# Emerging Postharvest Technologies

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**Abstract**

**Over the last decade, the fruit quality concept has evolved from a large bright red color to a flavorful, healthy, ‘ready-to-eat’, ‘easy-to-eat’, and safe fruit with high consumer acceptance. Current consumer preferences, hand labor costs, fruit prices, human safety concerns, and global markets have been forcing changes in the production and delivery of fresh fruit. Immediately after harvest, fruits begin to senesce, deteriorate and postharvest losses occur. As part of the fruit senescence process, commodities start to lose weight, firmness, flavor, and become more susceptible to cold storage stresses. Temperature and other environmental factors surrounding commodities control the biological processes associated with fruit senescence and deterioration. Breeding efforts using new genetic tools are now used to develop fruit that ripen uniformly in the canopy with diverse predominant visual, shape, flavor, and texture attributes; and physiological traits at ripening adapted to minimally processed fruit. Because of recent advances in new nondestructive sensor technology and the long-term lack of flavor in the market, there is high interest in using nondestructive sensors to segregate fruit in the packing line according to their postharvest/shelf life potential and consumer acceptance. However, consumers should be willing to pay a premium to justify the extra cost of using any new nondestructive sensor technology.**

## INTRODUCTION

This article describes cutting-edge postharvest technology information on current produce trends such as, improving automation, packaging, mechanical harvesting, ‘super fruit’, postharvest treatments to prepare fruit for consumers’ satisfaction and protect fruit during delivery to consumers. The use of this new technology should contribute to the increase of the relative competitiveness and productivity by enhancing the quality of agricultural products on a local, national and global basis.

## THE NEED FOR AVAILABLE TECHNOLOGY

New innovative technologies that can be applied to agriculture processes have developed very fast and many feasible opportunities are currently available. However, nondestructive sensors, mechanical harvesters, robotics, super fruit, or new postharvest technologies will not be adopted by the industry until the market pressures and/or regulations justify the changes, training, and cost involved in the establishment, adaptation, and use of these new technologies. A recent example that illustrated this point is the Clementine citrus specifically the W. Murcott’s situation in California. These citrus types are promoted as easy to peel, sweet and seedless. W. Murcott clementine does not produce seeds when grown away from other citrus (Valencias, lemons, etc.). This was the situation in the early years of this industry, but recently the dramatic increases in acreage has increased ambient pollen contaminating W. Murcott. This cross pollen contamination has become a problem as it produces seeds in the W. Murcotts. One recent practice is the use of netting covering all trees during the pollination period to avoid bees carrying pollen from pollinizing Clementine flowers and producing fruit with seeds.

## THE CONVENTIONAL BREEDING APPROACH

Another solution to this Clementine seed problem was using the conventional breeding approach. A new cultivar, a mutation of the successful commercial W. Murcott cultivar ('Tango') was created by irradiation treatment in the UC Riverside breeding program. 'Tango' produces none or very few seeds per fruit even growing under high pollen contamination pressure conditions. This approach cost is safer and cheaper than using the net.

## THE GENOMICS APPROACH

Genomic tools such as Marker-Assisted Selection (MAS) are supporting development of high quality cultivars. The recent releases of fruit genome sequences and the availability of tools and protocols such as the genome-wide, microarrays, transcriptome Mapping, MapMan platform are all aiding breeding efforts. This genomic information is also of great help in studying new insights into ripening physiology, physiological disorders, regulatory mechanisms and secondary metabolic pathways activated during fruit postharvest life.

## POSTHARVEST TECHNOLOGY

Domestic Transportation (truck): In the USA, some supermarket chains are requesting the transport of soft peaches at the 'ready-to-eat' stage (0.09-0.18 kg-force), thus, changes in packaging have been suggested for peaches. Among these changes, a suspended tray (Hammock) that was designed to allow soft ripe pears to be shipped and displayed at retail with minimal mechanical damage is being tested. During transport vibration damage is prevented because the fruit is held firmly in the steeply sloping walls of the deep suspended tray preventing relative motion between the fruit and container walls or neighboring fruit. However, less fruit weight per volume is packed in the "Hammock tray". Commercial performance of this suspended tray pack was evaluated by shipping full pallet loads of white and yellow peaches at different ripening stages and packaging using different boxes and trays including the Hammock tray. Fruit was transported using a truck with an air suspended shock absorber from Reedley, California to a distribution center in Atlanta, Georgia (3 days) and then to Gainesville, Florida for retail display consumer evaluations. During this 3-day journey, fruit temperature was maintained well during transportation close to the original 0°C setting air delivery point. Detailed inspection, at the distribution center, indicated that bruising and weight loss levels were low in overly-soft fruit across all packaging systems. In consumer evaluations on a normal rotation with properly stored fruit; packaging did not affect consumer visual or flavor perception. However, in a slow rotation with mishandled fruit, appearance scored slightly higher only for soft white flesh peaches packed in a hammock versus a standard tray. Thus, it was not necessary to promote this Hammock tray technology for yellow flesh peaches as there were no economic benefits to support the investment.

## ASSURING GOOD ARRIVAL TEMPERATURE FOR THE TREE FRUIT INDUSTRY AFTER OVERSEAS SHIPPING

In some export markets, "in-transit cold temperature protocol" is required as a quarantine treatment. This involves maintaining fresh fruit at a given temperature per a given period. Currently, in-transit cold treatment is enforced for tree fruit exported to New Zealand. Unfortunately, most of our fruit temperatures in container shipments are not meeting the in-transit cold temperature requirement. A large fruit and air temperature variability was observed inside containers for international transport in which fruit temperature was higher than the set-point suggesting that different rates of deterioration may occur as a consequence of this container temperature variability (Rodriguez-Bermejo et al., 2007). Therefore, tree fruit is being fumigated with methyl bromide at arrival, which involves an extra cost and reduces storage and shelf life of our fruit. Besides fulfilling the quarantine requirements, it is well established that the way to maximize the storage and shelf life of perishable products is to hold them at the lowest possible temperature that can be tolerated by that fruit type. Furthermore, in an earlier work we established that stone fruit exposed to the "Killing Zone" temperature range of 2-6°C has a shorter market life (Crisosto et al., 1999). Traditionally, in marine containers, cooled air is supplied to fruit from the bottom of the container throughout boxes to the top of the container. The success of this bottom air delivery system depends on the load pattern, box type and other factors and in some cases is not able to maintain flesh temperature. A promising improved system named Directed Airflow (DAF) distributed by Stopak, in which air is cold delivered, has been successfully tested in the Republic of South Africa (Dodd and Worthington-Smith, 2006; Dodd, 2013). The objective of this study was to investigate flesh temperature during a simulated overseas transportation in a container using DAF.

Currently, APHIS is evaluating temperature gradients of fruits during transport by means of temperature monitoring at three different locations. When agricultural commodities are transported from the USA to New Zealand, APHIS has established quarantine periods of 10, 11 or 12 days. In these periods, temperature gradients cannot be higher than 0.0, 0.5 and 1.1°C, respectively. Thus, our sensors were placed in the same location within the container as required by APHIS. A modified 40 foot marine container using the DAF kits (Stopak) was installed at the Kearney Agricultural Research and Extension Center and loaded with 18 pallets. Nectarines packed in volume filled shoe boxes on a 1×1.2 m pallet were used for this test. For this experiment, the external sensors were the TMC1-HD and TCM6-HA temperature probes. Accuracy and resolution varied according to attached logger model ranging from -40 to 100°C in air. According to the USDA technical requirements, two data loggers were located in pallet #16. The probe #1 was placed at the middle of the pallets one-half height of the stack, 1.5 m from the doors. The second probe was situated on the wall side of the pallet one-half height of the stack, 1.5 m from the doors. The third probe was located at the top of the pallet #10 stack.

Fruit temperature evolution during the 12 days duration of this simulated shipping test was close to 0°C during most of the simulated shipping period (Fig. 1). At loading, fruit temperature was near 6-8°C because of warming that occurred due to slow container loading. During the first three days of the trip, fruit cooling occurred that ended with fruit temperatures near 0°C (Table 1). After fruit reached the set point temperature, fruit temperature remained right at 0°C during the end of the simulated shipment. Fruit temperatures measured at probes #1 and #2 were always below 1.1°C. However, there were temperature differences of almost 0.5°C between them. Fruit temperature evolution measured by the probe located at the top of pallet #10 was very similar to the temperatures measured on USDA probes #1 & 2 (Fig. 1). Similar to other USDA probes, flesh temperature decreased slowly from the initial temperature to the set-point temperature. Then, temperature equilibrated to near 0°C (set point). During this simulated shipment, the minimum and maximum fruit temperatures were -0.1 and 0.3°C, respectively. Flesh temperature was maintained near to the container set point that in this study was 0°C. During days 3-12, flesh temperature only increased ~0.3°C and decreased up to ~0.61°C from this setting point. If this container temperature setting had been 1.0°C, the flesh temperature would have been very close to that setting point as measured in this study. This loading system assures flesh temperature close to the container setting point during shipment.

Our temperature results demonstrated that flesh temperatures were lower than USDA specifications for 12 days. Results from this 12-day simulated shipment experiment indicated steady flesh temperatures were maintained very close to 0°C when the container was loaded using the DAF system, closing container air exchange, loading cold fruit, using a set point near 0°C and the vented boxes facing the back door (Crisosto et al., 2010). Because of fruit temperature variations some fruit reached a temperature near -0.6°C; fruit with soluble solids concentration (SSC) higher than 10% should be used to avoid potential freezing damage.

**SUPER FRUIT-SUPER NUT**

Historically, fresh fruit and vegetables nutrition work has been gravitating from total antioxidants toward bio-nutrients; and from mice to humans. Recently, the healthy fatty acid concept and the critical role of ALA in salmon were demonstrated in a large European consumer trial which tested the benefits of the Mediterranean diet and omega 3 unsaturated fatty acids. Taking advantage of these positive results and the fact that walnut has the highest ALA content (9.2 g ALA per 100 g) among most fruit and nuts, a number of human medical studies using walnut in the daily diet supported previous studies on the health benefits of eating walnuts (California Walnut Board/Commission, 2013). These results were the basis of the walnut and other nuts promotional campaigns promoting increased consumption that improved sales.

## THE MECHANICAL HARVESTING ERA AND ROBOTICS

In California, the mechanically harvested horticultural crops such as almonds, pistachios, walnuts, wine grapes, oil olives, prunes, processing blueberries and raisins are not declining due to increasing hand harvest costs. In contrast, hand harvested table olives and some fresh blueberries are rapidly declining due to the combination of hand harvest costs, lack of labor and steady and/or declining consumption. There is also increasing interest in incorporating mechanical picking aides into the harvest of fruits still deemed too fragile for mechanical harvesting. Picker assists including platforms, transport tubes, bin layering technology and self-driving wagons are being investigated for pome and stone fruits, cherries, pears and strawberries. In all mechanical harvesting of tree crops, the tree canopy must be simultaneously adapted as mechanical harvesting prototype is developed. A research program led by Professor Vougioukas at UC Davis is currently building model-based design tools (Ampatzidis et al., 2009) that will enable researchers and manufacturers to investigate the interrelationships among orchard layout, tree canopy geometry and spatial fruit distribution, the mechanics of picking platforms and actuators, and the ergonomics of personnel-carrying orchard platforms. These tools can accelerate the development of next generation orchard mechanization and automation systems. Given the fact that robots cannot currently replace human perception and dexterity in harvesting, one approach is to design advanced autonomous machines that work together with agricultural workers in the field to improve labor efficiency and worker safety (Vougioukas, 2012). For example, autonomous agricultural vehicles to collaborate in order to improve field and orchard logistics while guaranteeing human and equipment safety are being tested in strawberry harvesting in California. Increasingly, food safety concerns are also being incorporated into mechanical harvesting. For example, almonds and walnuts, among the first mechanically harvested tree crops, drop to the ground when shaken. At that time no tree adaptation was required to ensure capturing the falling nuts as it is now because of food safety concerns. It is clear the tree and vine crops that will prosper in California will all be mechanically harvested due to labor availability and cost, efficiency and increasingly, food safety concerns.

## NONDESTRUCTIVE SENSORS

Because of recent advances in new nondestructive hand held technology there is high interest for using these sensors to segregate cultivars based on maturity-quality prior to/during harvesting to assure maximum customers' level of satisfaction. However, consumers should be willing to pay a premium to justify the extra cost of using any new nondestructive sensor technology and restrict their production to this elite fruit group. Our group has been assessing several instruments, such as the F750 (Felix Instruments, Inc., Washington, USA), based on NIR spectrometry, and the DA-meter series (TR Turoni srl., Forli, Italy), based on the measurement of chlorophyll, in order to predict non-destructively quality parameters such as the dry matter content in different cultivars of mangos, and to assist the establishment of our proposed consumer quality indexes (Crisosto and Crisosto, 2001). In addition, the DA-meter was evaluated to measure internal flesh color changes in mango as a maturity index. In cooperation with Compac Sorting Equipment, Inc. (California, USA) and Taste Technologies Ltd. (Auckland, New Zealand), we successfully segregated inline mangos according to two dry matter groups.

Groups were selected according to cultivars consumer quality index based on dry matter (Crisosto et al., 2014).

The sweet and seedless citrus consumption boom and strong market competition opened the doors for the new modern packinghouse technologies concept. For example, the Compac System™ that contains nondestructive sensors is being required to use during packaging of these clementine brands to assure consumer quality. In most of the cases, commercial inline segregation is focused on removing defects rather than sorting out fruit quality traits such as soluble solids concentration or dry matter related to sensory attributes. These citrus inline packing line sensors are designed to nondestructively detect color, size, skin blemishes, frost damage, granulations, and flesh dryness. In cherries, the Unitec CHERRY_VISION© inline nondestructive sensors reduced selection costs and sped up the packaging process.

Finally, many new technologies are available and validation and adaptation studies should be carried out before adopting them. Innovations are adopted only if the need and the economic incentives are in place.

**Literature Cited**


Ampatzidis, Y.G., Vougioukas, S.G., Bochtis, D.D. and Tsatsarelis, C.A. 2009. A yield mapping system for hand-harvested fruits based on RFID and GPS location technologies: field testing. Precision Agric. 10:63-72.

California Walnut Board/Commission. 2013. State of the Industry http://www.calasfmra.com/db_meetings/Dennis%20Balint%20-%20California%20Walnut%20Board%20-%20Commission.pdf.

Crisosto, C.H., Mitchell, F.G. and Ju, Z. 1999. Susceptibility to chilling injury of peach, nectarine, and plum cultivars grown in California. HortScience 34:1116-1118.

Crisosto, C.H., Crisosto, G.M., Makani, O., Gonzalez-Moscoso, S., Resende Nassur, R. and Rodriguez Bermejo, J. 2014. Developing a minimum quality index for the 'ready to eat' mango program. Report to National Mango Board, July 26, p.102.

Crisosto, C.H. and Crisosto, G.M. 2001. Understanding consumer acceptance of early harvested 'Hayward' kiwifruit. Postharvest Biol. Technol. 22:205-213.

Crisosto, C., Bermejo, J.R. and Ziegler, H. 2010. Assuring good arrivals temperature for the tree fruit industry after overseas shipping, CTFA Annual Research Report. p.104-111.

Dodd, M.C. 2013. Managing airflow inside reefer containers benefits produce quality. Acta Hort. 1012:1159-1166.

Dodd, M.C. and Worthington-Smith, P. 2006. Managing airflow in reefer containers benefits fruit quality. Proc. IIR-HACE Conference. Auckland, New Zealand 16-18 February. p.378-356.

Rodriguez-Bermejo, J., Barreiro, P., Robla, J.I. and Ruiz-Garcia, L. 2007. Thermal study of a transport container. J. Food Eng. 80:517-527.

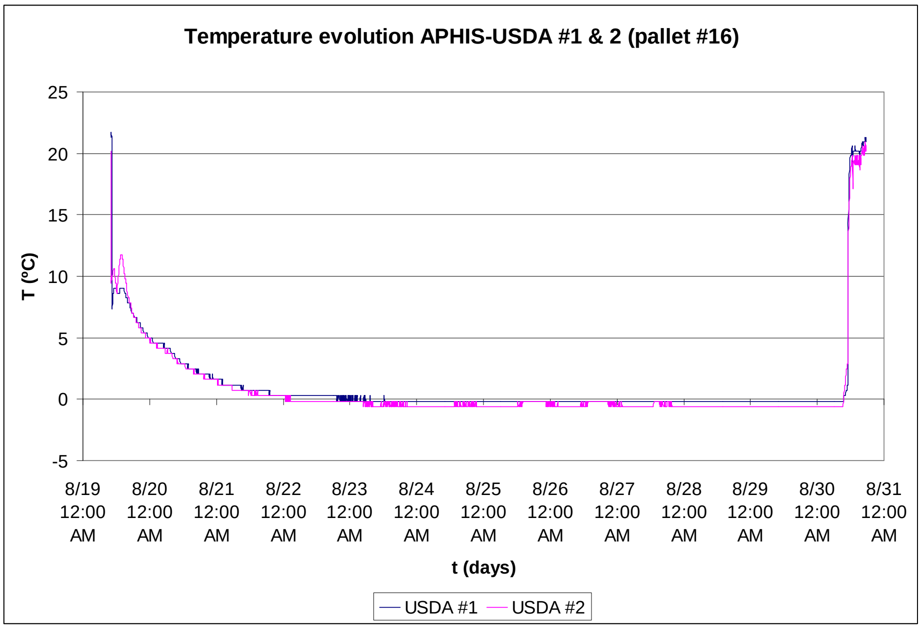
Vougioukas, S.G. 2012. A distributed control framework for motion coordination of teams of autonomous agricultural vehicles. Biosyst. Eng. 113:284-297.

## Tables

Table 1. Average flesh temperature (°C) during the simulated transportation shipment.

| Probe # | Average day 1-3 | Average day 3-12 | Max day 3-12 | Min day 3-12 |
|---|---|---|---|---|
| 1 | 1.03 | -0.16 | 0.29 | -0.16 |
| 2 | 0.75 | -0.53 | 0.29 | -0.61 |
| 3 | 0.55 | 0.02 | 0.29 | -0.16 |

## Figures



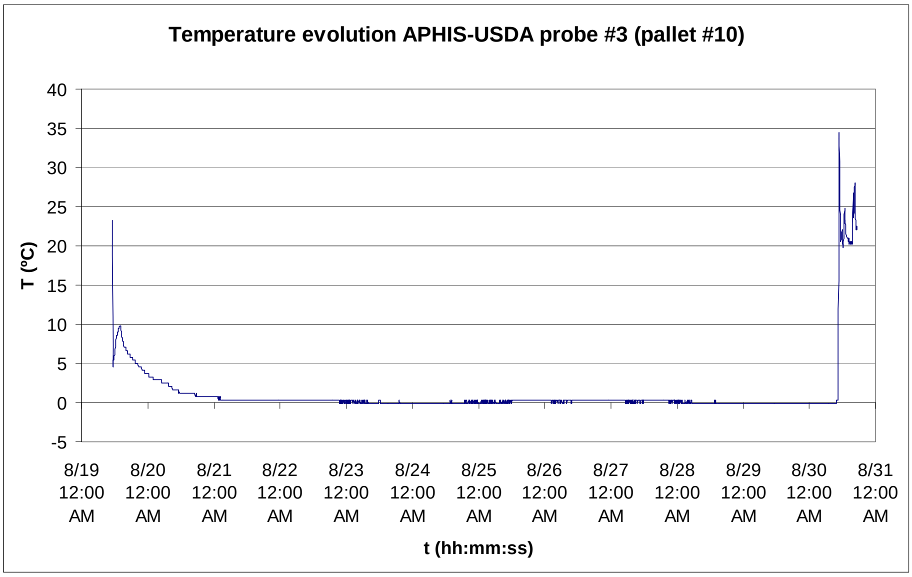




Fig. 1. Temperature evolution of USDA probes #1, 2 and 3 positions.