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A novel approach to determine the impact level of each step along the supply chain on strawberry quality

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ABSTRACT

Strawberries are among the most frequently wasted fruits because of their high perishability and handling requirements. Loss of quality begins at the farm and accumulates throughout the supply chain. There is a lack of information regarding the level of impact of each step along the supply chain on strawberry quality, and on how to prioritize actions along the supply chain to achieve an immediate and effective impact on waste reduction. The objectives of this study were to determine the impact level of each step along the supply chain, from the farm to the consumer, on the quality of strawberries, and to identify critical supply chain steps where the decline in strawberry quality was highest. To quantify the impact level of each step of the supply chain on strawberry quality, a control at constant optimum conditions (1 °C and 90% RH) plus 16 time-temperature supply chain scenarios were conducted simultaneously. Sensory quality was determined subjectively, and color, texture, weight loss, acidity, soluble solids, anthocyanins, sugars, and ascorbic acid contents were determined by quantitative analysis. Results from this study showed that maintaining constant optimum temperature throughout the supply chain is paramount to reducing losses in strawberry quality, particularly in appearance, texture, weight loss, sugars, and bioactive compounds. Non-optimum conditions such as storage at the grower at 5 °C, shipping to the stores at 8 °C and storage at the consumer level at 20 °C had the greatest impact on strawberry overall quality, in comparison to maintaining optimum conditions, and were considered critical supply chains steps.

1. Introduction

Food is a valuable resource, and yet around the world, a vast amount that could have been eaten is wasted every year. Fresh fruits and vegetables (FFV) are amongst the most frequently wasted foods because of their high perishability and postharvest handling requirements and because their appearance quality is often over-emphasized (Kader, 2005; WRAP, 2008; Parfitt et al., 2010; Gustavsson et al., 2011; WRAP, 2011; Gunders, 2012; Porat et al., 2018). It is estimated that in developed countries, loss and waste of FFV can be as high as 50% (Kantor et al., 1997; Kader, 2005; Buzby et al., 2011; Gunders, 2012;). Specifically, at the farm level, waste can be as high as 20% whereas postharvest waste is estimated to be 3%; at the retail and consumer levels, waste increase to 12 and 28%, respectively (Kantor et al., 1997; Kader, 2005; Gunders, 2012). Many factors contribute to the substantial waste of FFV throughout the supply chain. At the farm level, entire crop production can be rejected or never harvested, due to diseases, pests and weather, overproduction, or simply because the product does not meet the quality standards (Kantor et al., 1997; Buzby et al., 2011; Gunders, 2012; Fox and Fimeche, 2013). During postharvest, waste occurs during sorting, handling, storage, and distribution. Poor temperature management often encountered during storage, handling and distribution is one of the major causes of FFV deterioration in appearance and nutritional value (Nunes et al., 1995a, b; Nunes and Emond, 1999; Nunes et al., 2003, 2005a; Nunes et al., 2006, 2009; Lai et al., 2011; Nunes et al., 2011; Pelletier et al., 2011). Others have also reported that poor temperature management may cause FFV waste ranging from 25 to 50% (Harvey, 1978; Rippon, 1980; Desai and Salunkhe, 1991). Besides, current refrigeration systems in produce departments often are set to desired temperatures, but the actual temperatures inside the display may vary depending on the location of the load and loading charge (LeBlanc et al., 1996; Nunes et al., 1999; Villeneuve et al., 2002; Nunes et al., 2009, 2011). Finally, it was estimated that at the consumer level 1.2 billion kg of FFV are stored at ambient temperatures whereas they should be stored in the refrigerator (WRAP, 2008; Porat et al., 2018).

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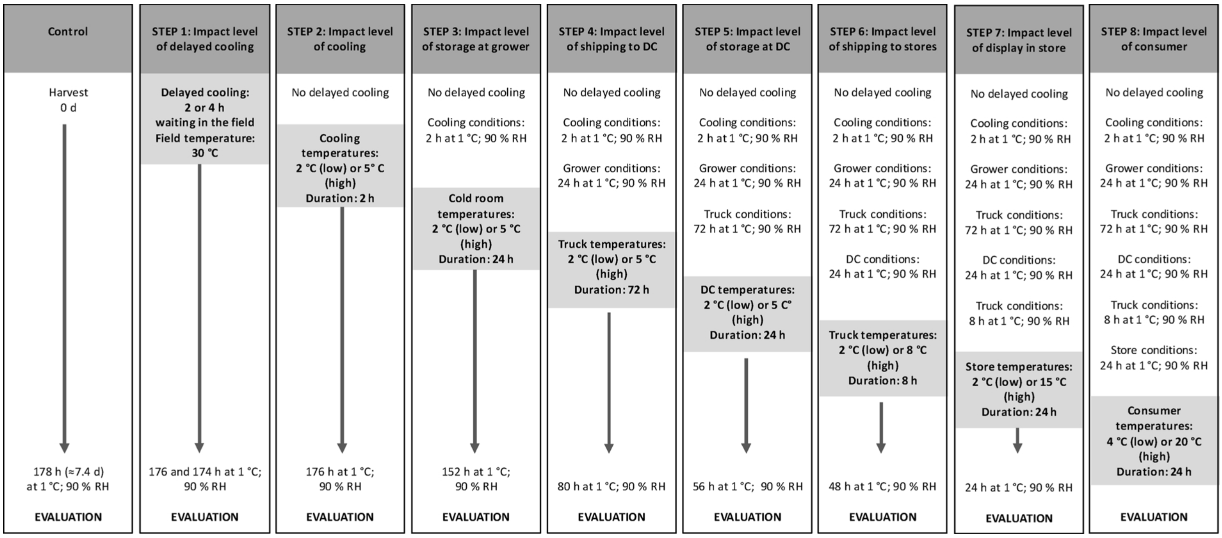

Fig. 1. Strawberry supply chain simulations from the field (step 1) to the consumer (step 8). Each section represents a supply chain step, and within each step, a best and worst time-temperature scenario was tested. (DC) distribution center.

Due to their perishable nature and mishandling, strawberries are one of the fruits most often discarded throughout the supply chain (Legard et al., 2000; WRAP, 2008; Buzby et al., 2009; Nunes et al., 2009; Muth et al., 2011; WRAP, 2011). Among the environmental factors that significantly affect strawberry quality, temperature has the greatest impact on fruit quality and shelf life (Collins and Perkins-Veazie, 1993; Kalt et al., 1993; Nunes, 2008). Delays before cooling, inadequate pre-cooling and abuse or fluctuating temperatures during storage and distribution combined with long transit times inevitably occur in commercial handling and reduce the quality and maximum potential shelf life of strawberries (Nunes and Emond, 1999; Ayala-Zavala et al., 2004; Lai et al., 2011). More specifically, at the farm, strawberry waste range from 2 to 20% due to misshaped or undersized fruit; handling and storage at the grower account for 0.5 to 3% of the waste and, at the retail level, waste may range from 2 to 10%, mainly due to insufficient temperature control, inappropriate stacking and inaccurate sales forecasting (Buzby et al., 2009; Gustavsson and Stage, 2011; WRAP, 2011). It was also estimated that waste at the retail and consumer levels combined could be as high as 28% (Buzby et al., 2011). At the retail level, approximately 2 to 10% of the strawberries are considered unacceptable for sale and are wasted (Buzby et al., 2009; Nunes et al., 2009; Gustavsson and Stage, 2011; WRAP, 2011) and, at the consumer level, strawberry waste can be as high as 35% (Muth et al., 2011), due to poor quality at the time of purchase (Nunes et al., 2009) or due to improper storage conditions at home (WRAP, 2008; Porat et al., 2018).

Although some studies have shown that strawberry quality deterioration and waste begins at the farm and accumulates throughout the supply chain, there is no information available regarding the impact of each step along the supply chain on strawberry quality, and on how to prioritize actions along the supply chain to achieve an immediate and effective impact on waste reduction. Therefore, the objectives of this study were to determine the impact level of each step along the supply chain, from the farm to the consumer, on the quality of strawberries, and to identify critical supply chain steps where the decline in strawberry quality was highest.

2. Material and methods

2.1. Plant material and experimental setup

'Florida Radiance' strawberries were harvested two times during the 2016 production season, on February 23 and March 15, from commercial fields in Plant City, Florida, USA. The cultivar 'Florida Radiance' (known as 'Florida Fortuna' outside the USA.) was chosen because it is the leading strawberry cultivar grown in central Florida (Wu et al., 2015; Whitaker et al., 2016). Eight flats of strawberries (i.e., a total of 96 clamshells containing approximately 0.453 kg of fruit each; total fruit weight ≈ 43 kg) were brought to the USF-Food Quality Laboratory in Tampa, Florida, USA, within approximately one hour of harvest. Immediately upon arrival, a total of 1575 strawberries were randomly selected from the initial sample for uniformity of color and freedom from defects. Forty-five of this fruit was used for initial quality evaluations. Three replicate samples of 15 fruit each per treatment (control plus 16 supply chain conditions) were carefully distributed to three clamshells (capacity ≈ 0.453 kg) and used for non-destructive analysis (i.e., subjective appearance and weight loss). For destructive analysis (color and texture analysis, and chemical analysis), three replicate samples of 15 fruit each per treatment (control plus 16 supply chain conditions) were carefully distributed to three clamshells (capacity ≈ 0.453 kg). The clamshells containing the fruit for both non-destructive and destructive quality evaluations were then stored for specific periods of time inside temperature and humidity-controlled chambers (Forma Environmental Chambers Model 3940 Series, Thermo Electron Corporation, OH, USA) set at 1.0 ± 0.3 °C, 2.0 ± 0.3 °C, 4.0 ± 0.2 °C, 5.0 ± 0.2 °C, 8.0 ± 0.1 °C, 15.0 ± 0.2 °C, 20.0 ± 0.3 °C and 30.0 ± 0.3 °C and 80 to 90% RH (Fig. 1). Quality of the fruit was evaluated, at each step individually, after a total supply chain length of 178 h (≈ 7.4 d). The total time (178 h) was chosen based on a typical supply chain for strawberry: harvest → cooling → storage at grower → transport from grower to distribution center (DC) → storage at DC → transport from DC to stores → display at the store → purchase by consumer and storage at home.

Simulated supply chain conditions within each step were selected based on time-temperature profiles previously measured during strawberry handling (Nunes et al., 2009; Lai et al., 2011; Pelletier et al., 2011). For each supply chain simulation, only one step differed from the control, and before and after each of those different time-temperature treatments, the strawberries were kept at constant optimum conditions (i.e., 1 °C and 90% RH) (Fig. 1). Strawberry optimum storage conditions (1.0 °C and 90% RH) were selected based on data from Mitcham (2014) and Nunes (2008). Cooling delays (2 or 4 h) and field temperatures (30 °C) were selected based on data from Nunes et al. (1995a) and on the average field temperatures measured in Florida between January and March (https://fawn.ifas.ufl.edu/). Pre-cooling times and temperatures (2 or 5 °C for 2 h), storage at the grower's