Postharvest Technologies of Fresh Horticulture Produce

Alejandro Isabel Luna-Maldonado[1], Clement Vigneault[2] and Kei Nakaji[3]
[1]*Department of Agricultural and Food Engineering, Faculty of Agriculture, Autonomous University of Nuevo Leon, Escobedo, N.L.,*
[2]*Department of Bioresource Engineering, Macdonald Campus, McGill University, Ste-Anne-de-Bellevue, Québec,*
[3]*Kyushu University, Laboratory of Agricultural Ecology, Division of Agricultural Ecology, Department of Plant Resources, Fukuoka,*
[1]*Mexico*
[2]*Canada*
[3]*Japan*

1. Introduction

The actual processing of fresh horticultural produce and the reducing labor force have begun to force the development of robots that are capable of dealing with the variations inherent in the produce being handled, stored and transported. All around the world, there is increasing interest in the use of robots to replace the drastic decreasing number of farmers due to the lower birth rate and the increasing average age of the remaining farmers (Kitamura *et al., 2004* & Wang, 2009). In the USA, the supply of workers available for hand harvesting is decreasing steadily and true shortages are occurring. Without enough workers when needed for a few weeks each year, a large amount of hand harvested crops will be lost. Fruit and vegetable crops need new productive harvesting technologies (Sarig *et al.,* 2010)

In general, with horticulture applications, the variations of fresh produce in size and color as well as in the internal structure and defects such as over-ripeness and bruising damage are considered the main barriers to the extension of robotics. Robots have to cope with produce delivered with random orientation and placement, and with environmental issues such as a wide range of humidity and temperature resulting in condensation problems on electronic circuit or dew on sensors of all kinds. It requires manipulator mechanisms, controls and end-manipulators to be designed to interact with the surrounding environment, sensing techniques, mobility, and work cell development. Typical applications where imaging and electro-sensing processes can be used to guide robots include sensing general fruit quality (ElMasry *et al.* 2009; Li *et al.*, 2006 & Lino *et al.*, 2008), measuring internal quality parameters (Chen, 2008 & Li *et al.,* 2009), or detecting mechanical (ElMasry *et al.,* 2008) or physiological (ElMasry *et al.,* 2009) damage, for either grading the produce accordingly or involving automatic trimming robots to remove the defect. In other words, processed items are picked from a conveyor belt and presented to a cutting or trimming device to further process the produce in order to maintain a consistency of quality in the finished produce. For example, during the inspection of lettuce heads and their core removal (Key Technology, 2010**)**, a fresh lettuce will be scanned to detect stones and insect damage. At the same time, a two directional measurement device can take images to provide core position and orientation information. Based on these pieces of information, the lettuce will be properly aligned with a blade mounted on a robot to perform the core removal (Applied Sorting Technologies, 2010).

The above example is considered as a typical robot application in horticulture. There is also a totally different type of robot application that is often forgotten due to its relative simplicity which is to fill produce in a standard package unit such as reusable plastic container (RPC) (Vigneault and Émond, 1998). This handling process of horticultural produce is likely comparable to handling any other industrial products such as a TV set or a microwave oven. The main differences are in: the specificity of the environment due to the fact that the horticultural produce is still alive and requires special environmental conditions; the fragility of the produce to mechanical damage and its sensibility to the variations of the environmental conditions; and the length of the time the robot is used for. The particularities of environmental conditions in which the produce are handled and stored require the robot to be able to operate properly at ambient as well as in cold temperatures (close to 0ºC) and very high relative humidity (close to 100%), as well as in gas compositions that are hazardous to humans (close to 1% O_2 and up to 20% CO_2) in which the produce is sometimes stored (Leblanc and Vigneault, 2006); as well in a continuous alternating conditions from ambient to any other conditions. In terms of fragility of the produce to mechanical damages, it is easy to understand that horticultural produce are much more sensitive than any industrial products made from metal, plastic or wood. In terms of period of usage, the industry robots are generally used for 12 months/year period, which makes their uses generally economically interesting. However for the horticultural application, each robotic application is of any duration from a few days to the entire year depending on the type of work the robot accomplishes, the produce the robot processes and the produce production period which is produce and localization dependent, and the production system (greenhouse *vs* in-field production, fresh *vs* stored produce, cold climate *vs* subtropical, climacteric *vs* non-climacteric produce, etc). All these horticultural produce particularities must be considered during the design of any robot designated to horticultural applications.

2. Handling of fresh horticultural produce

Postharvest technologies include the objectives of maintaining the fresh quality of the produce in terms of appearance, texture, flavor, nutritive value, etc, protecting produce, maintaining food safety, and reducing the average losses between harvest and consumption (Saraswathy *et al*., 2010**)**. The time a produce is exposed to any adverse condition is generally directly proportional to the decrease of quality of any horticultural produce (Leblanc and Vigneault, 2008). Hence, the processing time is one of the most important and controllable factors affecting the quality of the produce. Any delay will generate soon or later important effects on the final quality of the produce (Vigneault *et al*., 2004 & de Castro *et al*., 2005) at the marketing step, which may result in a significant loss of marketable value (Leblanc and Vigneault, 2008).

Another controllable factor affecting the quality of the produce is the number of times a product is manipulated or in contact with any fixed or mobile object without being protected (Vigneault *et al*., 2002 & Vigneault *et al*., 2009). Packaging systems should be designed for rapid and efficient cooling (Vigneault *et al*., 2002; Vigneault *et al*., 2004b & de Castro *et al*., 2005b) to prevent physical damage to the produce and to ease handling and storing processes (Vigneault *et al*., 2009). Finally, storage conditions of refrigerated and controlled atmosphere should be chosen and maintained to retard the deterioration of the perishable produce due to: (1) aging, ripening, softening and color changes (Hoenht *et al*., 2009); (2) undesirable metabolic changes and respiratory heat production(Leblanc and Vigneault, 2008) ; (3) moisture loss and the resulting wilting (Alvo *et al*., 2004); (4) spoilage by invasion of bacteria, fungi or yeasts (Kader, 2002); and (5) undesirable physiological processes such as sprouting (Bachmann, 2010).

2.1 Automation and robots for handling of fresh horticultural produce

To maintain the quality of horticultural produce by applying prior knowledge, manufacturers supply a range of solutions based on control, automation and robotics. For example, to reduce processing time a produce is exposed to any adverse conditions, the handling industry proposes to reduce the time between harvest and cold storage by using high speed processing systems such as display container loaders for potato, onion, carrot and other pre-packs, which are capable of obtaining a processing rate up to 80 units of 2.5 kg per minute (Abar Automation, 2011). The automated loaders are generally available for loading 800 × 600 mm footprint containers with options available for the 600 × 400 mm standard RPCs (Abar Automation, 2011). In this process, as all the main movements including package rotation are already carried out in the other industries by a robot, very few conventional technology and mechanical components are required, resulting in a very reliable system. Crate loaders are also available for pre-pack picking and placing systems that load bags, clamshell and other small package units into the 600 × 400 mm North America and Europe standard crates (Vigneault *et al*., 2009), 400 × 300 mm plastic crates or cases at a processing rate of more than one unit per second (Abar automation, 2009). The robot is housed with a compact space saving structure and space costs, and are fed with bulk or packed produce feeding conveyors. Outer types of packing units such as wooden crates, cardboard boxes, or RPCs are supplied to the system through conveyors either from remote or low level crate de-stackers. The remote de-stacker located on a mezzanine floor or adjacent to the pick-and-place robot separates the packing units from the top of the stack and delivers them over the packing lines. Robot de-stackers and palletizers provide a flexible and relatively low cost solution and high throughput with two or more action spots for single or multiple production lines of pallet loading.

During the picking and placing process in a packinghouse, the multitask operations allow bags, cases, boxes, RPCs and even layer sheets to be placed by a single robotic installation (Abar automation, 2009). Picking and placing is where a robot moves items from one place to another, for example from a conveyor in a production line to another in a packaging line.

The robot is often guided by a vision system (Piasek, 2010). Pick and place robot cells (Fig. 1) are available for pre-packed bags or trays containing fresh or processed vegetables, salads or mushrooms ranging in weights from a few grams to 50 kg, and are capable of loading plastic crates and roll containers (Abar automation, 2011 & Robots & Robot Controllers Portal, 2010).

Fig. 1. Pack rotation carry out by an ultra reliable (Courtesy: Abar automation, 2009).

The robotic work cells are becoming more complex. From de-moulding and assembling parts for the car industry to packaging complex objects, the robots are being asked to do faster and more complex moves. This ability to accomplish more sophisticated tasks lies in the capacity to develop more flexible end-of-arm end effecters. A customizable robot has the ability to increase functionality and repeatability as well as allow a higher percentage of automation function within the cell (KUKA Industrial Robots, 2010). For example, the crate sorting system at the Hofbräuhaus Brewery had to deal with different types of beer crates, meaning that the level of mixed packages in the system rose and manual handling became less cost-effective (Raghavan *et al.,* 2005). In addition, the brewery wanted to spare its employees from the heavy physical work of palletizing 2,500 to 3,000 crates per day. The new solution can also be integrated into the existing equipment. The brewery is looking for a customized automation concept. Finally, the system had to be installed in a small space, while at the same time being easily accessible (Raghavan *et al.,* 2005). This brewery example is quite similar in complexity to horticultural packinghouse where robots have to at the same time handle multiple types of fragile and light produce from conveyer to boxes, and heavy boxes to palette with care and precision, with a short time to maintain high production rate. Although the similarity in the complexity of the tasks to be accomplished is high which demonstrates the possibility of developing robots for horticulture application, the technologies are not directly applicable to horticultural produce with so many variations. Much modification to the industrial robots is required to adapt these robots for horticultural purposes. On April of this year was presented (Zheng, 2011) in China an intelligent robot (Fig. 2) ables to examine growing conditions such as temperature, humidity, light, detect disease of the vegetables and pick up the ripe ones through identifying the colour.

Fig. 2. A robot for vegetable planting (Courtesy: Xinhuanet, Zhu Zheng, 2011)

On the other hand, Dr. Hayashi Shigehiko in the Bio-oriented Technology Research Advancement Institution (Japan) developed the harvesting robot of strawberry in oder to keep the high quality of strawberry freshness (Fig. 3).

Fig. 3. A harvesting robot of strawberry (Courtesy: BRAIN, Shigehiko Hayashi, 2011).

3. Storing of fresh horticultural produce

Various storage methods for fresh horticultural produce are used commercially (Liu, 1991 & Li, 2009). The most common and frequently used storage system is the refrigerated storage room (Raghavan *et al.,* 2005). This storage system consists of continuous and uniform control of temperature and humidity inside of well insulated rooms or buildings (Li, 2009). The ambient storage conditions for fresh horticultural produce vary in temperature from 0 to 15° C and in relative humidity from 65 to 98% [Kader, 2002; Raghavan *et al.,* 2005; Liu, 1991 & Li, 2009). These conditions are generally controlled by mechanical refrigeration [FAO, 2010 & Hollingum, 1999] and electric thermostat and humidistat, or using an electronic automated system based on adjusted enthalpy of the ambient air (Markarian *et al.*, 2006).

The controlled atmosphere (CA) storage frequently used in postharvest technology of fruits and vegetables consists of controls on the concentrations of O_2, CO_2 and N_2, within a perfectly sealed refrigerated storage room [38]. Modified atmosphere (MA) storage or packaging (MAP) is also used for horticultural produce. It consists generally of modifying gas composition of the internal atmosphere of a package unit that could be as small as 200 g (eg, for leafy vegetable) or a large transportable unit such as a pallet size of 250 to 1,000 kg (eg, for strawberry). The gas concentration encountered in CA and MAP are not different generally except the size of the units which is extremely different and use completely different atmosphere generation and controlling systems. The O_2 gas concentration used for CA and MAP is from 21% (ambient air) to 0%, while the CO_2

concentration increases from 0.003% to values sometimes reaching 15 to 20% de-pending on the produce stored. The N_2 is normally used as a filling gas for both MAP and CA technologies (Raghavan *et al.,* 2010). The ethylene (C_2H_4) is sometimes controlled by scrubbing such as potassium permanganate or O_3 (ozone), or by flushing for better quality control of produce responding to it. The control of temperature, humidity and atmospheric composition may be performed manually, but automated systems frequently measuring the gas compositions and performing the adequate adjustment of the gas processing system also exist to achieve more accurate and uniform conditions (Raghavan *et al.,* 2010).

3.1 Robots for storing of fresh horticultural produce

For storage of fresh produce, the robot handling system must be able to operate within the ambient conditions generally encountered in the storage rooms. At the same time, the robots have to be able to work within the conditions encountered outside of the storage room since they are continuously required to handle the produce to and from the storage room. They must then be resistant to heavy ambient humidity condensation due to this continuously changing environment. Besides the humidity condition, the basic principles used for developing industrial storage robots are basically the same for horticultural purposes. The robot must be able to circulate in a specific environment recognising fixed and moving objects consisting of rows and columns of produce, walls, doors, humans and other robots working individually or in collaboration with human and other robots.

There are two great advantages of robots used for horticultural storage purposes. The first is the robot's capacity for managing extremely large quantities of information associated with any specific produce. These pieces of information could be related to the type of produce, the origin, the harvesting date, the processing date, the initial quality, and its eventual destination, etc (Leblanc and Vigneault ,2006). The information could be easily transferred from and to the robots for managing purposes and improvement of efficiency. For example, maintaining the link between the information and the produce is essential for choosing and executing any managing types such as "the first in first out", "consumer preference", "quality based" or "shelf live" objectives. The second advantage is that in a great facility, a robot can be considered as an economical aspect in the handling the produce such as optimisation of space occupancy, organisation of traffic circulation and managing picking order (Piasek, 2010) to maximise handling efficiency and minimise produce waiting time on docks or truck loading process duration.

Another advantage of a robot, which has not been explored yet in horticulture, is the robot's capacity to work in hazardous environment such as CA room or high O_3 concentration atmosphere for C_2H_4 control. In the case of C_2H_4 control, one has to understand that the optimal O_3 level for the best control of C_2H_4 is generally too high for worker safety, which considerably limits the use of this interesting technique. For a CA room, the main problem is the fact that the quality of the produce is highly related to the time delay between harvest and storage and between storage and commercialization. It is frequent to encounter produce that has been harvested at the optimum maturity level but has to wait for days and even weeks before being under CA due to the time required to fill the CA room. The same way, it is very common to encounter CA rooms that were degassed for marketing a first load of produce and had to wait weeks and months before the last load quits the room. An airlock system has been developed for CA apple storage which can maintain the gas composition inside of the room continuously (Vigneault, 2009), reduce the waiting time before and after storage to a few hours only. However, workers have to use autonomous breading systems to enter in the airlock and transfer the produce from and to the CA room, which has to be performed with a very high precaution level. Human life can be in danger if any mistake happens (Vigneault, 2009).

4. Transportation of fresh horticultural produce

Ground transportation of fresh horticultural produce is usually by trucks and occasionally by railway (Leblanc and Hui, 2005). Overseas transportation is by ship (Tanner and Smale,2005) or plane (Thompson et al., 2004). A limited amount of high-valued produce is sometimes transported overland by air (Vigneault et al., 2009). The basic requirements for conditions during transportation are similar to those needed for storage (Vigneault, 2005), including proper control of temperature and humidity, and adequate ventilation (Hui et al., 2006 & Hui et al., 2008a). In addition to ambient condition require-ment, the produce must be immobilised by proper packaging, stacking, and bracing methods to avoid excessive movement or vibrations (Vigneault et al., 2009) without being detrimental to air circulation to maintain a uniform temperature distribution within a load (Hui et al., 2008b).

4.1 Robots for transportation of fresh horticultural produce

Loading trucks with produce can be done robots with a vision machine and integrated sensors able to detect objects or people obstructing their way and find and follow a specific path (Belforte *et al.*, 2006). For the purpose of this handling associated with transportation, the robots should be compact enough to perform this task within a restricted work area (Garcia Ruiz *et al.*, 2007), robust but able to perform delicate and very precise operations since the load placement within the truck greatly affects the air circulation (Vigneault , 2005; Hui *et al.*, 2006 & Hui *et al.*, 2008a). To perform these tasks, transportation robots coupled with forks and elevator can carry packed industrial products as well as horticultural produce (Logistic Systems Design, 2010).

5. Conclusion

Packaging and refrigeration prevent physical damage and decrease the physiological and pathological damages to the produce. Automation and robots are capable of speeding up the postharvest processes, decrease the period during which the perishable produce is exposed to undesirable conditions, and enhancing the facility and the safety level of human tasks for handling fresh horticultural produce. Robot palletisers could provide more than one course at the time and work within multi line production. Picking and placing robot cells adapted from industrial uses for pre-packed bags, trays or boxes containing fresh fruits or vegetables are becoming more available and able to accomplish complex tasks, but they have to be redesigned to meet with the specific require-ments and environmental conditions of horticulture.

6. Acknowledgment

The authors would like to thank to the Mexican, Canadian and Japanese Ministries of Education for the financial support. Moreover, we thank the robot companies and institutions for the photographs.

7. References

Kitamura S.; Oka K and Takeda F. (2004). Development of Picking Robot in Greenhouse Horticulture. *SICE Annual Conference*, pp. 3176–3179, ISBN 0780320247 Okayama, Japan

Wang M. What will modern agriculture bring to people? Sciences by Experts, Series 3. (2009) *China Publishing Group*, ISBN/ISSN 9787500084785 pp. 145– 160, Beijing, China

Sarig Y, Thompson JF and Brown GK. (2010). Alternatives to Immigrant Labor? The Status of Fruit and Vegetable Harvest Mechanization in the United States. 2000: 29.07.2010. Available from http://www.cis.org/articles/2000/back1200.html

ElMasry G, Nassar A, Wang N and Vigneault C. (2008) Spectral methods for measuring quality changes of fresh fruits and vegetables. *Stewart Postharvest Review,* Vol.4 , No. 4, pp. 1–3.13, ISSN 1745-9656

Li Z, Wang N and Vigneault C. (2006) Electronic nose and electronic tongue in food production and processing. *Stewart Postharvest Review*, Vol.2, No.4, pp. 7.1–7.6., ISSN 1745-9656

Lino ACL, Sanchez J and Dalfabro I. M. (2006). Image processing techniques for lemons and tomatoes classification. *Bragantia*, Vol.3, pp. 85–789, ISSN 0006-8705

Chen M. (2008). Non-destructive Measurement of Tomato Quality using Visible and Near-infrared Reflectance Spectroscopy. Master degree thesis. G.S.V. Raghavan and C. Vigneault (Supervisors). *Department of Bioresource Engineering. Macdonald Campus, McGill, University.* Sainte-Anne de Bellevue, Québec, Canada

Li Z, Wang N, Vigneault C and Raghavan GSV. (2009). Ripeness and rot evaluation of 'Tommy Atkins' mango fruit through volatiles detection. *Journal of Food Engineering,* Vol. 91, pp. 319–324. ISSN 0260-8774

ElMasry G, Wang N, Qiao J, Vigneault C and ElSayed A. (2008). Early detection of apple bruises on different background colors using hyperspectral imaging. LWT – *Food science and technology*, Vol. 41, No.2, pp, 337–345, ISSN 0023-6438

ElMasry G, Wang N and Vigneault C. (2009). Detecting Chilling Injury in "Red Delicious" Apple Using Hyperspectral Imaging and Neural Network. *Postharvest Biology and Technology*, Vol. 52, No.1, pp. 1–8, ISSN 0925-5214

Key Technology. Lettuce Core Removal System. (2010). 25.07.2010. Available from http://www.key.net/ products/oncore-lettuce-core-removal-system/default.html

Applied Sorting Technologies. (2010). 24.07.2010. Available from http://www.appliedsorting.com.au/ index.php?~iframe1

Vigneault C and Émond JP. (1998). Reusable container for the preservation of fresh fruits and vegetables. *Agriculture and Agro-Food Canada and Laval University*. United States Patent Office, Washington, Washington DC, USA

Leblanc D.I. and Vigneault C. (2006). Traceability of environmental conditions for maintaining horticultural produce quality. *Stewart Postharvest Review*,Vol.2 , No. 2, pp. 4.1–4.10, ISSN 1745-9656

Saraswathy S, Preethi TL, Balasubramanyan S, Suresh J, Revathy N and Natarajan S. (2010). Postharvest Management of Horticultural Crops. *Agrobios*, India

Leblanc DI and Vigneault C. (2008). Predicting quality changes of fresh fruits and vegetables during postharvest handling and distribution. *Stewart Postharvest Review*,Vol.4 , No. 4, pp. 1.1–1.3., ISSN 1745-9656

Vigneault C, Gariépy Y, Roussel D and Goyette B. (2004a). The effect of precooling delay on the quality of stored sweet corn. *International Journal of Food, Agriculture and Environment*,Vol.2, No. 2, pp. 71–73. ISSN (printed) 1459-0255. ISSN (electronic) 1459-0263

de Castro LR, Vigneault C, Charles MT and Cortez LAB. (2005a). Effect of cool-ing delay and cold-chain breakage on Santa Clara tomato. *International Journal of Food, Agriculture and Environment* Vol.3 , No. 1, pp. 49–54. ISSN (printed) 1459-0255. ISSN (electronic) 1459-0263

Vigneault C, Bordint MR and Abrahão RF. (2002). Embalagem para frutas e hortaliças. In : Cortez LAB, Honório SL and Moretti CL (Eds). Resfriamento de frutas e hortaliças. *Embrapa Informaçã Tecnológica*, Brasília, DF, Brazil, ISSN 1678-3921

Vigneault C, Thompson J and Wu S. (2009). Designing container for handling fresh horticultural produce. In Benkeblia N (ed). *Postharvest Technologies for Horticultural Crops. Research Signpos*t, India, Vol. 2, pp. 25–47. ISBN 978-81-308-0356-2

Vigneault C, Markarian NR, da Silva A and Goyette B. (2004b).Pressure drop during forced-air ventilation of various horticultural produce in containers with different opening configuration. *Transaction of the ASAE*, Vol.47, No.3, pp. 807–814, ISSN 0001-2351

de Castro LR, Vigneault C and Cortez LAB. (2005b). Effect of container openings and airflow on energy required for forced air cooling of horticultural produce. *Canadian Biosystems Engineering*, Vol.47, No., pp. 3.1–3.9., ISSN 1492-9058

Hoehn E, Prange R and Vigneault C. (2009). Storage technology and applications. In: Yahia EM (ed). Modified and controlled atmospheres for the storage, transportation, and packaging of horticultural commodities. *CRC Press (Taylor & Francis Group)*, pp. 17–50, ISBN 9781420069570.ISBN10 1420069578

Alvo P, Vigneault C, DeEll JR and Gariépy Y. (2004). Texture characteristics of carrots as affected by storage temperature and duration. *International Journal of Food, Agriculture and Environment* 2004: 2(2): 33–37, ISBN 9781420069570

Kader A (ed). (2002). Postharvest technology of horticultural crops. *University of California*, 2002: Publication 3311. Davis, CA, USA

Bachmann J and Earles R. (2010). Postharvest Handling of Fruits and Vegetables. 27.07.2010. Available from http://attra.ncat.org/attra-pub/postharvest.html.

Abar automation. (2011). Pick and Place Robots for Fresh Produce, Netherlands. 18.10.2011. Available from http://www.abar.nl/pick_and_place_fresh_produce.htm

Piasek D. (2010). Order Picking: Methods and Equipment for Piece Pick, Case Pick, and Pallet Pick Operations. *Logistics Handling, Dematic*, Le Dôme, Luxembourg. 28.07.2010.Available from http://www.logisticshandling.com/absolutenm/templates/article-conveyors_sortation.aspx?articleid=36&zoneid=29

Robots & Robot Controllers Portal. (2010). Specify Multi-functioning End-of-Arm Tooling for Robotic Workcells. 26.07.2010. Available from http://www.automation.com/robots-robot-controllers/preview-articles/more

KUKA Industrial Robots. (2010). Handling of beverage crates with 180 PA robot. 25.07.2010. Available from http://www.kuka-robotics.com/en/solutions/solutions_search/L_R171_Handling_of_beverage_crates_with_180_PA_robot.htm.

Raghavan GSV, Vigneault C, Gariépy Y, Markarian NR and Alvo P. (2005). Refrigerated and controlled/modified atmosphere storage. In Barrett D, Somogyi L and Ramaswamy H (eds). *Processing Fruits, Science and technology. 2nd edition. CRC Press*. ISBN 9781420069570 ISBN10-1420069578

Zheng Zhu (2011). Robots for vegetable planting works at 12th China Int'l Vegetable Sci-tech Fair in Jinan, China's Shandong. 20.04.2011. Available from http://news.xinhuanet.com/english2010/photo/2011-04/20/c_13838241_2.htm

Shigehiko H. (2011). Specific Project Research Team (Robot) Bio-oriented Technology Research Advancement Institution. Japan. 30.11.2011 Available from http://brain.naro.affrc.go.jp/iam/Team/iam_team_robo00.html

Liu FW. (1991). Precooling of horticultural crops. In: Yahia EM and Higuera IHC. (eds.) Memorias Simposio Nacional Fisiologia y Tecnologia Post-cosecha de Productos Horticolas en Mexico. *Noriega Editores*, Mexico, pp.235–240.

Li FW. (2009). Postharvest Handling in Asia 2. Horticultural Crops Food and Fertilizer. 21.12.2009. Available from http://www.agnet.org/library/eb/465b/

FAO. (2010). Small-scale post-harvest handling practices. Section 6: Temperature and relative humidity control. 27.07.2010. Available from http://www.fao.org/WAIRdocs/ x5403e/x5403e08.htm.

Hollingum J. (1999). Robots in agriculture. *Industrial Robot: An International Journal,* Vol. 26, No. 6, pp. 438–446, ISSN 0143-991X

Markarian NR, Landry JA and Vigneault C. (2006). Development of a model for simulating ambient conditions in fresh fruit and vegetable storage facility. *International Journal of Food, Agriculture and Environment*, Vol.4, No.1, pp. 34–40, ISSN (printed) 1459-0255. ISSN (electronic) 1459-0263

Raghavan GSV, Gariépy Y and Vigneault C. (2010). Controlled Atmosphere Storage. *Encyclopedia of Agriculture, Food, and Biological Engineering, 2nd Edition. Taylor & Francis* 2010: (In press).

Vigneault C. (2009). La combinaison d'un sas AC et un système de refroidisse-ment à l'eau pour une meilleure gestion de la qualité des pommes. *Agriculture and Agri-Food Canada*, Saint-Jean-sur-Richelieu, Québec, Canada, 3pp

LeBlanc DI and Hui KPC. (2005). Land transportation of fresh fruits and vegetables: An update. *Stewart Postharvest Review,* pp. 1.4.1–1.4.13. ISSN 1745-9656

Tanner D and Smale N. (2005). Sea transportation of fruits and vegetables: An update. *Stewart Postharvest Review*,pp. 1.1.1–1.1.9, ISSN 1745-9656

Thompson JF, Bishop CFH and Brecht PE. (2004). Air transport of perishable products. *Agriculture and Natural Resources*, University of California, 2004: Publication 21618. 22 pp. Davis, CA, USA

Vigneault C, Thompson J, Wu S, Hui KPC and LeBlanc DL. (2009).Transportation of fresh horticultural produce. In Benkeblia N (ed). *Postharvest Technologies for Horticultural Crops. Research Signpost*, Kerale, India. Vol. 2, pp. 1–24, ISBN 978-81-308-0356-2

Vigneault C. (2005). Transport of fruits and vegetables. *Stewart Postharvest Review*,Vol.1, No.1, pp. 6.1–6.4, ISSN 1745-9656

Hui KPC, Raghavan GSV, Vigneault C and de Castro LR. (2006) Evaluation of the air circulation uniformity inside refrigerated semi-trailer transporting fresh horticultural produce. *Journal of Food, Agriculture and Environment* ,Vol.4, No. 1, pp. 109–114, ISSN 1459-0255

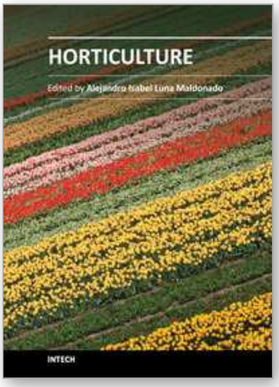
Hui KPC, Vigneault C, de Castro LR and Raghavan GSV. (2008a). Effect of different accessories on airflow pattern inside refrigerated semi-trailers transporting fresh produce. *Applied Engineering in Agriculture*, Vol. 24, No. 3, pp. 337–343, ISSN 0883-8542

Hui KPC, Vigneault C, Sotocinal SA, de Castro LR and Raghavan GSV. (2008b). Effects of loading and air bag bracing patterns on correlated relative air distribution inside refrigerated semi-trailers transporting fresh horticultural produce. *Canadian Biosystems Engineering,* pp. 3.27–3.35, ISSN 1492-9058

Belforte G, Deboli R, Gay P, Piccarolo P and Ricauda Aimonino D. (2006). Robot Design and Testing for Greenhouse Applications. *Biosystems Engineering*,Vol. 95, No. 3, pp. 309–321,ISSN 1537-5110

García Ruiz MA, Gutiérrez Díaz S, López Hernández HC, Rivera Ibáñez S and Ruiz Tadeo AC. (2007). Estado del arte de la tecnología de robots aplicada a invernaderos state of the art of robot technology applied to greenhouses. *Avances de Investigación Agropecuaria*, Universidad de Colima, México, Vol. 11, pp. 53–61.

Logistic Systems Design. (2010). Handling Systems. 21.07.2010. Available from http:/www2.isye.gatech.edu/ ~mgoetsch/cali/logistics_systems_design/material_handling_systems/ material_handling_systems.pdf.



Horticulture

Edited by Prof. Alejandro Isabel Luna Maldonado

ISBN 978-953-51-0252-6
Hard cover, 172 pages
Publisher InTech
Published online 16, March, 2012
Published in print edition March, 2012

This book is about the novel aspects and future trends of the horticulture. The topics covered by this book are the effect of the climate and soil characteristics on the nitrogen balance, influence of fertilizers with prolongation effect, diversity in grapevine gene pools, growth and nutrient uptake for tomato plants, post-harvest quality, chemical composition and antioxidant activity, local botanical knowledge and agrobiodiversity, urban horticulture, use of the humectant agents in protected horticulture as well as post-harvest technologies of fresh horticulture produce. This book is a general reference work for students, professional horticulturalists and readers with interest in the subject.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Alejandro Isabel Luna-Maldonado, Clement Vigneault and Kei Nakaji (2012). Postharvest Technologies of Fresh Horticulture Produce, Horticulture, Prof. Alejandro Isabel Luna Maldonado (Ed.), ISBN: 978-953-51-0252-6, InTech, Available from: http://www.intechopen.com/books/horticulture/postharvest-technologies-of-fresh-horticulture-produce

INTECH
open science | open minds

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821