Effects of Laser Labeling on the Quality of Tangerines during Storage

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Etching the required information on fruit and vegetables is an alternative means to label produce. A low energy CO₂ laser beam etches the surface with alphanumerical characters showing the contrasting underlying layer. These etched surfaces can promote water loss and potentially allow pathogen entry. Studies were conducted to measure water loss, peel appearance, and potential decay in laser labeled tangerine (Citrus reticulata) during storage. Laser labeled fruit stored at 10 °C and two different relative humidities (RH) (95% and 65%) for 5 weeks showed no increase in decay compared to control non-etched fruit, suggesting that laser labeling does not facilitate decay. These observations were confirmed by experiments where a suspension of Penicillium digitatum spores was applied on fruit surfaces before and after etching. No decay was observed in either case. Laser etching of agar plates covered in Penicillium digitatum spores reduced germination at the lasered areas. Water loss from etched areas and label appearance were determined during storage. Water loss leveled off after one day in storage and appearance deteriorated proportional to laser exposure times and ambient relative humidity.

Citrus is the major fruit crop of Florida. The state contributes with nearly 58% of all U.S. tangerine production, 78% of which goes to the fresh market. With the possibility of bioterrorism and other economic concerns, labeling of fresh market produce has become increasingly relevant in the last few years. In addition to making “check-out” easier, labeling helps with the tracking and traceability of the produce. Laser labeling is emerging as an alternative to traditional stickers/adhesive labels. With this method, a low energy CO₂ beam creates pinhole depressions into the product surface that forms the alphanumeric label information (Drouilliard and Rowland, 1997). However, these pinhole depressions disrupt the protective barrier of the produce and can potentially become entry sites for decay organisms and sites for enhanced water loss, despite the significant amounts of wax and lignin deposited by surrounding and underlying cells (Etxeberria et al., 2006). Little information is available on the impact of this new technology on the overall quality of the labeled produce, especially its effect on water loss and decay during storage. The present study investigates the effects of laser labeling on the quality of tangerine (Citrus reticulata Blanco) during storage. We conclude that: A) laser labeling does not enhance decay and B) the negative effects of water loss are minimal and can be diminished by a second wax application.

Materials and Methods

PLANT MATERIAL. Tangerine (Citrus reticulata Blanco) fruit was purchased from Haines City CGA, Haines City, FL, after commercial washing and waxing. Fruit was labeled using a low energy CO₂ laser etching machine (Model XY Mark 10, Sunkist Growers Inc., Fontana, Calif.) at the Citrus Research and Education center in Lake Alfred as described earlier (Etxeberria et al., 2006).

EXPOSURE TIME SELECTION. A label code “M1” was etched on fruit surfaces using 18 different exposure times corresponding to 30 µs to 140 µs label duration (Etxeberria et al., 2006). The energy level used was the recommended 0.000752 W/dot. To enhance resolution, labels were dyed with fruit-based black color. Five replicates per exposure time were used. Images of the dyed label were taken using a Canon Powershot S31S digital camera mounted on a Wild Heerbrugg 165083 stereoscope. Surface area altered by the label was measured using image processing software. Total area was calculated based on number of pixels within the area covered by the laser depressions with 1 pixel corresponding to 50 µm².

WATER LOSS MEASUREMENTS. Water loss from the fruit surface was measured using a modified leaf porometer (Decagon Devices, Pullman, WA). To estimate water loss as a function of exposure time, an etched rectangle of 7 × 8 dots matrix pattern was used for each of four exposure times, namely low (35 µs), medium (85 µs), and high (120 µs). The modified leaf porometer was placed on the top of the treated area immediately after etching until a stable reading was obtained.

Water vapor diffusion from fruit and vegetables was calculated using Eq. 1 based on Fick’s law where “water vapor flux density” or “evaporation rate” is the product of vapor conductance (gv) and the difference between vapor concentration at the evaporating surface (Cva) and water vapor concentration in atmosphere (Cvs). Values are expressed as mmol·m⁻²·s⁻¹. The modified leaf porometer estimates the value for water vapor conductance (gv) which can be computed in the equation below to obtain “evaporation rate.”
\[ F = g v (Cv_s - Cva) \]  
\[ (Eq. 1) \]

Vapor concentration was calculated using Eq. 2, where \( e_a \) is the vapor pressure (kPa) which is a function of temperature, and \( p_a \) is the atmospheric pressure (kPa) (information courtesy of Dr. Doug Cobos, Decagon Devices, Inc., Pullman, WA).

\[ C = \frac{e_a}{p_a} \]  
\[ (Eq. 2) \]

**Effect of waxes on water loss from labeled areas.** Nine different commercial waxes were tested for moisture loss reduction from the labeled area. Fruit were labeled using a single exposure time (45 \( \mu \)s) and wax applied using a painter’s brush. Evaporation rate measurements of the labeled surface were determined before and after waxing along with control (no label on fruit). Each experiment was replicated 30 times. The second part of the experiment followed water loss from the waxed etched area during storage. Half of the total number of etched rectangles (2 rectangles per 30 fruit) were waxed with one of the waxes tested (highest reduction in water loss) and kept at 10 °C and 95% RH for 7 d. Daily measurements of evaporation rate of the waxed label, unwaxed label, and control (no label on fruit) were carried out with the porometer.

**Peel Stability.** The label “Florida citrus” was etched on the fruit using four exposure times (35 \( \mu \)s, 45 \( \mu \)s, 85 \( \mu \)s, and 120 \( \mu \)s), and fruit kept at 10 °C at two different relative humidity levels (i.e., 65% and 95% RH) for 4 weeks. Five replicates (1 replicate = 1 box = 60 fruit) per exposure time and control (non-labeled fruit) were used. Weekly examination of the label appearance and surrounding area was done. Peel stability was determined on the basis of a visual rating scale according to the shrinkage of the skin around label as follows: 0 (no shrinkage), 1 (very low), 2 (low), 3 (medium), 4 (high), and 5 (very high) (Fig. 1). For better visualization, we show the scale using grapefruit.

**Decay Study.** Fruit were labeled using the commercially suggested exposure time (45 \( \mu \)s) and stored for 5 weeks at 10 °C and 95% RH. Five replicates of labeled and control (non-labeled fruit) (1 replicate = 1 box = 60 fruit) were used. Fruit were examined weekly for decay.

**Inoculation Study.** Experimental areas on the fruit were subjected to four treatments. The four treatments were: 1) inoculation of fruit prior to labeling, 2) inoculation after labeling, 3) inoculation on waxed label, and 4) waxing of inoculated label. A spore suspension of *Penicillium digitatum* Link \( (10^5/mL) \) was used as inoculum. Inoculation was carried out by applying a thin layer of spore suspension over the experimental areas using a painter’s brush. Inoculated fruit was stored at 10 °C and 95% RH for 3 weeks and examined for decay weekly. Labeling was done using one exposure time (45 \( \mu \)s). Thirty replicates consisting of one fruit each were used for all four treatments.

In a separate experiment, *Penicillium* spore suspension was spread on potato dextrose agar plates (BD/Difco, Sparks, MD). The plates were laser labeled and observed under the microscope immediately and 72 h after labeling. Each experiment was repeated five times.

**Results and Discussion**

The visual effect of increasing laser labeling exposure time on tangerine peel is shown in Fig. 2. At the lowest possible exposure time of 30 \( \mu \)s, the label was faint and hardly visible, whereas at the highest exposure times, the etch markings merged into solid lines. Calculations of laser etched surface area were done using image processing software. In general, the area covered by the etched markings increased with increase in exposure time (Fig. 3). The rate of peel surface area disruption declined at higher exposure times as etch markings began to merge. Etched markings created with 45-\( \mu \)s exposure time were selected as the best on the basis of visual appearance and area covered. This exposure time (45 \( \mu \)s) creates less surface disruption while generating a readable code. However, from Figs. 2 and 3, higher exposure times create darker labels without significantly increasing peel disruption.

![Fig. 2. A group photograph of labels etched using increasing exposure times.](image)

![Fig. 3. Surface area covered by 100 dots etched with exposure times ranging from 30 \( \mu \)s to 140 \( \mu \)s. Each point represents an average of five replicates. Vertical lines represent SE.](image)
**WATER LOSS MEASUREMENTS.** Moisture content is one of the important factors determining the marketable quality of produce. Fruit and vegetables start losing moisture immediately after harvest (Yehoshua and Rodov, 2002). However, laser-generated etched markings are physical pinholes penetrating through the cuticle and into the epidermis rendering the produce surface more susceptible to water loss than un-etched surfaces. There was a sharp increase in the rate of water loss between the 35- and 45-µs exposure times (Fig. 4). The difference in the rate of water loss was less pronounced at higher exposure times.

**Effect of waxes on water retardation of labeled area.** Natural waxes on the epidermis play a vital role in retaining moisture in fruit and vegetables (Kader, 2002). The openings created by laser labeling disrupt the natural waxy coating on the surface of produce. In this experiment, all nine commercial waxes that were applied helped in reducing water loss by sealing the etched area. However, significant differences in the capability of these waxes to prevent water loss were observed. Among all waxes, three reduced water loss by >80%, with Carnauba 505 resulting in the highest protection (86% reduction in water loss) (Fig. 5).

Rate of water loss from unwaxed labeled areas declined with time of storage. There was a sharp decline in the rate of water loss 24 h after labeling, which continued to decrease before reaching a constant value (Fig. 6). Water loss from waxed labeled (using Carnuba 505) areas was nearly equal to control unlabeled areas, which confirms the importance and necessity of waxing the fruit after labeling.

**Peel stability.** The rate of water loss from fruit depends upon the vapor pressure deficit between the commodity and surrounding air, which is influenced by temperature and relative humidity. Relative humidity has a direct effect on rate of moisture loss from produce (Forbes and Watson, 1992). Fruits are commonly stored at ≥90% RH (Nuñes, 2007). In the present study, at both 95% and 65% RH, some labels began to show low levels of shrinkage within a week (Figs. 7 and 8). Degree and percent fruit showing visible signs of shrinkage on the label increased with storage time,
exposure time (data not shown), and was inversely proportional to RH. However, even at the end of 5 weeks, labeled fruit peel at 95% RH had minimal shrinkage.

**DEcay Study.** Citrus fruits are relatively non-perishable and can be stored for long periods. Tangerine, in general, can be stored at 5 to 8 °C at 90% to 95% RH for 2–6 weeks (Arpaia and Kader, 2006). Decay of citrus fruit in storage is one of the major factors responsible for postharvest losses. Citrus fruits in storage are vulnerable to various decay organisms such as fungi (e.g., *Penicillium* spp.) and bacteria (Kader, 2002). Laser labeled fruit held at 10 °C and 95% RH conditions showed no decay around etched area (Fig. 9). All decay during the storage period was independent from the labeled areas, the most common being stem end rot. In the present study, decay rate of the fruits labeled with all the four exposure times were similar to the control (non-labeled fruit) which confirms that etching does not enhance decay (Fig. 9). These results are in accordance with those of Yuk et al. (2007) where laser labeling did not facilitate *Salmonella* infiltration and survival in tomato.

In a separate experiment, fruit were inoculated before and after laser labeling with a suspension of *P. digitatum* (10⁵/mL). In fruit inoculated prior to and after labeling, no symptoms of decay appeared after 3 weeks in storage. When inoculated plates were viewed under the microscope, laser labeling appeared to prevent spore germination as indicated by the lack of fungal growth at the points of laser impact (Fig. 10A). The laser also destroyed mycelial strands after germination as demonstrated in Fig. 10B.

The results obtained in the present study demonstrate that the epidermal openings created by the laser labeling do not promote decay in tangerines, as no decay symptoms associated with the laser etched area were observed. In fact, laser labeling appeared to prevent mold decay. Analysis of the data allows us to estimate an optimum exposure time that produces readable labels with minimal water loss (Fig. 11). For tangerines, a label using 45-65 µs exposure times is optimal. It is important that labels are protected with a wax coat to control water loss, or significant label collapse may occur.

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**Literature Cited**


