



Postharvest Handling and Food Safety – Layers of Protection

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Wholesalers, retailers, and consumers are concerned with three components of fruit and vegetable supply: consistency in quality, supply, and price. Some wholesale and retail buyers have stringent quality criteria for their suppliers. Maintenance of quality and reduction of losses during marketing requires a knowledge of optimum harvesting and handling recommendations, as well as a recognition of the limitations in the storage potential of different fruits and vegetables.

Quality is most easily defined as the absence of defects or degree of excellence. This definition incorporates all components that are recognized and requested by the consumer: appearance, freedom from pesticide residues and human pathogens, flavor, taste, texture, and nutritional content. However, the importance of each of these different quality components varies as a commodity moves through the supply chain (Paull 1999, Paull and Chen 2004, Love et al. 2014).

The increasing importance of food safety has led to changes in the way growers, handlers, and shippers see their roles (Parker et al. 2012, Laury-Shaw et al. 2015). Produce handlers in the supply chain can add value to fruits and vegetables with minimal processing that leads to ready-to-eat products by repacking into consumer packs that also ensure that a safe, high-quality product reaches the consumer (Holvoet et al. 2012, Manzocco



**Washing bananas with potable water
before packing**

et al. 2015). Other changes in handling contribute to greater sustainability of the food system, reduced energy needed to market fruits and vegetables and social agreements between producers, field workers, packers, wholesalers, retailers, and consumers.

Food Safety

Fruits and vegetables grown in the field cannot be expected to be completely free of all microorganisms. Although most of these microorganisms are harmless

to humans, some are potential human pathogens that can cause illness. Foodborne illness outbreaks have raised concerns about human pathogen survival and proliferation on fresh produce (Suslow et al. 2003, Kirezieva et al. 2015). Protected cultivation in glass- or plastic-houses significantly reduces contamination of a product by animals and birds but does not eliminate the possibility of these or other types of contamination (Holvoet et al. 2014).

The increasing numbers of fruit and vegetable recalls due to possible pathogen contamination not only indicate greater levels of contamination but also reflect better reporting and traceability, as well as the improved diagnostics needed in a globalized supply chain with its wide product distribution and increased points of potential contamination (Kirezieva et al. 2013, Gil et al. 2015). Foodborne illness outbreaks have been

associated with growing and harvesting practices as well as postharvest handling. Equal attention should be given to the handling of raw agricultural commodities (RAC) and fresh-cut fruits and vegetables. Poor sanitation and improper hygiene are major sources of contamination by human pathogens and can occur at any point in the supply chain (Banach et al. 2015, Murray et al. 2017). Most protected agriculture operations and the larger field growers have strict hygiene requirements for employees that are spelled out in their Standard Operating Procedures (SOP).

Layers of Protection

The “Layers of Protection” model is a risk-based approach to avoid contamination of fruits and vegetables with human pathogens from the field to the consumer. The Food and Drug Administration (FDA) Food Safety Modernization Act (FSMA) focuses on utilizing multiple Layers of Protection and on the important roles of those who handle fruits and vegetables in our food system to prevent foodborne illness (<https://www.fda.gov/Food/GuidanceRegulation/FSMA/ucm334114.htm>). FSMA represents a change from a reactive food-safety system to one that is proactive, preventing contamination of fresh produce before it happens. A critical layer to this model is that all those in the handling chain who fall

under the law need to be trained to meet FDA food safety standards and verify that they are being carried out. Multiple rules outlined under the FSMA affect the handling of fruits and vegetables at the potential sites for contamination (Figure 1). These science-based standards outline the safe growing, harvesting, washing, minimal processing, packing, storage, and shipping of fresh fruits and vegetables and are regulations under the FSMA that must be followed in addition to State regulations and industry standards. The application of the Layers of Protection standards outlined below can potentially increase the postharvest longevity of produce.

Depending on the type of fruit and vegetable, some exemptions may apply, as some of these commodities are not commonly eaten raw. Fruits and vegetables that are not commonly eaten raw, such as taro and sweet potatoes, usually include a “kill step.” A kill step occurs during processing, either in a processing facility or in the home. The most common method is heating (steaming, boiling). Other processing techniques that can also be used to create inhospitable environments for microorganisms include irradiation, lowering pH (pickling), and lowering water activity (dehydrating).

Most commonly (Suslow et al. 2003, Parker et al. 2016), breaches in the Layers of Protection (Table 1) for fresh fruits and vegetables and subsequent contamination

Figure 1. Potential sites for fruit and vegetable contamination in the supply chain from the field to the consumer.

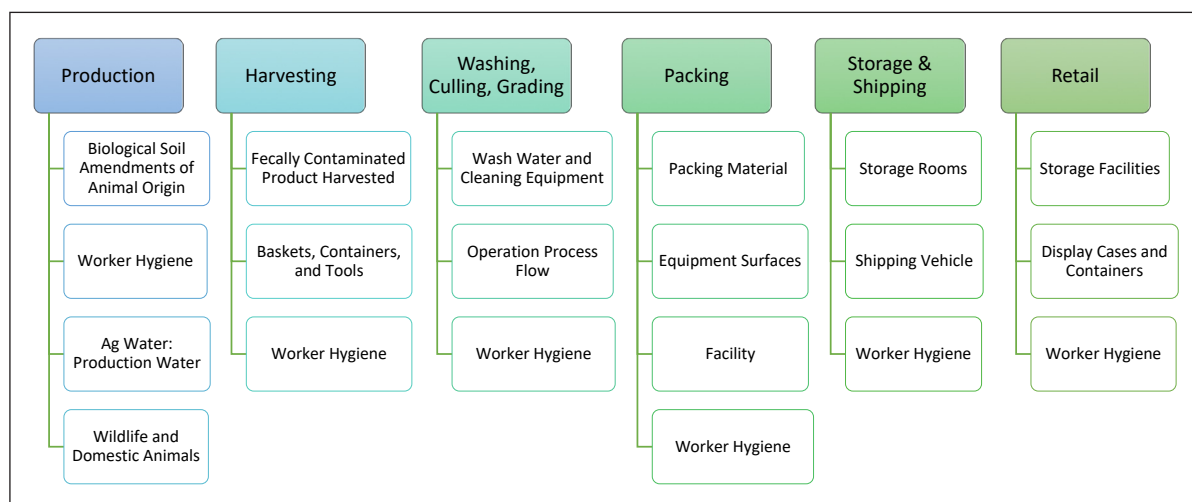


Table 1. Layers in the postharvest handling chain where breaks can occur that lead to contamination.

Layers in the Supply Chain	Risk of Contamination	Reduction of Risk
Production	Biological soil amendments of animal origin	Use proper application timing and placement, preparation and treatment, and storage.
	Wildlife and domestic animals	Exclude domestic and wild animals away from fruit and vegetable fields and facilities.
	Irrigation water	Monitor microbial quality of irrigation water. If irrigation water is of poor quality, limit contact with edible portion of fruits and vegetables, especially close to harvest date.
	Worker hygiene	Implement and follow training program and hygiene policy.
Harvesting	Contaminated product harvested	Leave produce that is contaminated with feces or has been dropped in field.
	Contaminated baskets, containers, and tools	Clean all equipment, tools, and containers before and after harvest.
	Worker hygiene	Implement and follow training program and hygiene policy.
Washing Culling, Grading	Produce wash water and cleaning equipment.	Use potable water to wash product and all food-contact surfaces and equipment. Use sanitizers approved for produce and food-contact surfaces, such as chlorine and peracetic acid, following all label requirements.
	Operation process flow	Design process flow to minimize cross-contamination of finished product with produce from field. Keep animals and store chemicals, soil amendments, and fertilizers away from produce-processing area
	Worker hygiene	Implement and follow training program and hygiene policy
Packing	Packing material	Use new single-use containers or cleaned and sanitized recyclable plastic crates.
	Equipment surfaces	Clean and sanitize all equipment that comes in contact with fresh fruits and vegetables.
	Facility	Regularly remove all trimmings and culled product. Clean floors, walls, and drains on a regular schedule.
	Worker hygiene	Implement and follow training program and hygiene policy,

Table 1, continued. Layers in the postharvest handling chain where breaks can occur that lead to contamination.

Layers in the Supply Chain	Risk of Contamination	Reduction of Risk
Storage & Shipping	Storage rooms	Clean and sanitize on a regular schedule. Cool product as soon as possible. Maintain facility to prevent pooling water and condensation dripping onto produce
	Shipping vehicle	Clean and sanitize before loading, check temperature setting and running of equipment.
	Worker hygiene	Implement and follow training program and hygiene policy
Retailing and at Open Markets	Storage facilities	Clean and sanitize on a regular schedule. Do not allow a build-up of rubbish on the floors. Monitor refrigerator temperatures.
	Display cases and containers	Clean and sanitize on a regular schedule. Ensure that containers used to display product are clean and sanitized on a regular schedule. Monitor temperature setting if refrigerated. Avoid surfaces, baskets, or containers that cause cuts and bruises on fruits and vegetable.
	Worker hygiene	Implement and follow training program and hygiene policy

“Layers of Protection” involves multiple steps responding to multiple risks at each step. Listed are the areas where breaches in protection can occur in the major steps in handling fresh produce that can lead to contamination. Often the level of risk is determined by the size and culture of an operation and complacency of food safety responsibilities; therefore, an operation’s food safety culture is most important to ensure a safe food supply.

occur because of the following:

- Poor production practices that allow for human pathogen contamination
- Improper cleaning and sanitizing of fruits and vegetables at all stages of the supply chain
- Poor personal hygiene and work habits of produce handlers working in the supply chain

The goal of Layers of Protection is to reduce, eliminate, and avoid risks that could lead to contamination (Table 1).

Worker hygiene and animal fecal contact are major sources of bacteria, viruses, and parasites that are human pathogens (Suslow et al. 2003, Parker et al. 2012). Education and training is the critical and crucial first step in avoiding contamination, coupled with easy



Left: Papaya fruit with bird droppings should not be packed. Right: Lack of toilet facilities or poorly maintained facilities without soap and water for washing or single-use towels for drying is a common problem.

access to clean, sanitary, and well-maintained toilet facilities near the work site (Gil et al. 2015). Workers should be healthy, without any illness, recent wounds, or injuries that cause bleeding. Hand washing before and after handling fresh produce and going to the toilet is critical. Hands should be washed for 20 seconds with soap and water. After education and training, all workers should be aware of their role and responsibility to keep produce they handle safe. Regular training will help to reinforce these concepts.

Fresh produce is often consumed uncooked (salads, fresh fruit), with no “kill step,” and microbial contamination is extremely difficult to remove once on produce. The difficulty of removing pathogens is

made worse by the presence of natural openings, stem scars, bruises, and cuts on fresh fruits and vegetables. Also, human pathogens, under the right conditions, can multiply on produce surfaces and in wounds that occur during harvest and postharvest handling. Often mechanical injury is due to impact and abrasion when a product comes into contact with rough surfaces, poor handling, and even the netting in consumer packs. As contamination occurs sporadically, handling throughout the layers of the supply chain should be reviewed on a continuous basis (Kirezieva et al. 2013).

Harvest, Maturity, and Postharvest Handling

Researchers and commercial fruit and vegetable handlers around the world have assembled a significant body of data on how most common fruits and vegetables should be harvested, graded, treated, stored, and marketed. This data is now available free online. One of the sources is the USDA Handbook #66, which has been recently updated. This handbook is available at <https://www.ars.usda.gov/oc/np/commercialstorageintro/>. In Hawai‘i, further updated versions of the tropical fruits and vegetables sheets can be found in the fruit and vegetable section at <https://www.ctahr.hawaii.edu/site/BrowsePubs.aspx> as “Postharvest Quality-Maintenance Guidelines.” These publications and fact sheets are components of ensuring food safety. The college also has a website devoted to Farm Food Safety at <http://manoa.hawaii.edu/ctahr/farmfoodsafety/>, as well as a statewide Extension team who can provide advice.

During the movement of fresh, raw fruits and vegetables to market, farmers, packers, shippers, wholesalers, and retailers frequently do not have enough facilities to set the optimum conditions for each commodity. This limitation is especially true for specialty crops handled in small quantities. Under these circumstances, the focus should be on rapid movement of a product to the next step in the supply chain, avoidance of exposure to high temperatures and direct sunlight, and avoiding rough handling of product (dropping, throwing, etc.).

Guidelines

Concerns about food safety have led to changes in produce-handling practices.

FSMA regulations have been developed to minimize microbial food-safety hazards on fresh fruits and



Poor postharvest handling and sorting at the side of the road without protection from contamination (above) and washing produce in non-potable water (below).

Table 2. Layers of Protection in the journey from the field to the consumer for fresh fruits and vegetables and the practices to minimize the possibility for contamination with pathogens

Layer of Protection	Practices
Production	<p><i>Soil Amendments</i></p> <ul style="list-style-type: none"> • Soil amendments, especially those that contain raw manure, can introduce produce safety risks • To reduce risks associated with soil amendments, apply untreated manure to non-producing fields and treat raw manure by composting • Extend the time between application of raw manure and harvest • Ensure storage areas do not contaminate fields, water sources, or packing areas • Train workers how to handle and apply soil amendments • Develop sanitation steps for tools and equipment • During application, do not bring soil amendments containing manure or compost into contact with the edible portion of the crop. • Do not side-dress with raw manure. • Keep records of all soil amendments and other treatments to reduce risks of contamination. <p><i>Animals in Fields</i></p> <ul style="list-style-type: none"> • Feces and urine from domesticated and wild animals can contaminate fields and water sources. • Steps should be taken to reduce risks from animals entering a field. • The presence of animals in a field does not mean that the produce is contaminated. • If animals do enter a field, monitor the field during the growing season for evidence of contamination. • Keep records of actions taken to exclude animals to reduce risks of contamination. <p><i>Irrigation water</i></p> <ul style="list-style-type: none"> • Depending water source, this can be a cause of contamination. Public water supplies are generally safe; ground water can be safe while surface water can be a risk. Testing is required. • If the water does not contact the harvestable portion, the risk of contamination is low. Sprinkler irrigation can contaminate a product and spread a pathogen. • Timing of application can alter the risk of contamination; application near harvest has the greatest risk.
Harvesting	<ul style="list-style-type: none"> • Only allow healthy personnel to carry out harvesting. • Avoid fruits and vegetables with animal feces. such as bird droppings. • Train personnel as to the optimum harvest indices for the fruit and vegetables. • Only harvest at appropriate maturity stages (color, firmness, stage of development, firmness, etc.). • Harvest either early in the morning or late in the afternoon in order to minimize the sun's effects. • Use sanitized harvesting picking bags and containers. • Optimize harvesting containers (size, materials, height, number of produce layers) to limit mechanical injury • Protect product from direct sun and possible contamination sources.

Table 2, continued. Layers of Protection in the journey from the field to the consumer for fresh fruits and vegetables and the practices to minimize the possibility for contamination with pathogens

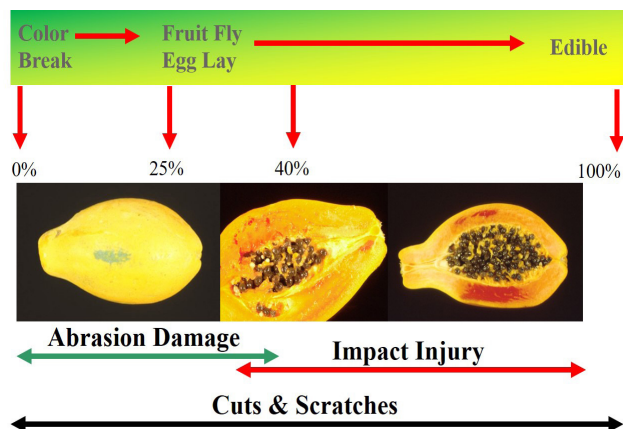
Layer of Protection	Practices
Postharvest Handling	<ul style="list-style-type: none"> • Postharvest water management is critical; use only potable water that has no detectable generic <i>E. coli</i> in 100 mL water sample • Wash water should be warmer than the product to avoid thermal shock that can lead to water absorption and bacteria entry. • If ice or ice slurry is used for cooling, it must be made from water that is free of detectable generic <i>E. coli</i>/100 mL water • Consider adding a sanitizer to all water used; chlorine is most commonly used. • Monitor both the water and any sanitizer used to ensure postharvest water quality. • Take corrective actions when needed; keep detailed records and develop Standard Operating Procedures (SOPs) for key water-management steps.
Grading, Packing, Loading	<ul style="list-style-type: none"> • All packing areas must have sanitation practices that minimize contamination. • Worker hygiene is essential; sick workers should be sent home. • Only new, single-use containers or cleaned, reusable containers should be used to pack fruits and vegetables. • Identify all of the food-contact surfaces as produce moves through the packing and storage areas—focus on keeping these surfaces clean. • Clean all surfaces that come in contact with produce, then use a sanitizer on the surface. • Safety practices such as cleaning, maintenance, and general housekeeping, along with pest control, are essential to reduce risks. Remove all trimmings and culled product and garbage every day or as needed throughout the day • Record keeping is critical and should include cleaning and sanitizing of contact surfaces, tools, equipment, and containers; pest management; building maintenance and monitoring; worker training on sanitation procedures; packing area and cold storage cleaning and monitoring; and vehicle cleaning and inspections prior to loading.
Transportation	<ul style="list-style-type: none"> • Inspect all vehicles prior to loading to ensure that they are clean and free from all debris and off odors. • If contracting your shipment, add to the contract that the vehicle must be in good condition, clean, and sanitized. • Refrigeration vehicles, besides being clean and sanitized, should have running refrigeration units set at the correct temperature and air exchange, and they should be checked prior to loading.

vegetables, based on guidelines for Good Agricultural Practices (GAP) and Standard Operating Procedures (SOP).

In the US, major retailers and food-service chains are establishing criteria for suppliers. Besides FSMA compliance, buyers may also require self and third-party audits to verify use of Good Agricultural Practices (GAP), Good Handling Practices (GHP), and Good Manufacturing Practices (GMP). Guidelines have been

issued by US Food and Drug Administration (FDA).

GAP and GHP are voluntary protocols intended to help, not regulations, while GMP are regulated and enforced. Most of the guidelines are commonsense and are likely being implemented in many operations anyway but may not be being monitored and recorded. Complying with these standards should be seen as adding value to your product and can distinguish your product from that of other suppliers.



Papaya ripeness at harvest and susceptibility to injury. All mechanical injury create sites that allow pathogens to grow.

Local Websites on Food Safety

Good Agricultural Practices on the Farm and in Your Home Garden. 2017. <https://www.youtube.com/watch?v=wO5miD90wMQ>

FSMA. Dissecting the Food Safety Modernization Act (FSMA). Produce Rule & Good Agricultural Practices (GAP) J. Sugano, J. Uyeda, L. Nakamura-Tengan, J. Hollyer, S. Motomura, J. Kahana, M. Murakami, F. Mencher, B. Miyamoto, E. Gushiken, K. Akahoshi, K. Wong, F. Reppun, K. Fiedler, & S. Sibonga, 2016. <https://cms.ctahr.hawaii.edu/Portals/224/SOAP/Policies/CTAHR%20FSMA%20Grower%20Overview-Interpretations%20May%202016.pdf>

James R. Hollyer, Vanessa A. Troegner, Robert H. Cowie, Robert G. Hollingsworth, Lynn C. Nakamura-Tengan, Luisa F. Castro, and Arlene E. Buchholz. 2010. Best On-Farm Food Safety Practices: Reducing Risks Associated with Rat Lungworm Infection and Human Eosinophilic Meningitis. CTAHR University of Hawai'i. Food Safety and Technology FST-39. <https://www.ctahr.hawaii.edu/oc/freepubs/pdf/FST-39.pdf>

References

Banach, J.L., Sampers, I., Van Haute, S. and Van der Fels-Klerx, H.J., 2015. Effect of disinfectants on preventing the cross-contamination of pathogens in fresh produce washing water. *International Journal*

of Environmental Research and Public Health 12:8658–8677.

Gil, M.I., Selma, M.V., Suslow, T., Jacxsens, L., Uyttendaele, M. and Allende, A., 2015. Pre-and postharvest preventive measures and intervention strategies to control microbial food safety hazards of fresh leafy vegetables. *Critical Reviews in Food Science and Nutrition* 55:453–468.

Holvoet, K., Jacxsens, L., Sampers, I. and Uyttendaele, M., 2012. Insight into the prevalence and distribution of microbial contamination to evaluate water management in the fresh produce processing industry. *Journal of Food Protection* 75:671–681.

Holvoet, K., Sampers, I., Seynnaeve, M., Jacxsens, L. and Uyttendaele, M., 2014. Agricultural and management practices and bacterial contamination in greenhouse versus open field lettuce production. *International Journal of Environmental Research and Public Health* 12:32–63.

Kirezieva, K., Jacxsens, L., Uyttendaele, M., Van Boekel, M.A. and Luning, P.A., 2013. Assessment of food safety management systems in the global fresh produce chain. *Food Research International* 52:230–242.

Kirezieva, K., Luning, P.A., Jacxsens, L., Allende, A., Johannessen, G.S., Tondo, E.C., Rajkovic, A., Uyttendaele, M. and van Boekel, M.A., 2015. Factors affecting the status of food safety management systems in the global fresh produce chain. *Food Control* 52:85–97.

Laury-Shaw, A., Strohhahn, C., Naeve, L., Wilson, L. and Domoto, P., 2015. Current trends in food safety practices for small-scale growers in the midwest. *Food Protection Trends* 35:461–469.

Love, K., Nancy J. Chen, Robert E. Paull. 2014. Quick Harvest and Postharvest Tips for Better Quality and Longer Postharvest Life. University of Hawaii at Manoa, College of Tropical Agriculture and Human Resources. Fruit, Nut, and Beverage Crops, July 2014, F_N- 36. http://www.ctahr.hawaii.edu/oc/freepubs/pdf/F_N-36.pdf

Manzocco, L., Ignat, A., Anese, M., Bot, F., Calligaris, S., Valoppi, F. and Nicoli, M.C., 2015. Efficient management of the water resource in the fresh-cut industry: Current status and perspectives. *Trends in Food Science & Technology* 46:286–294.

Murray, K., Wu, F., Shi, J., Jun Xue, S. and Warriner,

- K., 2017. Challenges in the microbiological food safety of fresh produce: Limitations of post-harvest washing and the need for alternative interventions. *Food Quality and Safety* 1:289–301.
- Parker, J.S., Wilson, R.S., LeJeune, J.T., & Doohan, D. (2012). Including growers in the “food safety” conversation: Enhancing the design and implementation of food safety programming based on farm and marketing needs of fresh fruit and vegetable producers. *Agriculture and Human Values* 29:303–319. <http://dx.doi.org/10.1007/s10460-012-9360-3>
- Parker, J.S., DeNiro, J., Ivey, M.L. and Doohan, D., 2016. Are small and medium scale produce farms inherent food safety risks? *Journal of Rural Studies* 44:250–260.
- Paull, R.E. 1999. Effects of temperature and relative humidity on fresh commodity quality. *Postharvest Biology & Technology* 15:263–277.
- Paull, R.E., Nancy Jung Chen. 2004. The potential of postharvest technologies to maintain quality. *Acta Horticulturae* 694:377–385.
- Suslow, T.V., Oria, M.P., Beuchat, L.R., Garrett, E.H., Parish, M.E., Harris, L.J., Farber, J.N. and Busta, F.F., 2003. Production practices as risk factors in microbial food safety of fresh and fresh-cut produce. *Comprehensive Reviews in Food Science and Food Safety* 2:38–77.