REDUCING THE POTENTIAL FOR BACTERIAL SOFT ROT IN POTATO TUBERS BY CHEMICAL TREATMENTS AND DRYING

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Abstract

The potential for bacterial soft rot caused by *Erwinia carotovora* in freshly inoculated potato tubers was reduced up to 99% by immersion for 5 min in solutions of sodium hypochlorite (chlorine bleach) containing up to 10,000 ppm chlorine. Reductions up to 93% were achieved using a combination treatment of immersion in 1% citric acid for 5 min followed by air-drying. Immersion treatment alone in 1% aqueous solutions of citric, acetic, ascorbic, or malonic acid also significantly reduced the soft rot potential. In contrast, no reductions accompanied treatment with solutions of potassium or calcium acetate. All treatments including the combination immersion/air-drying treatment were much less effective if tubers had been infiltrated initially with soft rot *Erwinia* or had numerous mechanical injuries. If tubers had not been infiltrated with the causal organism, immersing them in 1% citric acid reduced the potential nearly as much as a similar treatment with 1000 ppm chlorine. A 30-sec immersion in the latter was less effective than a similar treatment with 500 ppm a.i. CGA 78039, an experimental bactericide. However, air-drying, coupled with provisions for keeping tuber surfaces free from moisture, remains the most effective means of reducing losses to bacterial soft rot.

Resumen

El potencial de la pudrición blanda bacteriana causada por *Erwinia carotovora*, en tubérculos de papa inoculados recientemente, se redujo hasta en 99%, por la inmersión de los mismos, durante 5 minutos, en soluciones de hipoclorito de sodio (lejía) conteniendo hasta 10 000 ppm de cloro. Se lagraron reducciones hasta de 93% utilizando un tratamiento combinado de inmersión en ácido cítrico al 1% por 5 minutos, seguida por secado al aire. El tratamiento consistente en solo las inmersión en soluciones acuosas de ácidos cítricos, acético, ascórbico, y malónico al 1%, redujo también significativamente el potencial de la pudrición blanda. Por lo contrario, no se obtuvo reducción

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alguna por los tratamientos con soluciones de acetatos de potasio o de calcio. Todos los tratamientos, incluyendo la combinación de inmersión/secado al aire fueron menos efectivos cuando los tubérculos fueron infiltrados inicialmente con la Erwinia de la pudrición blanda o cuando los tubérculos tenían numerosas lesiones mecánicas. Si los tubérculos no habían sido infiltrados con el organismo causal, la inmersión en ácido cítrico al 1% redujo el potencial tanto como un tratamiento similar con 1 000 ppm de cloro. Una inmersión por 30 segundos en el último tratamiento mencionado fue menos efectiva que un tratamiento similar con 500 ppm de un bactericida experimental como el CGA 78039. Sin embargo, el secado al aire, acompañado de precausiones para mantener las superficies de los tubérculos libres de humedad se mantiene como el medio más eficaz para reducir las pérdidas debidas a la pudrición blanda bacteriana.

Introduction

Bacterial soft rot caused by pathovars of *Erwinia carotovora* is one of the most important diseases affecting potato (*Solanum tuberosum* L.) tubers during storage and transit (9, 17, 22, 23). Normally, bacterial soft rot develops in wet tubers (7), at the margin of lesions in diseased or badly injured tubers (21, 22), or at high temperatures (17). Tubers are susceptible to soft rot *Erwinia* only when tissues are deficient in oxygen (7, 10, 17, 18, 21, 22). Commercially, such conditions commonly occur in bins, packages (25), or shipments (9) if tubers become covered with a film of moisture. Oxygen levels in vented polyethylene bags of freshly harvested tubers are below those normally found in the atmosphere (25), but not at levels associated with tissue anaerobiosis (10).

Bacterial soft rot in potato tubers may be minimized commercially by practices that remove free moisture from tuber surfaces after washing or that prevent/eliminate condensation. The importance of drying washed tubers before packaging was first demonstrated over 40 yr ago (23), long before the presence of water films on tuber surfaces was related to tissue anaerobiosis (7), and susceptibility to soft rot (17, 18, 22). More recently, other practices and conditions that affect the potential for bacterial soft rot have been described (1, 3-6, 9, 10, 14-20, 22, 25). The potential for bacterial soft rot is influenced by the number and position of cells of soft-rot *Erwinia* in lenticels (1, 5), presence and type of fresh injury (3, 18, 19), age of tubers (1, 25), wound healing (curing) (15, 19), cultivar (1, 16), calcium level (20), and water potential of tuber tissues (14).

Since high numbers of soft rot bacteria on tuber surfaces have been related to high potentials for the disease, treatments that reduce these populations should also reduce the potential. In practice, air-drying reduces the number of soft rot *Erwinia* in the peel and usually reduces the potential for decay (6, 23). It follows that use of clean rather than recycled water at

packinghouses would help reduce the possibility that tubers would become inoculated with high inoculum concentrations during fluming and washing. In laboratory tests, increased disease was associated with immersion in high populations of Ecc (4), whereas less disease in comparison with control treatments resulted when various antibacterial compounds were used to inhibit *Erwinia* populations on tuber surfaces (2, 8, 12, 25, 27). Salts of certain organic acids that inhibit pectolytic enzymes were reported to reduce or delay bacterial soft rot (26). Applications of organic acids to plant surfaces have been proposed previously as a control of certain phytopathogenic bacteria (24).

The objective of this study was to compare the bacterial soft rot potentials in freshly washed potato tubers before and after treatment with air-drying, certain organic acids, hypochlorous acid, or an experimental bactericide.

Materials and Methods

General Procedures—The general procedures used, including preparation of cell suspensions of *Erwinia carotovora* subsp. *carotovora* (Jones) Bergey, *et al.* (Ecc) (strain SR-38), infiltration of tubers, incubation of tubers and disease rating have been described previously (3-6). Unwashed potato tubers, selected for size (200 to 400 g) and lack of evident wounds, were sampled from fields, packinghouses and storage facilities located in central Wisconsin. The tubers were either treated immediately upon arrival at the laboratory or if stored at 4 C, warmed to room temperature prior to treatment. The different samples used represented early and late crop tubers, hand and mechanically harvested tubers, tubers sampled before and after passage through a packinghouse, and uncured versus fully cured tubers from commercial storage.

Tubers were submerged for 5 min in water alone or suspension of Ecc diluted to about 5×10^6 colony forming units (cfu)/ml with deionized water and then stored in a plastic garbage bag until treated, dried or incubated. Tubers were infiltrated with cell suspensions of Ecc, solutions, or water alone by application of up to 530 cm hydrostatic pressure to submerged tubers as described previously (4-6). Samples of the treated tubers were air-dried until all traces of surface moisture had disappeared (1 to 2 hr). All tubers were then sprayed gently with tap water to insure initial uniform wetness and water films were maintained throughout incubation in a mist chamber at 20 C for a period of 3-4 days. A base-level soft rot potential was established for each sample of tubers as described previously (3-6).

Solutions of NaOCl were prepared by dilution of liquid laundry bleach (5.25% NaOCl) with tap water. Free chlorine concentrations were determined periodically with the DPD (N,N-diethyl-p-phenylenediamine) test (Hellige Inc., Garden City, NY 11530). The pH of the solutions was not

adjusted. In tests with tomato fruits, the pH (6 vs 9) of chlorine solutions did not consistently affect the level of control associated with exposure to a given level of free-chlorine (Bartz, unpublished). Except for cinnamic acid, solutions of organic acids or salts of those acids were prepared from standard dry laboratory chemicals diluted to 50 mM or 0.01, 0.1, 1 or 2% with tap water, depending on the test. Cinnamic acid, which is relatively insoluble in water, was dissolved in 50 mM NaOH.

After incubation, each tuber was rated for percentage surface area decayed using the Horsfall-Barratt system (13). The Horsfall-Barratt numbers were used in statistical analyses that were completed with the Statistical Analysis System (SAS Institute Inc., Box 8000, Cary, NC 27511) using computing facilities at the University of Wisconsin, Madison or the Northeast Regional Data Center (NERDC) at the University of Florida, Gainesville.

Other procedures varied according to the specific needs of the following experiments.

Organic Acid Treatment of Naturally Inoculated Potato Tubers—Machine-harvested tubers were sampled at the entrance to a packinghouse (pre-ph) and just before the bagging machinery inside the packinghouse (post-ph). Seven-tuber samples from each lot were submerged in a solution of organic acid or 1000 mg/L Cl_2 from NaOCl for 5 min. Tubers in one set of samples were infiltrated with the treatment solutions. Organic chemicals used at 50 mM included ascorbic acid, cinnamic acid, citric acid, malonic acid, and calcium acetate. Potassium sorbate, a known food preservative, was used in the form of a solution (2% w/v) with the pH reduced to 6.0 by addition of 0.5 M sodium acetate.

Organic Acid Treatment of Artificially Inoculated Tubers—Hand-harvested tubers (cv. Russet Burbank) were submerged in a suspension of Ecc or submerged and infiltrated with the suspension and then treated for 5 min in 50 mM solutions of citric acid, calcium acetate, or potassium acetate, chlorinated water at 250 or 1000 mg/L Cl_2, or water alone. Five tubers from each 10-tuber treatment were air-dried.

Infiltration of Lenticels on Inoculated Tubers with Solutions of Organic Acid or Sodium Hypochlorite—Uncured machine-harvested tubers (cv. Russet Burbank) were inoculated by submersion in a suspension of Ecc and then treated for 5 min in 0.01, 0.1 and 1.0% w/v solutions of citric acid, acetic acid, and NaOCl. A second set of tubers was infiltrated with the treatment solutions. Five tubers from each 10-tuber treatment were air-dried.

Comparison of Chlorine with Experimental Bactericide—Cured new-crop tubers (cv. Russet Burbank) obtained from commercial storage (about 6 wk after harvest) were submerged in a suspension of Ecc and then immersed for 30 sec in tap water alone or containing 1000 mg/L Cl_2 or 500 mg a.i./L CGA 78039. Half of the tubers were infiltrated with the treatments. CGA 78039,

7-chloro-1-ethyl-6-fluoro-1,4-dihydro-4-oxo-3-quinolinecarboxylic acid, is an experimental bactericide developed by Ciba-Geigy Inc. that was reported to be highly toxic to *E. carotovora* and several other plant pathogenic bacteria (11). Ten tubers from each 20-tuber treatment were air-dried. Half of the tubers in the 10-tuber treatments were evaluated for disease after the normal 4-day incubation period, whereas the remainder were evaluated after 6 days.

Results

General Observations—In most tests, the percentage of tubers with at least one soft rot lesion was 100%, whereas disease severity expressed as the percentage of surface area decayed (SAD) on individual tubers ranged from less than 1 to 100%. The base-level soft rot severity, a measure of the soft rot potential in the different batches of tubers prior to their use in the tests, varied from 2% for hand-harvested late crop tubers (cv. Russet Burbank) to 80% for early tubers (cv. Superior) taken from a packinghouse.

Organic Acid Treatment of Naturally Inoculated Tubers—Immersion in solutions of certain organic acids reduced the soft rot potential in freshly machine-harvested early crop tubers (Table 1). The effect was entirely on the base-level potential because the tubers had not been inoculated in the laboratory immediately prior to the treatments. The base-level potential

TABLE 1. — *Severity of bacterial soft rot in uncured, machine-harvested Superior potato tubers sampled before (bph) and after (aph) entering packinghouse in relation to infiltration of lenticels with various solutions.*[a,b]

		% Surface Area Decayed[c]			
		Not Infiltrated		Infiltrated	
Solution	pH	bph	aph	bph	aph
Water	7	41 abc	66 w	63 a	67 w
Ascorbic acid	3.4	27 cdef	62 wx	34 bcd	45 wxy
Citric acid	2.4	14 ef	47 wxy	17 cedf	48 wxy
Malonic acid	2.4	13 def	36 yz	16 cdef	50 wxy
Sodium cinnamate	5.9	17 cdef	34 yz	7 f	36 xyz
Calcium acetate	6.3	20 cdef	43 wxy	59 ab	38 xyz
NaOCl	<10	21 cdef	16 z	16 e	15 z
Potassium sorbate	6.1	25 cde	57 wxy	23 cdef	39 wxyz

[a]Tubers were submerged in 50 mM solutions of organic acid, or salt; 2% w/v potassium sorbate; or 1000 mg/l Cl_2 for 5 min. Lenticels were infiltrated by application of a 350-cm hydrostatic pressure to the submerged tubers.

[b]Tubers were incubated at 20 C in a mist chamber for 3 days.

[c]Each value is the average of seven tubers. Values not followed by the same letter in each group of tubers (a-e=bph and w-z=aph) were different, $P=0.05$ (Waller-Duncan multiple range test).

was rated at 67 or 80% average SAD after 3 days' incubation for the pre-ph and post-ph tuber samples, respectively. The latter tubers probably had been infiltrated with contaminated flume water since the packinghouse flume system included a vertical tube in which tubers in water were pumped from ground level to the packing line, a height of approximately 5 meters.

Both tuber source and solution used had a highly significant impact on the severity of bacterial soft rot ($\underline{P}P=0.0001$). The severity of disease was higher among the post-ph than among the pre-ph tubers, whereas the severity among tubers treated with the solutions was lower than that among tubers treated with water alone. Overall, severity was not significantly ($\underline{P}P>0.05$) affected by infiltration of tubers with solution and the infiltration treatment did not interact with the solution treatments or tuber source. In contrast, infiltration of tubers with calcium acetate was associated with more disease than the non-infiltration treatment with that solution ($\underline{P}P=0.05$).

Severities among tubers treated with the ascorbic or citric acid solutions were similar to those among tubers treated with 1000 ppm chlorine in the pre-ph, but not post-ph samples. Severity in both tuber samples treated with the chlorine was similar, whereas the other treatments were less effective when used on the post-ph sample. Solutions of three salts of organic acids were included in the tests. Tubers treated with sodium cinnamate had only 11 to 45% as much disease as the respective control treatments. However, due to the strong cinnamon aroma imparted to treated tubers, sodium cinnamate was not used in subsequent tests. Cinnamic acid was not very soluble in water and was not used. Another salt included in the tests, potassium sorbate, has numerous uses as a food preservative. The parent acid also is relatively insoluble in water (0.15% w/v). Neither a saturated solution of sorbic acid nor potassium sorbate at concentrations of up to 2% were particularly effective in reducing soft rot in immersion tests similar to the one described here. Calcium acetate, included in the test because of a possible combination effect of calcium and acetate, also was not particularly effective against soft rot in the present tests or in several subsequent tests as well (data not presented).

Organic Acid Treatment of Artificially Inoculated Tubers—In the preceding test, tubers sampled after passage through the packing line were probably infiltrated with contaminated flume water and had received additional injuries. The impact of these factors on the efficacy of organic acid treatment was evaluated in tests with hand-harvested late crop tubers (cv. Russet Burbank). The tubers had an extremely low base level, 2% SAD, whereas inoculation with Ecc led to high severities (Table 2). As noted previously (5), disease severities were higher when tubers were infiltrated with Ecc under pressure ($\underline{P}P=0.0001$) than when no pressure was applied. The increased disease resulting from inoculation was reduced by some of the treatments, but not completely eliminated. The lowest severity among

TABLE 2. — *Severity of bacterial soft rot in uncured, hand-harvested Russet Burbank potato tubers in relation to infiltration of lenticels with* Erwinia carotovora, *immersion in various solutions, and air-drying.*[a,b]

	% Surface area decayed[c]			
	Not infiltrated		Infiltrated	
Solution	Wet	Dried	Wet	Dried
Water	80 a	46 bcde	94 w	54 yz
Calcium acetate	81 a	17 hi	85 x	40 yz
Potassium acetate	68 ab	24 ghi	80 x	35 z
Citric acid	41 cdef	12 i	53 yz	27 z
NaOCl (250 ppm Cl_2)	68 abcd	28 efgh	68 xz	35 yz
(1000 ppm Cl_2)	22 fghi	28 efgh	37 z	41 yz

[a]Tubers were submerged in 5×10^6 cfu *E. carotovora* pv *carotovora*/ml water for 5 min. Lenticels were infiltrated with bacteria by application of a 180-cm hydrostatic pressure to the submerged tubers. The inoculated tubers were submerged in 2% w/v potassium sorbate; 50 mM citric acid, calcium, acetate, or potassium acetate; indicated concentrations of NaOCl; or water along for 5 min. Five of the 10 tubers in each treatment were air-dried for 2 hr.

[b]All tubers were wetted gently with tap water and incubated for 4 days in a mist chamber at 20 C.

[c]Values within each group of tubers (a-h=not infiltrated and w-z=infiltrated) not followed by the same letter were different at $P=0.05$ (Waller-Duncan multiple range test).

tubers not infiltrated with Ecc occurred among those treated with citric acid and then air-dried. This combination also led to the lowest severity among those infiltrated with the bacterium. Higher disease occurred among tubers treated with the solutions or air-drying alone as compared with the respective combination treatments for all but treatment with the higher rate of chlorine, where the respective severities were similar. In contrast, the lowest amount of disease in non-dried tubers occurred in those treated with the high rate of chlorine.

Treatment with solutions of calcium and potassium salts of acetic acid reduced decay relative to the respective control treatment, particularly when combined with air-drying. However, in terms of disease severity, levels among the non-dried tubers were nearly equal to that among the controls and much higher than among tubers air-dried alone.

Infiltration of Lenticels on Inoculated Tubers with Solutions of Organic Acid or Sodium Hypochlorite—Three concentrations of solution (0.01%, 0.1%, and 1.0), three chemicals (acetic acid, chlorine, citric acid), infiltration with solution, and air-drying were the main treatments in a test of combination treatment of machine-harvested late crop tubers (cv. Russet Burbank). Overall, with a few exceptions, disease severity decreased as concentrations of the three chemicals increased (Table 3—severities observed in the 1%

TABLE 3. — *Severity of bacterial soft rot in uncured, machine-harvested Russet Burbank potato tubers in relation to immersion in 1% w/v solutions of acetic acid, citric acid or NaOCl, infiltration of lenticels with those solutions and air-drying.*[a]

	% Surface area decayed[b]			
	Not infiltrated		Infiltrated	
Solution	Wet	Dried	Wet	Dried
Water	69 ab	35 cde	86 a	48 cd
Acetic acid	24 de	19 de	28 de	39 cde
Citric acid	31 de	5 f	54 bc	24 de
NaOCl	3 fg	1 g	1 g	3 fg

[a]Tubers were submerged in 5×10^6 cfu *Erwinia carotovora* pv. *carotovora*/ml water for 5 min and then submerged in the solutions or water alone for 5 min. Lenticels were infiltrated when a 350-cm hydrostatic pressure was applied to the submerged tubers. Five of the 10 tubers in each treatment were air-dried for 2 hr. All tubers were gently wetted with tap water and incubated in a mist chamber at 20 C for 4 days.

[b]Values not followed by the same letter were different at $P=0.05$ (Waller-Duncan multiple range test).

treatments). Severities below the sample base-level (20%) were observed only among tubers treated with the 1% chlorine solution (which bleached tuber surfaces) or among non-infiltrated tubers treated with citric acid and then air-dried. Disease severities in the acetic acid treatments were equivalent to those in the citric acid treatments except in the immersion/air-dried combination treatments. In the latter, lower severities were recorded when citric acid was used. Severities observed among tubers submerged but not infiltrated with the 0.1% solutions were 56, 46, and 76% for the acetic acid, sodium hypochlorite and citric acid treatments, respectively. Values for the air-dried combination treatments were 24, 18 and 11%, respectively. Higher values were observed if tubers were infiltrated with the organic acid solutions as compared with non-infiltrated, whereas in the hypochlorite treatments a similar response occurred only in the 0.01% treatments.

Comparison of Chlorine with Experimental Bactericide—Bacterial soft rot potentials in tubers treated with 1000-ppm chlorine were compared with those in tubers treated with a non-systemic bactericide reported to be highly toxic to *E. carotovora* (11). Exposure periods were reduced to 30 sec in order to simulate more closely potential commercial usage of these materials.

Main treatment effects in the factorially designed experiment were chemical (water alone, bactericide, and hypochlorite), infiltration, air-drying, and incubation period. After both 4 and 6 days' incubation, less disease was observed among tubers treated with bactericide as compared with water alone or hypochlorite (Table 4). The severity of disease in tubers

TABLE 4. — *Severity of bacterial soft rot in cured, machine-harvested new crop Russet Burbank potato tubers after incubation in a mist chamber at 20 C for 4 days or 6 in relation to air-drying after infiltration of lenticels with an experimental bactericide or chlorinated water.*[a]

		% Surface Area Decayed[b]			
		Period of Incubation			
		4 days		6 days	
Treatment	Infiltrated	Wet	Dried	Wet	Dried
Water	-	22 ab	9 cd	44 vw	29 wx
	+	26 a	11 bcd	65 v	34 wx
CGA 78039	-	2 fg	1 fg	8 y	3 z
	+	4 ef	0 g	4 yz	3 z
NaOCl	-	5 de	6 de	33 wx	38 wx
	+	14 abc	9 cd	36 wx	19 x

[a]Tubers were submerged in 5×10^6 cfu *Erwinia carotovora* pv. *carotovora*/ml water for 5 min and then submerged in 500 ppm a.i. CGA 78039, 1000 ppm Cl_2 from NaOCl or water alone for 30 sec. A 350-cm hydrostatic pressure was applied to the submerged tubers in order to infiltrate lenticels. Five of the 10 tubers in each treatment were air-dried for 2 hr. All tubers were wetted with tap water prior to incubation.

[b]Values within each incubation period (a-g=4 days and v-z=6 days) not followed by the same letter were different at $P=0.05$ (Waller-Duncan multiple range test).

treated with the bactericide was at or below the base-level, 4%, for the tuber sample. However, lesions were observed on at least some of the tubers in each of the treatment combinations. The 0% reported for bactericide plus air-drying resulted from rounding off 0.3%. Disease severity among tubers infiltrated with the chlorine solution or bactericide suspension were not different from the respective non-infiltrated treatments. Air-drying led to significant reductions in severity in all but the chlorine treatments and when used alone, was equivalent to treatment with 1000 ppm free-chlorine for 30 sec. The chlorine treatment reduced the amount of disease as compared with the control treatment after 4 but not 6 days incubation. The 6-day incubation period was associated with greater disease ($P_P=0.0001$) as compared with the 4-day period, but the treatments interacted significantly with the incubation period ($P_P=0.0406$) because the increase in disease between 4 and 6 days incubation among tuber treated with hypochlorite was greater than that in the other treatments.

Discussion

The potential for bacterial soft rot quantified in potato tubers by rating the severity of decay after a 4-day period in a mist chamber was reduced by immersing tubers in solutions of organic acids or chlorinated water and/or

air-drying before incubation. Significant reductions occurred when tubers were treated immediately after inoculation as well as when tubers inoculated in a packinghouse were treated several days later. Treatment was most effective when bacteria were on tuber surfaces rather than in lenticels. In preliminary tests, an approximately 100-fold reduction in the population of soft rot *Erwinia* in the tuber periderm occurred during the 5-min immersion in either 1000 ppm chlorine or 1% citric acid solution (Bartz, unpublished). Previously, air-drying tubers after washing was shown to reduce both surface populations of Ecc and the potential for decay (6). In other reports, disease severity was reduced by treatment with antibiotics, chlorine, and certain antibacterial chemicals that reduce or inhibit the population of soft rot *Erwinia* on tubers (8, 12, 25, 27). In contrast, rinsing tubers with clean tap water removed some cells of Ecc, but did not lower the potential for disease (4).

The chlorine treatments are of special interest because of the widespread use of chlorine or hypochlorite ion in fruit and vegetable packinghouses. Solutions containing hypochlorous acid, the active ingredient in chlorinated water, are relatively inexpensive to generate at packinghouses. Solutions of hypochlorous acid are highly effective in destroying populations of soft rotting bacteria on tubers and in water if organic content is low. However, in previous tests on potato tubers chlorine treatments have reduced decay in some (25, 27) and had no effect in others (23). The effect of chlorine appears to be temporary because after continued predisposition treated tubers may have more decay than untreated ones (25). In the tests reported here, more decay developed among chlorine-treated tubers between 4-day and 6-day of an incubation period than in the controls. A one to five dilution of hypochlorite-based laundry bleach severely bleached tuber surfaces (evidence for the activity of hypochlorite), but failed to prevent bacterial soft rot. Moreover, when tubers were immersed in 5000 ppm Cl_2 for 20 min, air-dried, stored for 1 wk, moistened and then incubated, much more disease was observed in the chlorine treated as compared with untreated controls (Bartz, unpublished). These observations are evidence for a phytotoxic effect of high concentrations of hypochlorite on tubers previously observed by Scholey, *et al.* (25).

The maintenance of recommended levels of chlorine in wash and flume water (75 to 450 ppm) is a difficult task, particularly when large quantities of soil and plant debris accompany the harvested vegetable (as with potato tubers). Free-chlorine reacts rapidly with and is inactivated by minerals and organic matter in the soil and debris. Moreover, high concentrations of free-chlorine used in sprays, washers, or baths are associated with volatile compounds that can make packinghouses uncomfortable if not hazardous working places. Chlorination is an extremely valuable and necessary water treatment in some vegetable packinghouses. However, chlorination of water in potato packinghouses should be recommended only if the limitations

including expense of treatment, increased soft rot potentials at later time periods, and corrosion of machinery are outweighed by the immediate benefits of a marked reduction in soft rot potential.

The best control practice as suggested over 40 yr ago (23) and illustrated recently (6), is to dry wet tubers promptly and then keep them dry. In the literature, none of the reported treatments including air-drying prevented bacterial soft rot in tubers predisposed by surface moisture or incubation in an anaerobic environment (1, 6, 8, 12, 20, 23, 25, 27). The difficulty in preventing bacterial soft rot in wet tubers is underscored by the results of the CGA 78039 treatments. This bactericide is as toxic to Ecc as streptomycin (MIC=1 ppm) (11). In tests reported here and previously (2), treatment with CGA 78039 controlled bacterial soft rot better than 10,000 ppm Cl_2. However, it did not completely prevent the disease or the continued expansion of lesions that had formed. Only keeping tuber surfaces free of moisture has the potential to prevent bacterial soft rot.

Air-drying has some limitations as a control practice. It will neither prevent subsequent condensation nor counteract previous mishandling of tubers. It usually reduces the soft rot potential, but may not reduce potentials to levels occurring prior to harvest or handling (6). Extremely high potentials may develop in dry tubers, particularly if lenticels have been infiltrated with soft rot *Erwinia* (5) or tubers have been severely injured (19). Therefore, practices that lead to infiltration or severe injury should be avoided. In contrast, practices that prevent condensation in packages (as well as in stored tubers) compliment air-drying. Packages containing tubers should be ventilated. Polyethylene bags that have only a few holes should be avoided (25). In storages adequate air movement over tuber surfaces should be assured by the storage design or arrangement of packages. Situations where cooled tubers, packaged or bulk, are abruptly thrust into a warm humid atmosphere should be avoided unless air movement is sufficient to dry the ensuing condensation. Finally, the control of temperature in truck or storage should be adequate to prevent abrupt warming.

Treatments such as citric acid may reduce the population of soft rot *Erwinia* on tuber surfaces without affecting the susceptibility of the underlying tissues. These treatments appear to have merit at least for control of bacterial soft rot in situations where drying is delayed or brief periods of condensation are likely. However, further tests on long term effects, costs and concentrations are needed before recommendations can be made.

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