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Transit temperatures experienced by fresh-cut leafy greens during cross-country shipment

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A B S T R A C T

There have been very limited time and temperature profiles published for the United States indicating the conditions experienced by fresh-cut, bagged leafy greens during U.S. cold chain transport and distribution. The objective of this study was to monitor and fully characterize truck trailer temperatures during the transport of fresh-cut leafy greens shipped from Salinas, CA and Yuma, AZ, to distribution centers across the United States. A total of sixteen shipments were monitored for trailer temperature from June, 2010 to May, 2011, utilizing trailers provided by multiple major Western processor/shippers. Twenty-four or thirty temperature loggers, total, were placed on six pallets and along the sidewalls during the loading of each trailer. Sensors were placed on pallet stacks at the front, middle and rear of each trailer. Two pallet stacks positioned side-by-side were monitored at each location. Additional sensors were placed 4 feet above the floor on each sidewall adjacent to the monitored stacks. In five of the sixteen shipments, an additional sensor with a probe was placed in each monitored stack at the middle position and the probe was inserted 24 inches into the center of the stack. Data was analyzed for the effect of location within a trailer, on a sidewall, or on or within a pallet; and on a pass/fail basis where *any* sensor in a trailer recording temperatures above 5 °C subjected the entire load to rejection. Analyzing sensor data on a pass/fail basis yielded highly skewed results as the analysis indicated all trailers failed to maintain adequate temperature during transit. However, only 16.7% of the 431 sensors used in the study recorded temperatures greater than 5 °C and nearly twice as many (47) were found on sidewalls than pallets (25). The FDA standard for pre-cut leafy greens appears to overestimate high temperature abuse as it does not consider where the abuse is occurring in a trailer. Cold temperature abuse was less extensive with only 39 of 431 sensors recording temperatures below −0.17 °C. The data suggests that the product was also under-heated in fall as 22 of 39 sensors recording temperatures <−0.17 °C did so during this period. Though the interior was not greatly different in temperature than the exterior of pallet stacks (2.87 vs. 2.09 °C, respectively), the results indicate the importance of proper stacking and good air-flow around boxes of product in a trailer. For some runs, localized freezing of pre-cut greens may have occurred but, overall, the trailer refrigeration units appeared to be efficient though there was large variability in trailer performance. Microbial modeling utilizing *Escherichia coli* O157:H7 and *Listeria monocytogenes* should be conducted based on the cold−abuse profiles generated in this study to determine the potential for the growth of these microbes on pre-cut leafy greens during subsequent retail storage and display.

1. Introduction

Listeria monocytogenes and *Escherichia coli* 0157:H7 can contaminate produce prior to and during postharvest handling (DeNoon, 2011; FDA, 2010; FDA, 2014; 2006a; Johnston et al., 2005). In recent years, these pathogens have been linked to many food-

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borne illnesses involving produce (FDA, 2015; Painter et al., 2013). Since 1993, there have been more than 800 illnesses and 8 deaths attributed to the consumption of leafy greens, particularly spinach and lettuce grown in California (FDA, 2005). *L. monocytogenes* is particularly concerning because of its ubiquitous nature and ability to grow at low refrigerated temperatures (Junttila, Niemelä, & Hirn, 1988; Todar, 2012; Walker, Archer, & Banks, 1990).

L. monocytogenes and *E. coli* 0157:H7 have been implicated in numerous outbreaks and product recalls in the last 10 years. In the summer of 2006 contaminated California-grown, baby flat-leaf spinach caused more than 200 cases of *E. coli* 0157:H7 infection in 28 states, resulting in 3 deaths and 31 confirmed cases of hemolytic uremic syndrome (FDA, 2006b). Additionally, in 2011 cantaloupe contaminated with *L. monocytogenes* caused 147 cases of listeriosis resulting in 33 deaths and one miscarriage (CDC, 2012). There are very few cases of listeriosis caused by *L. monocytogenes* on leafy greens, but since 2010 there have been 8 recalls issued due to possible contamination (Zeng et al., 2014). These recalls indicate a legitimate risk of contaminated leafy greens entering the supply chain and eventually causing a large scale outbreak.

Numerous studies have demonstrated the survival of verotoxigenic *E. coli* at 5.5 and 6.5 °C – the temperature range frequently encountered during commercial transport of many fruits and vegetables when shipped long distances (Abdul-Raouf et al., 1993; Kauppi, Tatini, Harrell, & Feng, 1996; Koseki & Isobe, 2005a). Under these conditions, survival, rather than increases in population, was observed. In contrast, appreciable growth of *E. coli* O157:H7 was reported on leafy greens held at 10 °C or higher (Koseki & Isobe, 2005b) though Abdul-Raouf et al., (1993) found that *E. coli* O157:H7 populations decreased on shredded lettuce when stored for 14 days at 12 °C. Regardless, verotoxigenic *E. coli* has not been observed to proliferate at normal transit temperatures (Abdul-Raouf et al., 1993; Danyluk & Schaffner, 2011; Delaquis, Bach, & Dinu, 2007; Delaquis, Stewart, Cazaux, & Toivonen, 2002; Kauppi et al., 1996; Koseki and Isobe, 2005; McKellar & Delaquis, 2011; McKellar, Leblanc, Lu, & Delaquis, 2012).

L. monocytogenes populations decreased on the surface of shredded lettuce held at 10 °C (Beuchat & Brackett, 1990) indicating that at temperatures below 10 °C, there may be no substantial risk for the growth of *L. monocytogenes* on this product. Previous studies have found growth in fresh-cut produce with the most recent work by O'Beirne et al., 2015 suggesting growth at 7 °C in reduced oxygen atmosphere on fresh-cut Iceberg lettuce (Delaquis et al., 2002; Francis & O'Beirne, 1997; Jacxsens, Devlieghere, Falcato, & Debevere, 1999; Koseki and Isobe, 2005a; Li, Brackett, Chen, & Beuchat, 2002; O'Beirne et al., 2015; Sant'Ana et al., 2012; Sant'Ana et al., 2013). However, *L. monocytogenes* is known to be a psychrotrophic bacterium (Zeng et al., 2014) with estimated minimum growth thresholds, depending on strain, of +1.7 ± 0.5 °C (Junttila et al., 1988), −0.1 to −0.4 °C (Walker et al., 1990) and 1 °C (Todar, 2012).

The shipment of fresh-cut leafy greens by truck trailer requires precise temperature control. If the load is subject to high temperatures, i.e., temperatures above 5 °C (FDA, 2010, 2009), it is subject to rejection at distribution centers or wholesale markets (Chang & Fang, 2007; Kim et al., 2008; Sant'Ana et al., 2012; Sant'Ana et al., 2013; Tromp, Rijgersberg, & Franz, 2010; Van der Linden et al., 2013). Likewise, temperatures below −0.17 °C for lettuce (Cantwell & Suslow, 2013; Hardenburg, Watada, & Yang, 1986) can lead to freezing of the tissues, breakdown and a potential for increased microbial growth. To date, there have been very limited time and temperature profiles published for the United States indicating the conditions experienced by fresh-cut, bagged leafy greens during U.S. cold chain transport and distribution (Zeng et al., 2014). The objective of this study was to monitor and fully characterize truck trailer temperatures during the transport of fresh-cut leafy greens shipped from Salinas, CA and Yuma, AZ, to distribution centers across the United States. Shipments were made over the course of a year to determine the effect of season on trailer temperature. A temperature of 5 °C was selected as the overall upper acceptable temperature during transit (FDA, 2010, 2009). Based on the growth potential for *E. coli* (Koseki and Isobe, 2005a,b), temperatures and durations of exposure above 10 °C were also considered. Since tissue damage to leafy greens may occur if temperatures are too low leading to increased microbial growth, a lower temperature limit of −0.17 °C was also considered as this is just above the freezing point of lettuce (Cantwell & Suslow, 2013; Hardenburg et al., 1986).

2. Materials and methods

Initial runs were made using a satellite-assisted GPS system (Sensor Wireless, Charlottetown, PE, Canada) so that temperatures and truck location could be monitored in real time. The system worked well, and temperatures within the trailers as well as truck locations were easily determined by logging into a central database maintained by Sensor Wireless. However, for the majority of testing, temperatures were recorded using conventional Temptale 4® programmable temperature loggers (Sensitech, Beverly, MA).

2.1. Sensor location during shipment

A total of sixteen shipments were monitored for trailer temperature from June, 2010 to May, 2011, utilizing trailers provided by 2 major Western processor/shippers (Table 1). Mid-spring, summer and fall shipments originated in the Salinas, CA area while winter and early spring shipments originated in Yuma, AZ. Twenty-four or thirty temperature loggers were placed on six pallets and along the sidewalls during the loading of each trailer. The data loggers were set to begin recording 30 min after installation.

Sensors were placed on pallet stacks at the front, middle and rear of each trailer. If the trailer was shipped with a partial load, sensors were placed on pallet stacks at the front, middle and rear of the load. Two pallet stacks positioned side-by-side were monitored at each location. Additional sensors were placed 4 feet above the floor on each sidewall adjacent to the monitored stacks.

Each monitored pallet stack had sensors positioned on the outside of the cartons at three locations: the sensor at the bottom

Table 1
Cross-country shipments: Origin-destination, date of departure and season of shipment for truck trailers leaving Salinas, CA or Yuma, AZ.

Origin – destination	Date	Season[a]
Salinas, CA–Bessemer, NC	June 2, 2010	Spring
Salinas, CA–Springfield, OH	June 2, 2010	Spring
Salinas, CA–Houston, TX	June 16, 2010	Spring
Salinas, CA–Tempe, AZ	June 16, 2010	Spring
Salinas, CA–Bessemer, NC	June 25, 2010	Summer
Salinas, CA–Springfield, OH	June 25, 2010	Summer
Salinas, CA–Springfield, OH	August 23, 2010	Summer
Salinas, CA–Bessemer, NC	August 24, 2010	Summer
Salinas, CA–Tempe, AZ	September 8, 2010	Summer
Salinas, CA–Houston, TX	September 21, 2010	Fall
Salinas, CA–Houston, TX	November 18, 2010	Fall
Yuma, AZ–Bessemer, NC	January 8, 2011	Winter
Yuma, AZ–Springfield, OH	January 8, 2011	Winter
Yuma, AZ–Springfield, OH	January 29, 2011	Winter
Yuma, AZ–Bessemer, NC	January 30, 2011	Winter
Salinas, CA–Bessemer, NC	May 25, 2011	Spring

[a] Spring = March 21 – June 20; summer = June 21 – Sept. 20; Fall = Sept. 21–Dec. 20; winter = Dec 21 – March 20.