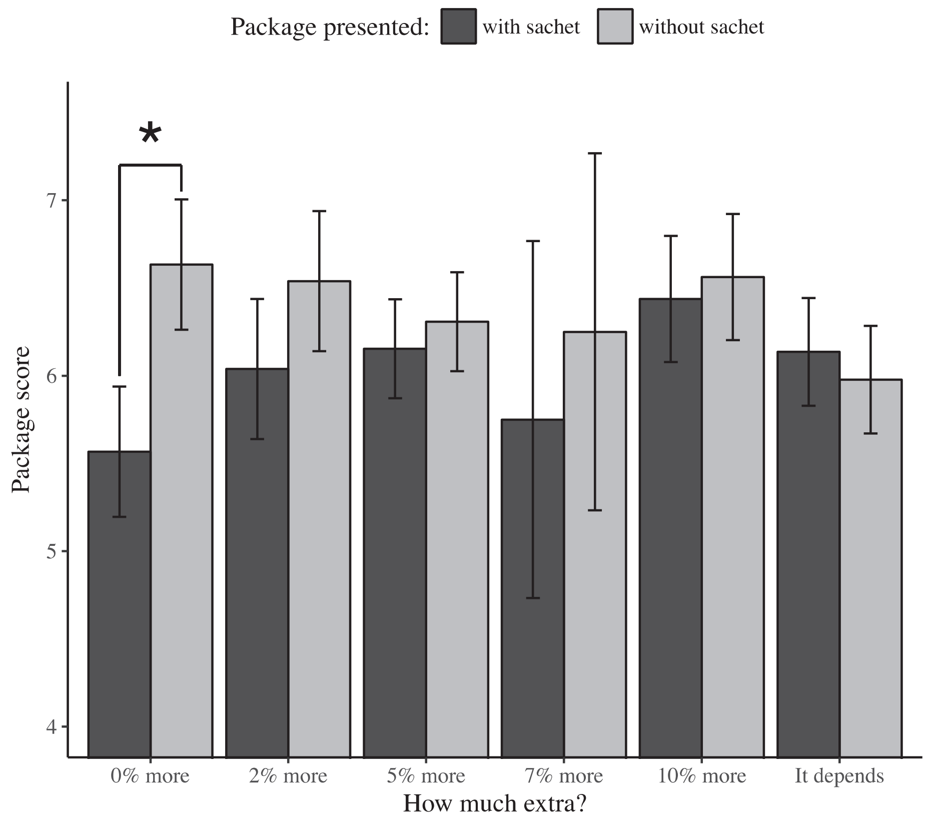

Figure 21. Effect of sachet presence on package acceptability as affected by questionnaire response to "How much more would you be willing to pay for a package that will preserve the quality of the cantaloupe for multiple days after opening?". The * indicates a significant difference at $P < 0.05$. Error bars represent standard error on the mean.

4.2.3. Cantaloupe acceptability due to sachet presence

Following evaluation of the package, panelists were asked to rate the appearance, firmness, sweetness, flavor, and overall acceptability of the fresh-cut melon; this was to see if a liking or disliking of the package would carry over to evaluation of the product inside. An overall trend of cantaloupe packaged with a sachet being less-liked remained for all cantaloupe acceptability questions, as seen in Table 7. This presumably is a halo-effect response, where the initial impression of the package due to the sachet carries over to the product. However, differences in cantaloupe acceptability due to sachet presence did not reach the $P = 0.05$ significance threshold, indicating that the carryover impression was weaker than that expressed in the initial package question. This speaks for the results of the Likert-scale questions on color, firmness, sweetness, flavor, and overall acceptability. As panelists answered questions about a sample, their answers tended to moderate, which may reflect psychological factors such as habituation to the samples or declining motivation to seek differences over the course of the sampling (Meilgaard, Civille and Carr, 2007). For example, in the first question on package acceptability, there was a significant difference in liking based on sachet presence (P = 0.0129); by the final question on overall acceptability, this difference had moderated to non-significance (P = 0.086). Therefore, sachet presence in the package did not significantly affect consumer liking of the fresh-cut cantaloupe inside. Rather, the difference was entirely in the visual package evaluation, prior to consumption (or purchase, in a retail setting). Previous work has shown that the type of packaging used is key to the perception of the taste of food (Mascaraque, 2016). In our study, the impact of the sachet presence on perception of the package was not strong enough to significantly influence consumer ratings of the product. The reason could be that produce is not produced artificially and, therefore, its flavor, texture, and other attributes are not expected to be engineered. Furthermore, this result indicates that panelists did not expect a quality improvement resulting from the use of a sachet, indicating that companies interested in using active sachets for fresh-cut produce packaging should explain their intended benefits to consumers.

Following analysis of the whole panel, the impact of population segments on the acceptability of the appearance, firmness, sweetness, flavor, and overall acceptability of the fresh-cut melon due to sachet presence was evaluated to determine if groups within the panel had differing opinions. The results show that opinions differed by age, but not by sex or cantaloupe consumption frequency. The over-35 age group rated melon color in the packages with sachets significantly lower than in the packages without sachets (P = 0.0345). This may indicate that the older demographic group projected their dislike of the sachet onto the color ratings. Previous studies have noted that older age groups are less enthusiastic about active packaging and similar technologies (O' Callaghan and Kerry, 2016). However, these findings support the idea that active sachets may be successfully implemented in products targeted towards younger consumers.

4.2.4. Lack of impact from pads during storage on consumer acceptability

No significant difference ($P > 0.05$) was noted between samples kept with or without a drip-absorbent pad during 6 days of storage (Table 7). This result was consistent for subsets of panelists along sex and age lines, as well as by their responses to the questionnaire. As shown in the previous chapter, drip-absorbent pads were found to have minimal impact on the physicochemical properties of fresh-cut cantaloupe. While drip-absorbent pads contribute to melon weight loss (Figure 8, Figure 9), this desiccation had not crossed the threshold of consumer acceptability in the six-day timeframe of the present study.

4.2.5. Responses to choose-one guided questions on package attributes

Following the sensory evaluation, where panelists were exposed to the active packages, consumers were asked how they felt about the absorbent sachet underneath the cantaloupe (Table 8). Overall, just over 40% of panelists responded that they did not mind the absorbent sachets. This response was consistent across age groups and sexes. Combined with the 7.5% who liked the sachets and the 11.7% who said they did not notice them, this study found that most panelists accepted the sachets with no additional information, while slightly under 15% wanted to know more about the intention of the sachet. On the other hand, 25.5% of the panelists responded that they did not like the sachet. This is similar to the range reported in a survey of active packaging for cheese (O' Callaghan and Kerry, 2016), but more favorably viewed than in surveys of active packaging (emitters) for beef (Van Wezemael, Ueland and Verbeke, 2011) or oxygen scavengers for fresh meat (Mikkola *et al.*, 1997). Similar proportions of each age group responded that they did not like the absorbent sachet. However, between age groups, responses to this question showed a difference between those who did not notice the pad, and those who wanted more information. The older (over 35) and younger (under 25) groups were more likely to not notice the sachet, while the 25-34 group was most attentive and wanted more information about the sachet. The reason may be that Millennials are more accustomed to get information about food prior to purchase than other age groups (*The Produce News*, 2016).

The responses to the question that explored how panelists felt about change in fresh produce packaging (Table 8) showed that 46.8% of panelists like to see new types of packaging, 41.5% do not care about packaging, and 11.7% preferred packaging to remain the same. These responses show that consumers are open to packaging changes and innovation. This may reflect previous work, which has shown that consumers are quite receptive to upcoming packaging materials, such as bio-based plastics (Koutsimanis *et al.*, 2012). Responses to this question also show that women were more likely to report that they like to see new packaging types, while men were more likely to respond that they do not care about packaging. This contradicts the two-way interaction between sachet presence and sex found when analyzing results from the first part of the questionnaire, as well as the literature surveys focused on active packaging (O' Callaghan and Kerry, 2016; Aday and Yener, 2015). This could be because types of packaging other than active packaging were considered prior to responding, such as graphic design or utility-adding features. Responses were similar between the 25-34 and the 35-and-up age groups, while the under-25 group was much less likely to respond that they like to see new packaging types. This runs counter to common thinking that younger demographics prefer newness, while older demographics are expected to be resistant to change.

The final question explored consumer willingness to pay for a package that would give extra use life, a core benefit to many active packaging technologies. In this study, 60.6% of panelists were willing to pay between 2% and 10% more for a package that extended use life. This response was highly influenced by sex and age. Only 40.6% of men were willing to pay for extra use life, compared with 70.5% of women, primarily due to 43.8% of men responding, “it depends.” Panelists commented that their willingness to pay would be affected by their plans of whether to eat the fresh-cut produce soon or later. Among age groups, 84.2% of the under-25 population showed willingness to pay some amount for extra use life, while the 25-and-older age groups showed higher frequencies of selecting “0% more” or “It depends” in response to the question. In particular, 31.9% of the 25-34 age group marked, “It depends,” which reflects that group’s desire for more information about the absorbent sachet in the first question (Table 8). This was expressed by many panelist comments, where a common theme was seeking assurances of improved product quality, not simply increasing the longevity of mediocre produce. Other works have shown less willingness to pay for similar technologies and results than were found in this study. Mikkola *et al.* (1997) found that 40% of survey respondents were willing to pay more for a product packed with oxygen absorbers, while O’ Callaghan and Kerry (2016) found that between 24.6% and 32.7% of consumers were willing to pay more for shelf life extension. Previous studies have also shown that consumers find price and shelf life to be the most important aspects of fresh produce purchase decisions (Koutsimanis *et al.*, 2012), meaning that economical shelf-life extension is an important goal. The responses to this question show the importance of providing consumers with information about the function and value of active packaging for fresh-cut produce, as they show willingness to pay when it works.

Table 8. Responses to questions in part two of the questionnaire, with demographic breakdowns

	Age (%)			Sex (%)		Total (%)
	U25	25-34	35 +	Female	Male	
HOW DO YOU FEEL ABOUT THE PRESENCE OF AN ABSORBENT PAD* AT THE BOTTOM OF THE PACKAGE, UNDER THE FRUIT?						
I liked the absorbent pad	5.26	6.38	10.71	8.2	6.25	7.45
I did not mind that it was there	42.11	40.43	39.29	42.62	37.5	40.43
I did not like it	26.32	25.53	25	22.95	28.13	25.53
I would not care if I knew why it was added	10.53	23.4	3.57	14.75	15.63	14.89
I did not notice an absorbent pad	15.79	4.26	21.43	11.48	12.5	11.7
HOW MUCH MORE WOULD YOU BE WILLING TO PAY FOR A PACKAGE THAT WILL PRESERVE THE QUALITY OF THE CANTALOUPE FOR MULTIPLE DAYS AFTER OPENING?						
0% more	10.53	14.89	21.43	16.39	15.63	15.96
2% more	26.32	10.64	10.71	18.03	6.25	13.83
5% more	42.11	21.28	28.57	32.79	15.63	27.66
7% more	5.26	2.13	0	3.28	0	2.13
10% more	10.53	19.15	17.86	16.39	18.75	17.02
It depends	5.26	31.91	21.43	13.11	43.75	23.4
HOW DO YOU FEEL ABOUT THE PACKAGING USED FOR FRESH PRODUCE?						
I prefer to see new packaging types	36.84	48.94	50	50.82	40.63	46.81
I prefer packaging to stay the same	15.79	10.64	10.71	13.11	9.38	11.7
I do not care about the packaging	47.37	40.43	39.29	36.07	50	41.49

For age and total responses, n=94. For sex, n=93. *Called “pad” here due to consumer unfamiliarity with the word “sachet.”

5. CONCLUSIONS

In the safety study, HO-AMAP treatments successfully held *L. monocytogenes* populations below the levels experienced in PMAP and LO-AMAP packages. While best for safety, HO-AMAP led to melon reddening (falling a*) and declines in pH in the quality study, which were not experienced in other atmosphere treatments. Further evaluation is necessary to determine if these changes in quality parameters are viewed positively or negatively by consumers.

While the drip-absorbent pads took up ~2.5% of the fresh-cut melon's weight over 9 days of storage at 5°C, cantaloupe surface moisture was not sufficiently modified to reduce the growth of *L. monocytogenes*. Furthermore, results from the quality study, where pads absorbed 3-6% of the cantaloupe's weight over 15 days of storage, revealed minimal impacts on quality attributes, with only SSC impacted (slight decrease over time). The exception to this was when the pad was combined with the LO-AMAP treatment, which led to increased bacterial populations and decreased growth of yeasts and molds. This was likely due to higher levels of drip delivering nutrients to the surface of the fresh-cut melon. Other areas where the drip-absorbent pads would be expected to impact quality were unaffected, particularly firmness, which declined similarly in all packaging treatments. These findings, while only shown for fresh-cut cantaloupe, call into question commercial claims of fresh-cut produce shelf-life extension that have been attributed to drip-absorbent pads (Johnson, 2017).

Because *L. monocytogenes* continued to grow in all packages over time, this study shows that none of the technologies examined were sufficient to suppress the pathogen. Therefore, other approaches to assure consumer safety would be more appropriate for fresh-cut cantaloupe, because *L. monocytogenes* is "zero tolerance" in fresh-cut fruits and vegetables. PMAP is recommended due to its effective maintenance of quality attributes, lower cost than either AMAP design, and retention of desired O_2 levels. Based on the results of this study, drip-absorbent pads did not improve quality, but may be useful in applications where drip is more prevalent.

In the sensory evaluation, panelists rated that they liked packages of fresh-cut cantaloupe with sachets less than packages without sachets. This difference was entirely driven by the panelist seeing the sachet, as no information was provided about its presence. The difference in liking was driven by preferences of female panelists, who rated packages without sachets significantly higher than packages with sachets, while male panelists did not differentiate them. Although sachet presence significantly impacted panelist ratings of the package, those differences largely did not carry over to quality ratings of the fresh-cut cantaloupe inside. Additionally, presence of the drip-absorbent pad during storage for the week prior to the sensory evaluation had no significant effect on the panelist ratings of the package or quality attributes of the fresh-cut cantaloupe.

In the second part of the questionnaire, panelist responses showed that the population was generally receptive to packaging changes and innovation. While most panelists verbally accepted the use of sachets in the packages of fresh-cut cantaloupe, 25% responded that they did not like them. Overall, 60% of panelists expressed that they were willing to pay between 2 and 10% more for a package that extended use life by multiple days after opening. This shows that active packages incorporating compounds by means other than visible sachets may see greater acceptance, particularly if their ability to extend use life is communicated.

6. FUTURE WORK

Going forward, some possible future steps:

Further study of coextrusion and coating of active compounds would be valuable, to deliver the benefits of active packaging without the visible sachet. Some current research has investigated coextrusion (e.g., Rux *et al.* (2015, 2016)) and package coatings (e.g., Mastromatteo *et al.*, (2011)) as delivery mechanisms for active compounds for fresh produce applications. More *in vivo* work is critical, as many active packaging studies show *in vitro* effectiveness but fail to prove themselves on a horticultural commodity. Additionally, determining the consumer acceptability of these approaches will be important. The current market is dominated by "clean label" trends, which encourage food manufacturers to avoid ingredients and additives with unnatural-sounding names. Future work could explore how different label descriptions and active compound choices influence consumer purchase decision.

Further, the commercial drip-absorbent pads utilized in this study were ineffective to improve the quality of fresh-cut cantaloupe. Based on the modified humidity packaging principles discussed earlier, this may be due to the pads insufficiently changing the in-package relative humidity to affect microbial loads. However, it may also be reflective of the product, as fresh-cut cantaloupe is an abundantly moist product, which can readily supply moisture to the surface if it begins to dry out. Future work could look to investigate the potential of more potent desiccants and humidity buffers, as well as focusing on products where surface dryness is more isolated from the product interior.

Finally, a major justification for the use of drip-absorbent pads in meats and poultry is that they soak up unsightly liquids, indicating that consumers prefer those liquids out of sight. In fresh-cut produce, work has not been published that investigates how consumers perceive accumulated liquid in fresh or fresh-cut produce packages.

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