Microbiological Safety of Fresh Produce from the Farm-to-Table Food Chain

Hidemi Izumi

Abstract

On-farm food safety program such as Good Agricultural Practices (GAP) has been recommended in the United States, because fresh produce can become contaminated with microorganisms along the farm-to-table food chain and can be the source for foodborne pathogens. However, a more intensive and extensive research studies are needed to establish and implement a validated GAP program for all produce in Japan. Our research showed that the microbial count was basically higher on vegetables than on fruits, and approximately 80% of the total isolates were bacteria in vegetables and molds in fruits. Most of the bacteria and molds isolated from produce are phytopathogenic and soilborne organisms. The on-farm sources of microbial contamination are from soil, fertilizer, agricultural water, pesticide solution, and humans at the preharvest level and soil, agricultural and rinse waters, packing shed equipment, and humans at the postharvest level. To better understand the interaction of environmental conditions and various treatments in reducing and regulating spoilage and human pathogens, we have researched preharvest treatments including chlorination of agricultural water and ethyl alcohol spraying on packing shed equipment, postharvest treatments including chemical disinfectants with electrolyzed water and ozonated water for fresh produce, and packaging technologies including active modified atmosphere packaging (MAP) of high CO_2 during storage and distribution. These procedures will be effective in establishing a scientific baseline for designing and improving food safety guidelines that will control microbial quality and assure safety of fresh produce in Japan.

1. Introduction

The U.S. Food and Drug Administration (FDA), the U.S. Department of Agriculture (USDA), and Centers for Disease Control and Prevention (CDC) recommend the Good Agricultural Practices (GAP) program [(1)] in combination with the Hazard Analysis and Critical Control Point (HACCP) program [(2)] as the most effective and flexible programs for assuring food safety of produce on all stages of the farm-to-table food chain. GAP addresses microbial food safety hazards in the agricultural and management practices for growing, harvesting, washing, sorting, packing, and transporting of most fresh fruits and vegetables. The produce guide identifies potential points of contamination along the farm-to-table chain and prevention of microbial contamination rather than corrective actions once contamination has occurred. Four potential sources of microbial contamination are: (1) water quality (agricultural water, processing water, and washing water); (2) treated and untreated manure/municipal biosolids; (3) worker health and hygiene; and (4) field, facility, and transport sanitation (toilet facilities and hand washing station, sewage disposal, equipment maintenance, and pest control). GAP is a voluntary program and performed by many growers, packers and shippers in the U.S.A.

Since the food safety guidelines in Japan are still in its infancy for implementation, intensive and extensive research studies are needed to better understand the interaction of environmental conditions and various treatments in reducing and regulating spoilage and human pathogens in Japan. We initially identified origin of microflora and potential sources of microbial contamination of fresh produce, which is the first step to identifying appropriate solutions. Subsequently, we determined effects of preharvest sanitation treatments, postharvest chemical treatments, and modified atmosphere packaging (MAP) technologies on microbial control of fresh produce. Results of these studies are discussed here, which will be helpful in establishing a scientific baseline for designing and improving food safety guidelines such as GAP to result in safe fresh produce in Japan.

2. Microflora in fresh produce

2.1 Fresh vegetables

Approximately 80% of the total isolates are bacteria in vegetables and the remainder is yeasts and molds. Bacterial counts on

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Department of Science and Technology on Food Safety, Kinki University, Wakayama 649-6493, Japan

vegetables vary widely within and among produce types. With cucumber, lettuce, spinach, and carrots, counts of total bacteria and coliform group range from 3.0 to 6.5 log CFU/g and 3.3 to 4.3 log CFU/g, respectively, while in tomatoes, onions, and garlic, the bacterial count is below the detection level (2.4 log CFU/g) (Table 1)[3]. The degree of contamination is dependent on the environmental conditions from growing to marketing[4], the morphological stage [5], and the physiological and physicochemical condition including pH and water activity of the product [6].

The bacterial flora of vegetables comprises primarily phytopathogenic bacteria such as the genera *Agrobacterium* and *Pseudomonas* and Enterobacteriaceae such as the genera *Enterobacter* and *Pantoea* (Table 2) [7]. The most frequently identified bacteria are *Pantoea agglomerans* and *Pseudomonas fluorescens*, which are pectinolytic and cause soft rots in fresh vegetables[8, 9]. Other Gram-negative rods such as *Stenotrophomonas* and *Xanthomonas* and Gram-positive bacteria such as *Bacillus* and *Staphylococcus*, and lactic acid bacteria such as *Enterococcus* and *Leuconostoc* are present in various fresh vegetables. These bacteria isolated from vegetables are found frequently in soil, agricultural water, and pesticide solution and do not usually represent a public health concern [6, 9].

Table 1 Counts of total bacteria and coliform group from outer and inner tissues of several vegetables sampled from retail outlets [3]

Vegetable	Tissue	Log CFU/g	
		Total bacteria	Coliform group
Cucumber	Outer	6.5	4.3
	Inner	3.5	< 2.4
		**	**
Tomato	Outer	< 2.4	ND
	Inner	ND	ND
Lettuce	Outer	4.7	3.3
	Inner	3.0	< 2.4
		**	**
Spinach	Outer	4.5	3.9
	Inner	4.9	3.9
		NS	NS
Carrot	Outer	5.4	3.3
	Inner	< 2.4	ND
		**	**
Onion	Outer	ND	ND
	Inner	ND	ND
Garlic	Outer	< 2.4	ND
	Inner	< 2.4	ND

< 2.4: Below the detection level (2.4 log CFU/g)
ND: Not detectable
NS, ** : Nonsignificant or significant at 1% level, respectively, between paired outer and inner tissues within total bacteria or coliform group

Table 2 Bacteria isolated from cucumber, bell peppers, carrots, and spinach [7]

Gram type	Bacteria	
	Genus	Species
Positive	*Arthrobacter*	*mysorens,nicotianae*
	Bacillus	*megaterium, niacini, popilliae, subtillis, cereus*
	Curtobacterium	*citreum, luteum*
	Enterococcus	*casseliflavus*
	Exiguobacterium	*acetylicum*
	Leuconostoc	*mesenteroides*
	Staphylococcus	*sciuri, saprophyticus*
Negative	*Agrobacterium*	*rhizogenes, tumefaciens*
	Citrobacter	*freundii*
	Enterobacter	*asburiae, amnigenus, cloacae, dissolvens,*
	Klebsiella	*pneumoniae*
	Leclercia	*adecarboxylata*
	Pantoea	*agglomerans, ananas, dispersa*
	Pseudomonas	*aeruginosa, alcaligenes, cichorii, fluorescens, fulva,*
	Rahnella	*aquatilis*
	Serratia	*plymuthica*
	Stenotrophomonas	*maltophilia*
	Xanthomonas	*campestris*

2.2 Fresh fruits

Microbial population in most fresh fruits is below the detection level (2.4 log CFU/g for bacteria and 3.0 log CFU/g for fungi) except for the peel of a few fruits, in which the counts of total bacteria and fungi range from 2.9 to 3.6 log CFU/g and 3.3 to 4.0 log CFU/g, respectively (Table 3) [10]. External barriers such as peel and the interior low pH in flesh prevent microorganisms from entering and growing, respectively.

The frequency of bacteria and yeasts is few and molds comprise approximately 80% of the total isolates in fresh fruits, probably due to low pH and high sugar content in the flesh. The mold flora consists of phytopathogenic

Table 3 Counts of total bacteria, coliform group, and fungi in peel and flesh of several fruits sampled from different farms [10]

Fruits (Farm name)	Part of fruit	Log CFU/g		
		Total bacteria	Coliform group	Fungi
Persimmon (Farm A)	Peel	<2.4	<2.4	3.3
	Flesh	<2.4	ND	ND
Persimmon (Farm B)	Peel	<2.4	ND	<3.0
	Flesh	<2.4	ND	<3.0
Satsuma mandarin	Peel	<2.4	ND	<3.0
(Farm A)	Flesh	ND	ND	<3.0
Satsuma mandarin	Peel	3.9	<2.4	3.5
(Farm B)	Flesh	<2.4	ND	<3.0
Lemon	Peel	3.6	<2.4	4.0
	Flesh	ND	ND	<3.0
Japanese apricot	Peel	2.9	<2.4	<3.0
(Farm A)	Flesh	<2.4	ND	<3.0
Japanese apricot	Peel	<2.4	<2.4	<3.0
(Farm B)	Flesh	<2.4	ND	<3.0
Japanese plum	Peel	<2.4	<2.4	<3.0
	Flesh	<2.4	<2.4	<3.0

< 2.4, < 3.0: Below the detection level (2.4 log CFU/g for bacteria and 3.0 log CFU/g for fungi)
ND: Not detectable

organisms such as the genera *Alternaria*, *Diaporthe*, *Fusarium*, *Penicillium*, and *Pestalotia* and soil borne organism such as the genera *Cercophra*, *Cladosporium*, and *Ochroconis* (Table 4)[10]. We found that no human pathogens such as *Salmonella* and verotoxin-producing *Escherichia coli* were detected from any of the produce sampled in Japan [10-14].

Table 4 Bacteria, molds, and yeasts isolated from persimmon, satusma mandarin, and Japanese apricot fruits [10]

Fruits	Part of fruit	Bacteria		Molds		Yeasts	
		Genus	Species	Genus	Species	Genus	Species
Persimmon	Peel	*Curtobacterium*	*flaccumfaciens*	*Aschersonia*	sp.	ND	
		Terrabacter	*tumescens*	*Coprinus*	*micaceus*		
				Diaporthe	*melonis*		
				Dichomitus	*squalens*		
				Eutypa	sp.		
				Phanerochaete	*sordida*		
				Phialemonium	*aff*		
				Phialophora	sp.		
				Trichoderma	*inhamatum*		
	Flesh	*Pediococcus*	*parvulus*	ND		ND	
Satsuma mandarin	Peel	*Pantoea*	*agglomerans*	*Alternaria*	sp.	*Occultifur*	*externus*
			ananatis	*Diaporthe*	*melonis*	*Pichia*	*guilliermondii*
				Fungal	sp.		
				Glomerella	*cingulata*		
				Letendraea	*helminthicola*		
				Nalanthamala	*squamicola*		
				Pestalotia	*photiniae*		
				Plectosphaerella	*cucumerina*		
	Flesh	ND		*Fungal*	sp.	*Pichia*	*guilliermondii*
Japanese apricot	Peel	*Curtobacterium*	*albidum*	*Cercophora*	*mirabilis*	*Candida*	*fructus*
			citreum	*Cladosporium*	sp.	*Issatchenkia*	*terricola*
			flaccumfaciens	*Colletotrichum*	*gloeosp*		
				Fusarium	*bactridioides*		
				Mycosphaerella	*rabiei*		
				Myrothecium	*roridum*		
				Ochroconis	sp.		
				Penicillium	*digitatum*		
					minioluteum		
				Pestalotia	sp.		
				Phialophora	sp.		
				Septoria	*calendulae*		
	Flesh	ND		*Hyphoderma*	*setigerum*	ND	
				Penicillium	*aculeatum*		
				Phialophora	*repens*		

ND : Not detectable

3. Sanitation for food safety program of fresh produce

3.1 Chlorination of agricultural water

Many opportunities for cross-contamination of produce exist during production, because anything that comes in contact with produce becomes a potential source of microbial contamination. Preharvest sources of contamination include feces, animals, insects, irrigation water, pesticide solution, manure, and humans [15-18]. Agricultural water is one of the most important preharvest contamination sources, because we found that verotoxin-producing *Escherichia coli* (*E. coli* O157:H7) was identified from agricultural water and *Salmonella* was detected in agricultural water, pesticide solution containing the agricultural water for the mixture, and soil after application of the pesticide solution in persimmon orchards in Japan [12]. We also reported that the pesticide solution after mixing with agricultural water was positive for *Salmonella* in satsuma mandarin orchard [13] and verotoxin-

Table 5 Bacterial flora in agricultural water, chlorinated water, and pesticide solution containing agricultural water or chlorinated water for the mixture in cabbage production field [20]

Sample	Total bacteria (Log CFU/ml)	Bacteria		
		Gram type	Genus	Species
Agricultural water	1.5 ± 0.1	Positive	*Bacillus*	*licheniformis*
				simplex
			Geobacillus	*thermoglucosidasius*
			Mycobacterium	*chlorophenolicum*
		Negative	*Sphingomonas*	*yanoikuyae*
Pesticide solution containing agricultural water	1.7 ± 0.0	Positive	*Bacillus*	*amyloliquefaciens*
				cereus
				megaterium
			Paenibacillus	*polymyxa*
		Negative	*Burkholderia*	*cepacia*
			Pseudomonas	*antimicrobica*
Chlorinated water	ND		ND	
Pesticide solution containing chlorinated water	ND		ND	

ND : Not detectable

producing *Escherichia coli* was detected in agricultural water and weeds after irrigation in Japanese apricots orchard [19].

Thus, we proposed chlorination of agricultural water as sanitation measures for reducing the risk of microbial contamination in production field of fruits [14] and vegetables [20]. Chlorinated water (ca 10 ppm available chlorine) reduced the microbial counts to levels below the lower limit of detection (1.4 log CFU/ml for bacteria and 2.0 log CFU/ml for fungi) in most agricultural water samples. Microbial counts and the numbers of microbial species detected in pesticide solution containing chlorinated water for the mixture were lower than those of pesticide solution diluted with agricultural water. In cabbage production field, bacteria were not detected in chlorinated water and pesticide solution containing chlorinated water (Table 5) [20].

3.2 Ethyl alcohol spraying on packing shed equipment

Several researchers have reported that postharvest strategies to minimize contamination were important as well as preharvest strategies, because microbial contamination of several produce significantly increased from field through packing [13, 21-23]. Postharvest sources of contamination include feces, insects, transport vehicles and containers, dump and rinse waters, packing and sorting, and humans [15-17, 24]. We reported that some packing shed equipment was assumed to be postharvest sources, because *Bacillus cereus* was not identified from the satsuma mandarin fruit in the production field but was detected on the peel after sorting and on equipment such as gloves, plastic harvest basket, and size sorter [13].

Therefore, ethyl alcohol (70%) spraying as sanitation measures was evaluated on disinfection of packing shed equipment during packing facility operations to minimize postharvest contamination [14, 20]. The ethyl alcohol spray reduced the microbial counts and the diversity of microflora on gloves used in satsuma mandarin packing shed (Table 6) [14]. The alcohol spray treatment on packing shed equipment resulted in a substantial microbial reduction not only on gloves but also plastic harvest basket and container, scissors, and size sorter. No human pathogens such as *Salmonella* and verotoxin-producing *Escherichia coli* were detected in any of the fruit and equipment samples. Our findings indicate that uses of sanitizers such as chlorine for agricultural water and ethyl alcohol for packing shed equipment would be useful in GAP program of produce in Japan.

Table 6 Bacterial and fungal flora on gloves treated with and without ethyl alcohol spray in satsuma mandarin packing shed [14]

Treatment	Total bacteria	Bacteria		Fungi	Molds	
	(Log CFU/100cm^2)	Genus	Species	(Log CFU/100cm^2)	Genus	Species
Control	2.6 ± 0.4	*Bacillus*	*cereus*	2.4 ± 0.3	*Cladosporium*	sp.
			fusiformis		*Davidiella*	*tassiana*
			pumilus		*Epicoccum*	*nigrum*
		Curtobacterium	*luteum*		*Nigrospora*	sp.
		Micrococcus	*luteus*		*Penicillium*	sp.
		Paenibacillus	*polymyxa*		*Trichosphaeria*	*pilosa*
		Flavimonas	*oryzihabitans*			
Ethyl alcohol spray	0.6 ± 0.6	*Paenibacillus*	*amylolyticus*	1.5 ± 0.1	*Penicillium*	*digitatum*
		Flavimonas	*oryzihabitans*			sp.
					Pithomyces	sp.

4. Disinfection and bacteriostasis for food safety program of fresh produce

4.1 Chemical treatment

Product washing is a step to reduce microbial population after harvest. A 100 to 150 ppm chlorine solution, prepared from sodium hypochlorite, is widely used in the food industry [25], but a high concentration of sodium hypochlorite for increased effectiveness may cause product tainting [26], toxic by-products formation [27], and sodium residue on the product and equipment [28]. Thus, electrolyzed water and ozonated water were evaluated as Japanese-devised alternatives to sodium hypochlorite.

Electrolyzed water approved as food additives include electrolyzed strong acidic water (pH<2.7, 20-60 ppm available chlorine) and weak acidic water (pH 5-6.5, 10-30 ppm available chlorine). In the pH range of 5-6 in the electrolyzed weak acidic water, hypochlorite acid (available chlorine), which kills the pathogens, is present at maximum concentration [29], while the low pH of 2-3 in electrolyzed strong acidic water sensitizes the outer membranes of bacterial cells, thereby enabling hypochlorous acid to penetrate the bacterial cells efficiently [30]. When the microbicidal effect of electrolyzed strong acidic water (pH 2.7, 25 and 50 ppm available chlorine) and weak acidic water (pH 6.5, 25 and 50 ppm available chlorine) was compared on fresh-cut vegetables by rinsing for 3 min, the reduction of bacterial counts of both electrolyzed water was similar and the count was 1 to 2

logs lower than tap water regardless of available chlorine concentration (Table 7) [31]. As regards to treatment method, rinsing or dipping/blowing treatment was more effective in reducing microbes than dipping only treatment [32]. For bacterial isolates from indigenous microflora of sliced cucumber, both electrolyzed acidic water were more effective against Gram-positive bacteria including *Staphylococcus* spp. than against Gram-negative bacteria including *Pseudomonas* spp. [31]. Electrolyzed water could be an effective disinfectant not only for spoilage but also for foodborne pathogens, resulting from effectiveness of the acidic waters in killing *Escherichia coli* O157:H7, *Salmonella* enteritidis, *Listeria monocytogenes*, and *Bacillus cereus* in aqueous system [30, 33].

Table 7 Total bacterial counts of trimmed spinach leaves, sliced cucumber, and shredded carrots dipped in tap water, electrolyzed strong acidic or weak acidic water containing 25 and 50 ppm available chlorine for 3 min [31]

Treatment	Available chlorine	Log CFU/g		
		Spinach	Cucumber	Carrots
Nontreatment	—	6.4 a	5.2 a	4.3 a
Tap water	0.3ppm	5.2 b	4.8 ab	3.1 b
Electrolyzed strong acidic water	25ppm	2.9 c	3.2 c	3.0 bc
	50ppm	2.9 c	3.1 c	2.7 c
Electrolyzed weak acidic water	25ppm	3.0 c	4.3 b	3.0 bc
	50ppm	3.3 c	3.1 c	2.4 c

abc: Mean separation in the same column by Duncan's multiple range test (P=0.05)

Table 8 Total bacterial counts of shredded cabbage and chopped lettuce dipped in tap water or ozonated water containing 5 and 10 ppm ozone for 3 min [36]

Treatment	Ozone	Log CFU/g	
		Cabbage	Lettuce
Tap water	0ppm	4.5 a	5.2 a
Ozonated water	5ppm	3.6 b	5.1 a
Ozonated water	10ppm	3.5 b	4.7 b

ab: Mean separation in the same column by Duncan's multiple range test (P=0.05)

Ozonated water may be an effective alternative to chlorinated solution, since ozone is a powerful antimicrobial gas due to its potential oxidizing capacity and leaves no residues because it degrades to oxygen quickly in water [34]. Ozonated water has been shown to be effective in killing spoilage and human pathogenic bacteria, yeasts, and molds, with the effectiveness being greater on Gram-negative pathogens [35]. We reported that dipping in ozonated water (5 and 10 ppm ozone) for 3 min reduced counts of total bacteria on fresh-cut cabbage and lettuce by 0.5 to 1 log CFU/g as compared to water dipped control (Table 8) [36]. When the treated fresh-cuts were stored at 10°C, the residual effect was observed throughout the storage period with fresh-cut cabbage, but not with fresh-cut lettuce. The degree of effectiveness appears to be dependent on type of vegetables, as noted with baby carrots [37], fresh-cut celery [38] and fresh-cut green peppers [39]. Therefore, effectiveness of a disinfectant differs with produce and needs to be evaluated and defined accordingly.

4.2 MAP technologies

It is important to consider microbial quality and safety of fresh produce during storage and distribution. In addition to temperature management as the most effective tool, controlled atmosphere (CA) and MAP, which reduced O_2 levels (1-5%) and/or increased CO_2 levels (5-10%), have been shown to be beneficial in extending shelf life of fresh produce by reducing physiological and physicochemical changes [40-43]. The O_2 and CO_2 levels in CA and MAP commonly used for fresh produce could reduce microbial growth indirectly by retarding advanced stages of senescence of the host tissue, which resists attack by microorganisms. To inhibit microbial growth directly, high CO_2 levels of >10% and/or high O_2 levels of >21% are expected not only for spoilage bacteria but also for foodborne pathogenic bacteria [44, 45]. However, exposure of

Table 9 Total bacterial counts of 'Carabao' and 'Nam Dokmai' mango cubes stored under air and high CO_2 controlled atmospheres at 5°C and 13°C [48]

Temperature (℃)	Days in storage	Treatment	Log CFU/g	
			'Carabao'	'Nam Dokmai'
5	0		< 2.4	2.9
	7 ('Carabao') or 6 ('Nam Dokmai')	Air	< 2.4	< 2.4
		3% CO_2	< 2.4	2.6
		5% CO_2	< 2.4	< 2.4
		10% CO_2	ND	< 2.4
13	0		< 2.4	5.3
	5 ('Carabao') or 2 ('Nam Dokmai')	Air	3.2 a	6.5 a
		3% CO_2	3.8 a	6.4 a
		5% CO_2	2.9 a	6.3 a
		10% CO_2	< 2.4 b	3.7 b

< 2.4: Below the detection level (2.4 log CFU/g)

ND: Not detectable

ab: Mean separation in the same column by Duncan's multiple range test (P=0.05)

produce to high O_2 >21% may stimulate, have no effect, or reduce physiological responses and sensitivity of microorganisms, and the response depends on the commodity, O_2 concentration, time and temperature of storage, and CO_2 and C_2H_4 concentrations in the atmosphere [46].

In our studies on fresh-cut produce stored in CA/MAP, a 10% CO_2 atmosphere helped in reducing bacterial population and the bacterial density in microbial flora of fresh-cut cabbage [47] and mango held at 5 and 13°C (Table 9) [48]. Active modification of the atmosphere inside the package by application of the gas could be helpful in achieving the equilibrium atmosphere readily and quickly. Therefore, active MAP with initial 10% CO_2 would be recommended for the storage of fresh produce based on microbiological quality [49, 50]. However, we also reported that a 20% CO_2 atmosphere accelerated the growth of facultative aerobes such as coliform group and lactic acid bacteria on fresh-cut cabbage [47] and a 60% O_2 atmosphere stimulated the growth of bacteria and yeasts on fresh-cut mango [51]. The increase of the microorganisms appears to be the main cause of deterioration of produce. These results indicated that a 10% CO_2 in active MAP in combination with good temperature management would be desirable for controlling microorganisms on fresh produce, but CO_2 levels >20% and high O_2 atmospheres should be avoided for CA or MAP.

5. Conclusion

There are several technologies that are being evaluated or used for controlling microbiological quality and assuring safety of fresh produce. However, technologies that are selected in reducing or eliminating microorganisms should be those that do not affect the organoleptic nor nutrient quality. Uses of sanitizers such as chlorine for agricultural water and ethyl alcohol for packing shed equipment would be useful in establishing a scientific baseline for designing GAP program of fresh produce. Washing with disinfectants such as electrolyzed water and ozonated water followed by active MAP of 10% CO_2 also could be effective procedures to control food safety hazard of fresh produce. These practices can serve as a general model of on-farm food safety program to be developed in a step wise manner in Japan.

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和文抄録

農場から食卓までの青果物の微生物的安全性

泉　秀実

青果物は農場から食卓までの間に微生物汚染を受け、食性疾患の原因となる可能性がある。米国では、農場の食品安全プログラムである適正農業規範（GAP）が推奨されている。しかし、日本では、青果物に有効なGAPプログラムを確立して実施するには、さらに広く深い微生物的研究が必要である。野菜と果実では、野菜のほうが果実よりも付着微生物は多く、微生物叢の約80%を野菜では細菌、果実ではカビが占める。これらの付着微生物は、植物病原菌および土壌由来菌が中心である。農場における栽培中の微生物汚染源は、土壌、肥料、農業用水、農薬およびヒトであり、収穫後の微生物汚染源として、土壌、農業用水と洗浄水、収穫と出荷用具およびヒトが挙げられる。安全性を確立するためには、これらの青果物を取り巻く環境から微生物（腐敗原因菌と食性病原菌）汚染を防ぐための技術が要求される。筆者らは、収穫前では農業用水の塩素殺菌と収穫用具のエタノール消毒、収穫後では電解水やオゾン水を利用した青果物の化学的殺菌、さらに貯蔵・流通中では高二酸化炭素を充填したフィルム包装技術（MAP）を検討してきた。これらの微生物制御技術は、日本における青果物の衛生管理法として、科学的技術に基づくGAPの確立と発展に役立つものと期待される。

近畿大学生物理工学部 食品安全工学科，〒649-6493 和歌山県紀の川市西三谷930