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Temperature abuse timing affects the rate of quality deterioration of commercially packaged ready-to-eat baby spinach. Part I: Sensory analysis and selected quality attributes

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ABSTRACT

Temperature abuse of fresh-cut products occurs routinely during transport and retail store display. However, the stage of product shelf life during temperature abuse and its impact on sensory attributes have not been studied. This study evaluated the effect of temperature abuse occurring immediately after processing and late in shelf life through measurements of sensory attributes, and membrane integrity of commercially packaged ready-to-eat baby spinach. The packaged products were received within 2 days of processing. Samples subject to early temperature abuse were immediately placed at 1, 4, 8, 12, 16 and 20 °C storage upon arrival, and those subject to late temperature abuse were stored at 1 °C for six days, and then transferred to 4, 8, 12, 16 and 20 °C storage. Package headspace gas composition, in-package visual appeal, purchase intent, product color, off-odor, decay, texture, overall quality, and tissue electrolyte leakage were evaluated every 1–2 day up to 16 day total. Results indicate that when the product temperature is maintained at 1–4 °C, the quality of commercially packaged baby spinach can be retained for up to 18 days post-processing. However, storage temperature of 8 °C or above, significantly ($P < 0.001$) shortened product shelf life as exhibited by accelerated tissue electrolyte leakage, product yellowing, decay and off-odor development. Most importantly, the product's shelf life stage significantly affected its response to temperature. Quality deterioration proceeded more rapidly when temperature abuse occurred in late as opposed to early shelf life stage.

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1. Introduction

Consumers have become more health conscious and actively demand ready-to-eat, nutritious packaged minimally processed vegetables. However, tissue injuries sustained during fresh-cut processing promote faster physiological deterioration, induces undesirable biochemical changes in the product, and facilitate microbial proliferation. Spinach is an annual cool season crop and commonly grows in temperate areas. Baby spinach leaves contain relatively high levels of bioactive compounds such as vitamin C, vitamin A and minerals (Pandrangi and Laborde, 2004). Similar to other fresh-cut vegetables, although not cut, the washing, drying/dewatering, and packaging steps involved in the preparation of packaged "ready-to-eat" baby spinach stimulate tissue deterioration. Major defects reported for packaged baby spinach leaves are the development of unpleasant odors, decay, discoloration, and loss of turgor (Medina et al., 2012; Tudela et al., 2013; Watada and Qi, 1999; Wang, 2003).

Temperature management is often the most effective way to delay deterioration and maintain the quality of fresh-cut fruits and vegetables (Jacxsens et al., 2002; Luo et al., 2009). Many studies have shown that lowering the storage temperature can significantly reduce the growth of spoilage microorganisms and delay the physiological deterioration of plant tissues (Jacxsens et al., 2002; Luo et al., 2009; Smyth et al., 1998). Enriquez et al. (2000) observed that lower temperatures were effective in decreasing Malabar spinach yellowing, ascorbic acid loss and respiration rate. Pandrangi and Laborde (2004) reported that spinach color and appearance became unacceptable after 8, 6, and 4 d at 4, 10, and 20 °C, respectively. Luo

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et al. (2009) observed that product quality scores for commercially packaged baby spinach held at 12 °C remained high for the first 6 d of storage and then declined sharply by d 9. Processors recommend that fresh-cut vegetables be stored at 1–3 °C to maintain product quality for maximal shelf life.

Low temperature should theoretically be maintained throughout product distribution, retail and home use (Kader, 2002; Willocx et al., 1994). However, the distribution chain rarely has the facilities to store each commodity under optimal conditions and requires compromises about choices for storage temperature. In reality, suboptimal temperature exposure occurs frequently during fresh-cut product distribution and in retail display cases (Koseki and Isobe, 2005). In the United States, 20% of domestic and commercial refrigerators operate at a temperature of >10 °C (50 °F) (Jol et al., 2006). A survey of processed vegetables in Belgian retail display cabinets also showed that there are more than 5 °C temperature differences in the decks of retail display cabinets (Willocx et al., 1994). In France, 50% of the domestic and 32% of the commercial refrigerators had temperatures greater than or equal to 9 °C (Taoukis et al., 2005).

Traditionally, "first-in-first-out" for intact fruits and vegetables, and "best if used by date" have been used for inventory management of fresh and fresh-cut produce. Increased understanding of the important impact of temperature abuse on product quality deterioration has led to the development and application of time and temperature based inventory management software programs, and end user oriented time temperature indicators/integrators (TTI) for fresh and fresh-cut produce. However, almost all of these technologies available today were developed based on a model which tracks the time lapse for which storage temperature exceeds the threshold temperature and overlook the confounding factor of produce shelf life stage on their response to temperature abuse (Bobelyn et al., 2006; Taoukis et al., 1999). Although no specific scientific information are available documenting such impact, a number of studies have shown that a product's shelf life stage or physiological condition significantly affects its response to environmental stressors (Arora et al., 2002; Zhou et al., 2004; Pandrangi and Laborde, 2004; Francis and O'Beirne, 2001). Therefore, the objective of this study was to evaluate the effects of temperature variations occurring at different stages of product storage life on the changes in sensory quality of packaged baby spinach over time. Data obtained will provide pertinent information to the industry on how to factor shelf life stage into the development of inventory management systems and thus further improve the accuracy and usefulness of these systems for perishable fresh and fresh-cut produce.

2. Materials and methods

2.1. Sample and storage facility

Commercially packaged baby spinach (70 cases = 420 bags) was obtained from Dole Fresh Vegetables, Inc. (Bessemer City, North Carolina, USA). Spinach leaves were machine harvested, cooled to below 5 °C within 4 h, triple washed, and packaged in laser-perforated bags. Biological variation between packages of baby spinach was minimized by obtaining product processed from the same line and shift. The samples were transported by a commercial refrigerated truck (2–4 °C) to the Food Quality Laboratory (Beltsville, MD), and were immediately sorted and labeled at 1 °C and then placed at their assigned temperature storage. Prior to arrival of the samples, cold rooms were equilibrated at the assigned temperatures. Data loggers were used to record the temperature in each room every 5 min during the 16 d storage period (Log Tag temperature recorder, TRIX-8, MicroDAQ.com, Ltd., Contoocook, NH, USA).

2.2. Temperature abuse 2 days (early stage) and 8 days (late stage) post-processing

In order to simulate temperature abuse occurring at early stage post-processing, on arrival day (d 0), five replicate bags of packaged baby spinach were placed in cold storage rooms with temperatures maintained at 1, 4, 8, 12, 16 and 20 °C. The samples were evaluated on d 0, 1, 2, 4, 6, 8, 10, 12, 14 and 16. Late stage temperature abuse was modeled by storing bags at 1 °C for 6 d, and then transferring them to 4, 8, 12, 16 and 20 °C storage. The evaluations were performed for these samples on d 6, 7, 8, 9, 10, 12, 14 and 16. The evaluation was discontinued when either scores for purchase intent or visual quality declined to 40 or below (out of 100), or off-odor reached or exceeded 60 (out of 100), or the overall quality fell below 50 (out of 100), as these values indicated that the product was no longer marketable (López-Gálvez et al., 1996; Zhou et al., 2004).

2.3. Analysis of packaging headspace composition

The package atmospheres were measured immediately upon removal of the samples from storage. The O_2 and CO_2 concentrations of the samples were analyzed using a gas analyzer (Check mate II, PBI Dansensor Co., Denmark) by inserting the needle of the measuring assembly through a septum adhered to the packaging film.

2.4. Sensory attributes

Sensory attributes of baby spinach leaves were evaluated at the Food Quality Laboratory Sensory Facility consisting of ten individually partitioned booths equipped with individual computers. The products were evaluated with a trained five member sensory panel. Prior to the evaluation, training sessions were provided for the panelists on scoring the quality attributes. For decay scores, the decayed samples from preliminary studies were grouped by the panelists based on severity and extent of decay. The samples were photographed and the sample images and the scores were used for additional panel training. All quality attributes were rated using unstructured 100-mm scales. On-screen ballots were prepared and data were collected using Compusense Five program (Version 5.4) (Compusense Inc., Guelph, Canada). The sealed sample bags were coded with random 3-digit numbers and presented to the panelist for the evaluation of 'visual appeal' and 'purchase intent'. Visual appeal was rated from poor (0) to excellent (100) based on the product appearance viewed from the non-printed areas of the package film. Purchasing intent was rated from definitely would not buy (0) to definitely would buy (100). Baby spinach leaves were then transferred to sampling trays (20–25 g per tray) and panelists evaluated the off odor, decay extent, texture, and overall quality. The off-odor was determined by smelling the product on the tray, and assigned a rating from none (0) to very strong (100). Decay was examined based on the severity and prevalence of decayed leaves according to a pre-determined scale; none (0) to severe (100). Texture was evaluated by folding and breaking over 10% of the leaves using fingers and rated from flaccid (0) to very crisp (100). Overall quality was rated from poor (0) to excellent (100), following a similar procedure by Saftner et al. (2002). The acceptable or marketable range for visual quality, purchase intent and overall quality was considered to be a score of 60 or above, while an off-odor and decay score of 40 or below was considered to be acceptable.

2.5. Color assessment

Each sample was composed of approximately 35 g of baby spinach leaves that were placed on a white tray (17 cm × 13.5 cm × 3 cm) and color coordinates (L^*, a^*, b^*) were