Influence of Postharvest Handling Practices and Dip Treatments on Development of Black Root Rot on Fresh Market Carrots

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ABSTRACT

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Standard postharvest handling practices for fresh market carrots (*Daucus carota*) grown in organic soils in the Fraser Valley of British Columbia were monitored during 1990–1992 at two grading and packaging operations. Root samples were obtained from 29 loads over the harvest season (July to November) at various stages after carrots were washed, sized, graded, and packaged; and the samples were assessed for the development of black root rot, caused by *Chalara elegans* (*Thielaviopsis basicola*). Disease was not detected on carrots harvested by hand from fields infested with the pathogen, and was less than 5% on carrots sampled from the truck following mechanized harvesting. The percentage of carrots that developed disease upon incubation at 25 C increased after each step of the grading and packaging operation (washer, brush rollers, sizer, and grader). The highest disease incidence was observed on carrots that were graded and packaged into polyethylene bags and stored at room temperature; however, no visible disease symptoms developed on these carrots when they were stored at 7–10 C. The pathogen was detected with a carrot root disk baiting assay in more than 60% of the carrot loads, mostly in soil adhering to the roots, and was also found in the wash water and on the surface of the conveyor belts. The inoculum level was generally found to increase with each step of the grading process. A laboratory study was conducted to determine the effects of wounding, time and frequency of inoculation, and incubation temperature on the development of black root rot. Wounding at harvest, a postharvest inoculation treatment, incubation at 30 C for 24 hr, and additional postharvest wounding were all found to significantly ($P = 0.05$) enhance disease development. When artificially wounded and inoculated carrot roots or root slices were dipped in a 0.05 or 0.1 M solution of either calcium propionate or potassium sorbate for 2 min, disease development was significantly ($P = 0.05$) reduced compared to the standard sodium hypochlorite treatment (100 μg/ml of chlorine). Treatments applied to carrot tissues within 24 hr after inoculation provided a significantly higher level of disease reduction than those applied just prior to inoculation. The effectiveness of both calcium propionate and sodium hypochlorite was considerably better at low pH than at a higher pH. Ammonium bicarbonate, potassium carbonate, and sodium bicarbonate also reduced disease development compared to the water control; but the level of disease control achieved was not economically acceptable.

Additional keywords: propionic acid, sorbic acid, wound pathogen

Carrots (*Daucus carota* L.) are grown primarily on organic (muck) soils in the Fraser Valley of British Columbia, Canada, to provide an in-season supply for the fresh market. One of the major postharvest problems in recent years has been black root rot, caused by *Chalara elegans* Nag Raj & Kendrick (synanamorph = *Thielaviopsis basicola* (Berk. & Broome) Ferraris) (16). This soilborne plant pathogen occurs worldwide and has an extensive host range which comprises both cultivated and noncultivated plants (10,29). On carrot, the disease appears after the crop is harvested and placed in storage. Black lesions bearing characteristic chlamydospores and phialospores of the pathogen develop within 4–8 days on roots packaged in polyethylene bags and incubated at 20–25 C (19). There are only a few previous reports of the occurrence of *C. elegans* on carrot, indicating that disease incidence is sporadic (6,13,14). In commercial carrot production fields in the Fraser Valley, black root rot has been recognized as a sporadic but occasionally severe postharvest problem since 1975 (21). A large number of the fields in this area are naturally infested with the pathogen, and severe outbreaks of disease were observed during the growing seasons of 1989 and 1990 (18). These outbreaks resulted in reduced shelf life and lower market sales (R. W. Gilmour, B.C. Coast Vegetable Co-operative, *personal communication*). It is not known whether disease development resulted from infections on the growing crop, after harvest, or during storage.

In a recent study, the conditions under which carrots are infected by *C. elegans* and the factors that can predispose the tissues to infection were described (19). Presently, there are no control measures available for reducing black root rot development. The only treatment that is recommended after harvest and washing is a 2–3 min dip in hydrocooled water (at 4–7 C) which contains sodium hypochlorite (at approximately 80 μg/ml of chlorine). This treatment has not proven to be effective in preventing infection and/or reducing the growth of *C. elegans* on the root surface. Since no fungicides are currently registered for postharvest use on carrots in Canada, alternative chemicals need to be evaluated for the ability to prevent or reduce disease. Several inorganic salts, including those containing bicarbonate and carbonate anions (12,20,23,30), and organic acids such as propionic acid and sorbic acid (2,8,25) have shown broad antifungal activity and could potentially be used on carrots as a postharvest treatment.

The objectives of this study were 1) to monitor and evaluate the influence of standard postharvest handling procedures on the severity of black root rot on commercially grown carrots; 2) to determine the influence of wounding, postharvest inoculation, and incubation temperature on disease development; and 3) to evaluate the efficacy of various salt solutions, including those containing bicarbonate and carbonate anions, and organic acids, in comparison to the currently used sodium hypochlorite treatment for reducing black root rot development.

MATERIALS AND METHODS

Monitoring of handling practices. During the harvest seasons (July–November) of 1990, 1991, and 1992, samples of carrots from commercial loads originating from different fields in the Fraser Valley were obtained at the onset and at various stages during standard commercial washing, grading, and packaging (Fig. 1). The varieties most commonly assessed were Eagle, Paramount, Cimarron, and Top Pak. A large-scale commercial packaging operation at the B.C. Coast Vegetable Co-operative Association in Richmond, B.C., and an on-farm packaging operation at Cloverdale Produce Farms in Cloverdale, B.C., were both monitored in 1990 and 1991; and the first location was also monitored in 1992.

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Two replicate samples of carrots, each comprised of 10–15 roots, were obtained arbitrarily from the processing line at various stages during the washing, grading, and packaging operation at each location (Fig. 1).

In addition, the presence of *C. elegans* in soil adhering to the roots, in the wash water, in the hydrocooled water, and on the surface of various conveyor belts was monitored with a carrot root disk baiting assay (19,28). At the Co-op, 14 loads were monitored at various sampling times from August to November 1990, 10 loads from July to September 1991, and five loads in 1992. On the farm, three loads were monitored in July and August 1990, and two loads in 1991. After retrieval, all carrot samples and root disks were stored at 24–28 C for 10 days, after which the development of black root rot was evaluated. The percentage of infected roots and the number of lesions on each root were visually recorded. The standard error of the mean was calculated from all of the replications at each sampling stage from various loads. During 1990 only, additional samples were obtained at the end of the packaging line from 267 loads of carrots and either stored in a cooler (at 7–10 C) or incubated at 24–28 C. The extent of disease development was rated as described.

Effect of wounding, time and frequency of inoculation, and incubation temperature on development of black root rot. A commercial field in Cloverdale, B.C., that was previously determined to be naturally infested with *C. elegans* (3,19) and that was cropped with carrots was selected for this study. Carrots in 15-m sections in two adjacent beds were harvested by hand in July 1990, at the same time as the onset of commercial harvesting. Samples comprised of 25 carrots were arbitrarily placed in polyethylene bags that were assigned a treatment number. The samples were either subjected to artificial wounding by physical abrasion of the bagged carrots against a metal surface, resulting in breakage of some roots and visible surface wounds, or were left unwounded. Following this initial treatment, carrots were either inoculated in the field by atomizing 2 ml of a phialospore suspension (1×10^3 spores per milliliter) of *C. elegans* onto the roots in each bag or left noninoculated. All samples were transported to the laboratory within 3 hr following inoculation. Representative samples from each treatment were incubated at either 4 or 30 C for 24 hr. Subsequently, all carrots were removed from the bags, washed gently by hand under running tap water to remove adhering soil and inoculum, and placed in polyethylene bags. Samples from each of the first set of treatments (wounded, not wounded, inoculated, or not inoculated) were then wounded again or left unwounded and either inoculated as before or left noninoculated. The experimental design was a completely randomized block with 16 treatment combinations each for the initially wounded and nonwounded carrots. For each treatment, there were four replications with 25 carrots in each. The experiment was repeated a second time in August 1990 with carrots obtained from the same field, and a third time in July 1991. The percentage of carrots that developed disease was determined for each treatment after 10 days of incubation at 25 C. Data analysis was performed with the SAS statistical package (24). Two-way analysis of variance was conducted on nontransformed data by the general linear models procedure. Mean separations were determined by the least significant difference method. The data presented are the means of all repetitions and replications of the experiment.

Influence of postharvest dip treatments. *Carrots.* Carrot roots of several commercial cultivars were hand harvested at various times during the growing seasons (July–October) of 1990 and 1991. In addition, carrots were obtained from retail outlets for experiments that were conducted when local carrots were not available. To reduce potential background contamination, the roots were surface-disinfested by immersing them in a 5% solution of commercial bleach (Javex, 6.25% sodium hypochlorite) for 3 min, followed by two rinses in sterile distilled water. For each root, 1-cm-long sections of epidermal tissue were removed with a hand peeler at 5–8 evenly spaced sites along the length of the root. Five roots were included in each replicate, and they were incubated on moistened paper towels in a sealed polyethylene bag. Experiments were also conducted with root slices (5 mm thick) cut from the carrots and placed in petri dishes lined with moistened filter paper.

Inoculation. Inoculum of *C. elegans* was comprised of a phialospore suspension, which was obtained by flooding a 14–21 day old culture grown on V8 agar at 20 C in the dark with 10 ml of sterile distilled water. The concentration was adjusted to either 10^2 or 10^5 spores per milliliter following spore counts in a hemacytometer. For inoculation, the spore suspension was atomized uniformly over the roots in each bag (2 ml volume) or onto the root slices (0.5 ml volume). For preinoculation dip treatments, carrot roots or slices were immersed in the treatment solution (see below) for 2 min, allowed to dry for 1 hr, and then inoculated. For postinoculation treatments, inoculum was applied onto the roots or slices, which were then incubated at 25 C for 24 hr, and the carrots were subsequently treated. Control roots were atomized with sterile distilled water. The percentage of wounds colonized on roots and the percent surface area colonized on the slices were rated after 4–6 days of incubation at 25 C.

Treatments. Three inorganic salts (ammonium bicarbonate [NH_4HCO_3], potassium carbonate [K_2CO_3], and sodium bicarbonate [$NaHCO_3$]) and two organic acids (propionic acid, hemicalcium salt [Ca-propionate] and sorbic acid, potassium salt [K_2-sorbate]) were compared to sodium hypochlorite. The salts and organic acids were tested at three concen-

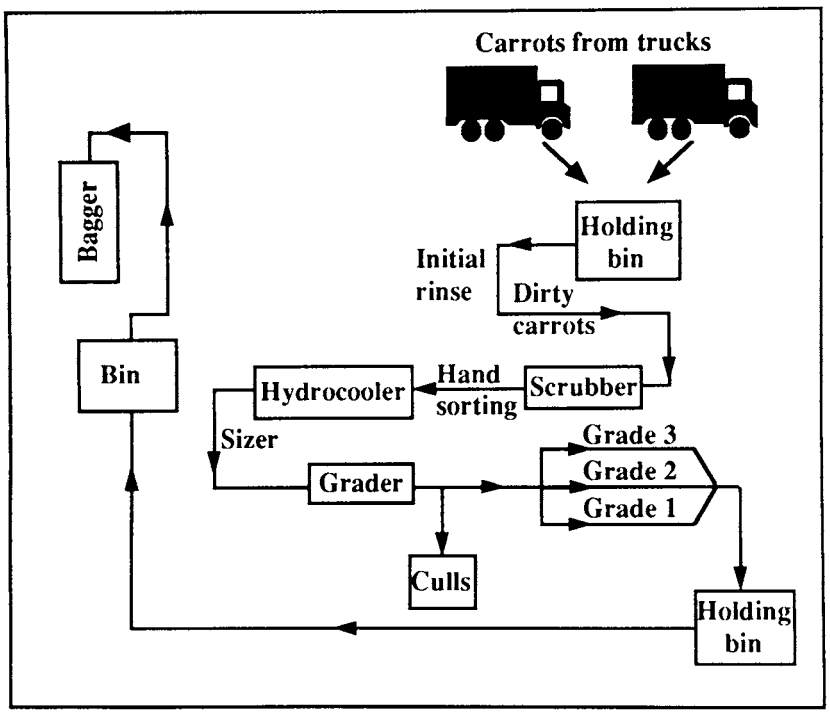

Fig. 1. Schematic representation of the carrot washing, grading, and packaging operation at the B.C. Coast Vegetable Co-op Association. Arrows indicate direction of movement of carrots.

trations (0.01, 0.05, and 0.1 M) in sterile distilled water. The pH of the solutions was measured prior to use. Calcium propionate was also tested at low pH (adjusted to 4.0–4.2 by adding 1.0 N HCl). The pH of the potassium sorbate solution was adjusted to 6.0. Sodium hypochlorite was tested at concentrations of 220 and 440 μg/ml (100 and 200 μg/ml of chlorine) with pH unadjusted or adjusted to 6.8 with KH_2PO_4. Carrot roots or slices were immersed in the solutions for 2 min at ambient temperatures of 20–25 C. Control roots were immersed in sterile distilled water. Each dip treatment had four replications, each with five roots or slices. The experiment was conducted three times. The data presented are the means of all replications and repetitions of the experimental trials. Data analysis was performed with the SAS statistical package (24). Analysis of variance was conducted on nontransformed data by the general linear models procedure. Mean separation was determined by the least significant difference method.

RESULTS

Monitoring of handling practices. The percentage of carrots at the Co-op that developed symptoms of black root rot after retrieval at each stage of the washing, grading, and packaging operation (Fig. 1) followed by incubation at 24–28 C for 10 days is shown in Figure 2. The data represent the combined average of all replications from four representative loads sampled in 1990. No disease developed on carrots harvested by hand, and infection levels were less than 5% on samples obtained from the truck prior to the onset of washing. After each step of the commercial operation (washer, brush rollers, sizer, and grader), the percentage of carrots that developed disease increased (Fig. 2). The highest disease incidence was observed on carrots that were packaged. The results obtained from the on-farm packaging operation showed a similar trend. Data from two representative loads sampled in 1990 are shown in Figure 3. Disease incidence increased significantly after the sizer and was greatest on culled carrots. In loads sampled in 1991 and 1992, the data at both locations showed similar trends, although final disease incidence values differed (*data not shown*).

Samples taken from the end of the packaging line of 267 loads of carrots in 1990 yielded black root rot at a frequency of 89% when the carrots were incubated at 24–28 C; however, none developed disease symptoms when stored at 7–10 C (*data not shown*).

The presence of *C. elegans* was detected in more than 60% of the loads monitored at the Co-op during 1990–1992, using carrot root disks as bait, and was found in soil adhering to the roots, in the wash water, and on the surface of the conveyer belts. Estimates of the colony forming units (cfu) at various sampling locations ranged from three to 21 (Fig. 4). Inoculum level (as indicated by the number of colonies and the extent of root disk surface area colonized) tended to increase with each step of the grading process, and the highest fungal contamination was detected on the grading belts and the belts leading to the packager (Fig. 4).

Effect of wounding, time and frequency of inoculation, and incubation temperature on development of black root rot. Carrots hand harvested from a field infested with *C. elegans* and artificially wounded developed a maximum of 5% disease in the absence of additional inoculation (Fig. 5). When inoculum was applied after field wounding, infection increased significantly ($P = 0.05$) on carrots held at postinoculation temperatures of 4 or 30 C. An additional postinoculation wounding treatment prior to an 8-day incubation period at 20 C further increased disease, and a second inoculation increased disease to 78 or 82% (Fig. 5). The highest level of infection was obtained with sequential treatments of field wounding, field inoculation, postharvest wounding, and post-

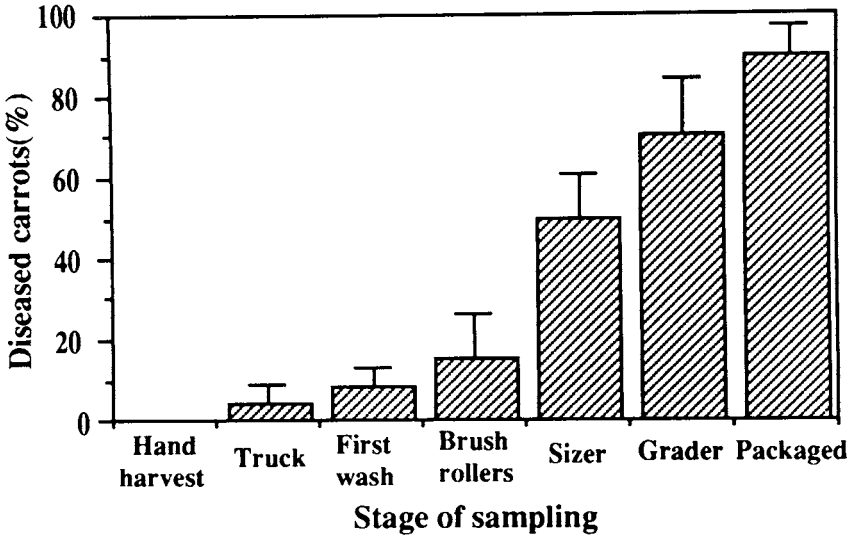

Fig. 2. Percentage of carrots with black root rot after various stages of the postharvest washing, grading, and packaging operation at the Co-op. Carrots were retrieved at the stages indicated and incubated at 24–28 C for 10 days. Data are the combined averages from four representative loads sampled in 1990, each with two replicate samples. Bars represent standard error of the mean.

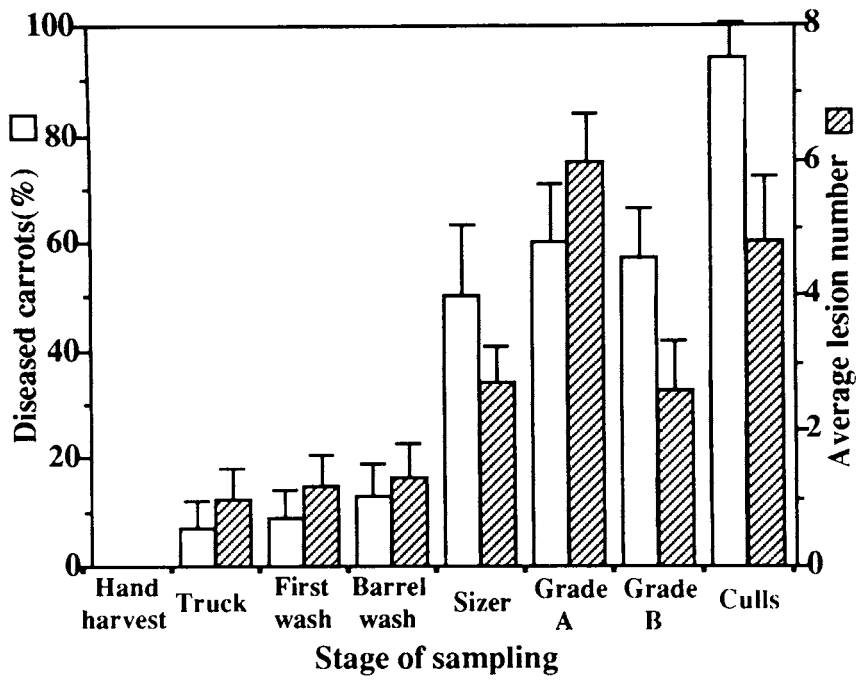

Fig. 3. Percentage of carrots with black root rot after various stages of processing on an on-farm location. Carrots were retrieved at the stages indicated and stored at 24–28 C for 10 days. Data are the averages of two representative loads, each with two replications. Bars indicate standard error of the mean.

harvest inoculation (Fig. 5). Different combinations of these treatments provided various levels of disease development, ranging from 25 to 82%.

Carrots harvested by hand that were not initially wounded generally had reduced infection compared with wounded carrots (Fig. 5). When inoculum was applied, disease incidence increased slightly on carrots preincubated at 4 or 30 C, while subsequent postharvest wounding prior to an 8-day incubation at 20 C did not increase disease significantly. A second inoculation increased disease significantly to 34 or 48% on carrots preincubated at 4 or 30 C, respectively (Fig. 5).

The extent to which black root rot lesions developed following artificial wounding and inoculation is shown in Figure 6. Dark lesions with growth and sporulation of the pathogen developed only at sites of wounding (Fig. 6A), and chlamydospores and phialospores were readily visible (Fig. 6B). When carrots harvested by hand and those obtained after mechanized harvesting, washing, and grading were inoculated with phialospores of *C. elegans,* disease only developed on the latter carrots (Fig. 7). Most lesions occurred at sites of abrasions or where the periderm had been injured.

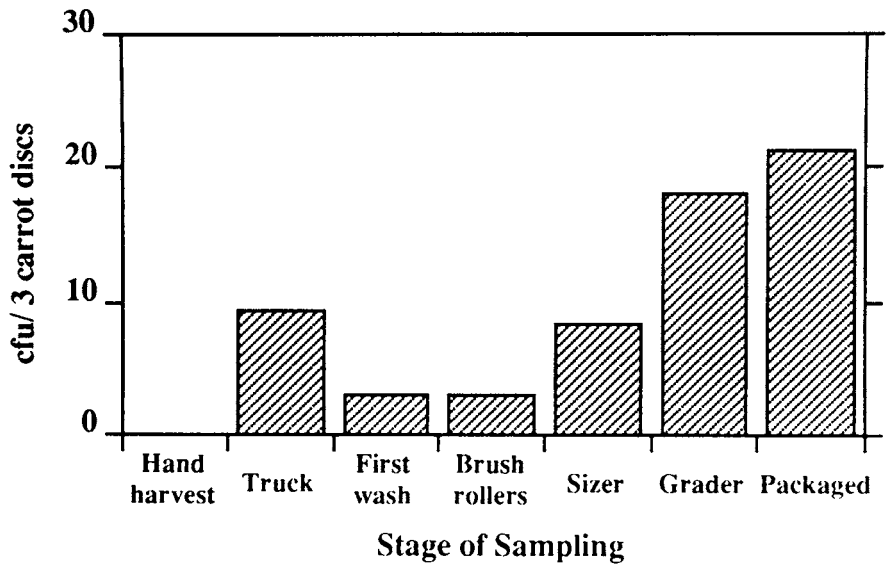

Fig. 4. Inoculum level of *Chalara elegans* at different stages of sampling during postharvest processing of carrots at the B.C. Coast Vegetable Co-op. Data represent the colony forming units on belts leading from the area of sampling as estimated using carrot root disks.

INOCULATE AT HARVEST	4 C FOR 24 HR	30 C FOR 24 HR	WOUND POST HARVEST	INOCULATE POST HARVEST	INFECTION (%) with wounds	INFECTION (%) without wounds
	→				0 a	0 a
		→			5 a	0 a
	→		→		0 a	1 ab
		→	→		5 a	4 abc
	→			→	25 b	1 ab
		→		→	28 bc	6 bc
	→		→		36 cd	13 de
		→	→		38 d	16 e
→					26 b	2 ab
→		→			35 cd	8 cd
→			→		36 cd	3 abc
→		→	→		55 e	12 de
→				→	62 ef	8 cd
→		→		→	68 f	14 e
→			→	→	78 g	34 f
→		→	→	→	82 g	48 g

Fig. 5. Development of black root rot on carrots following various combinations of artificial wounding, inoculation treatments, and incubation temperatures. Arrows indicate the treatment combination used. Disease was rated after 10 days of incubation at 25 C. Means within a column followed by the same letter are not significantly different ($P = 0.05$). Data were analyzed by the least significant difference method following analysis of variance of nontransformed data. Values represent the means of four replications in each treatment. The experiment was conducted three times.

Influence of postharvest dip treatments. Carrot roots and disks were inoculated with two different concentrations of phialospores (10^2 or 10^5 per milliliter) prior to or following a dip treatment in one of eight solutions. The extent of disease development was rated after 4 or 6 days of incubation at 25 C. Carrot root slices provided a more uniform tissue with more consistent disease development than did whole roots, and therefore only data from root slices are presented. When the salt solutions were evaluated at a concentration of 0.01 M, disease (expressed as percent surface area colonized) was not significantly different from the water control (*data not shown*). At a concentration of 0.05 M applied prior to inoculation with the lower inoculum level (5.5×10^2 spores per milliliter), Ca-propionate (pH 4.2) and K_2-sorbate (pH 6.0) provided the best level of control, followed by $NaHCO_3$, bleach (pH 6.8), K_2CO_3, and NH_4HCO_3 (Table 1). When applied as a postinoculation treatment, disease reduction was more pronounced; and Ca-propionate (pH 4.2), K_2-sorbate, and bleach (pH 6.8) gave the best level of control (Table 1). At a higher inoculum level (1.4×10^5 spores per milliliter), only Ca-propionate (pH 4.2) reduced the percent surface area colonized to below 30%.

When the treatment solutions were evaluated at a concentration of 0.1 M, and bleach at 200 μg/ml of chlorine, a significant reduction in disease ($P = 0.05$) was observed at both inoculum concentrations and two different application times with Ca-propionate (pH 4.0) and K_2-sorbate, followed by bleach (pH 6.8) and K_2CO_3 (Table 2). Both Ca-propionate and bleach were much more effective at the lower pH than at unadjusted pH. Ca-propionate (pH 4.0) was the only treatment in which infection was reduced to less than 0.5% (Table 2).

DISCUSSION

The susceptibility of carrots to infection by *C. elegans* is well known, since carrot root disks are widely utilized as a sensitive bioassay method to isolate the pathogen from soil (13,14,19,26,28,29). However, the scarcity of previously published reports on the occurrence of black root rot on carrots suggests that the disease is sporadic or nonexistent in many fresh market production areas. In all instances where *C. elegans* was previously seen on carrot, however, the pathogen was reported to develop primarily during postharvest storage of the roots (6,14,21). The temperature at which carrots are stored after harvest can dramatically influence the development of black root rot. When infected roots were placed at 7–10 C, no disease symptoms developed;

in contrast, a majority of the roots were visibly infected at 24–28 C. In addition, carrot tissues subjected to a 24-hr treatment at 30 C either prior to or following exposure to inoculum had more infection than tissues placed at 4 C (19). Thus, storage of roots at appropriate postharvest temperatures can considerably minimize the incidence of disease. Roots with incipient infections that were stored at 4 C, however, showed resumed fungal growth when they were subsequently placed at 25 C, even after a storage period of 12 wk at 4 C (19). These findings indicate that while disease may not be apparent at harvest or after a prolonged period of cold storage or shipping, when ambient temperatures exceed 10 C (such as at retail outlets), black root rot has the potential to become a problem. Thus, although the disease may not occur in carrot production areas, postharvest occurrence at locations far removed is possible under the appropriate conditions.

Results from the present study clearly indicated that infection by *C. elegans* on carrot occurred primarily at sites of injury or abrasion that occurred during the washing, sorting, and grading process. Most of the wounds were incurred during size sorting of the roots; subsequent contact of the wound sites with inoculum deposited on the conveyor belts resulted in the most significant increase in disease. In the absence of wounding, *C. elegans* was incapable of penetrating the periderm layer of the carrot root (19), and disease did not develop. The incidence of several other postharvest diseases on crops such as potatoes, apples, and stone fruits similarly was shown to be enhanced by injury incurred during various harvesting and grading processes (8,9).

Throughout the lower Fraser Valley, many commercial production fields cropped with carrots and other vegetables are naturally infested with inoculum of *C. elegans* (19). The soils in many of these fields are primarily organic (muck), which are well suited for carrot production but also favor the growth and survival of *C. elegans* (3,4). Peat-based media also are reported to harbor the pathogen (11). The occurrence of black root rot during postharvest handling of carrots is accentuated by the adherence of organic matter to the roots, even after washing, which is then introduced and disseminated in various areas of the grading system. Over time, a film of organic debris containing cfu of *C. elegans* was found to accumulate on the conveyor belts. Very low inoculum levels are capable of initiating disease on carrot tissues (19), and the levels found on the surfaces of the belts usually were at or above this threshold. Therefore, scrubbing and cleaning of the belts are recommended to minimize the buildup of organic matter and inoculum during carrot grading. These sanitation practices can result in a significant reduction in

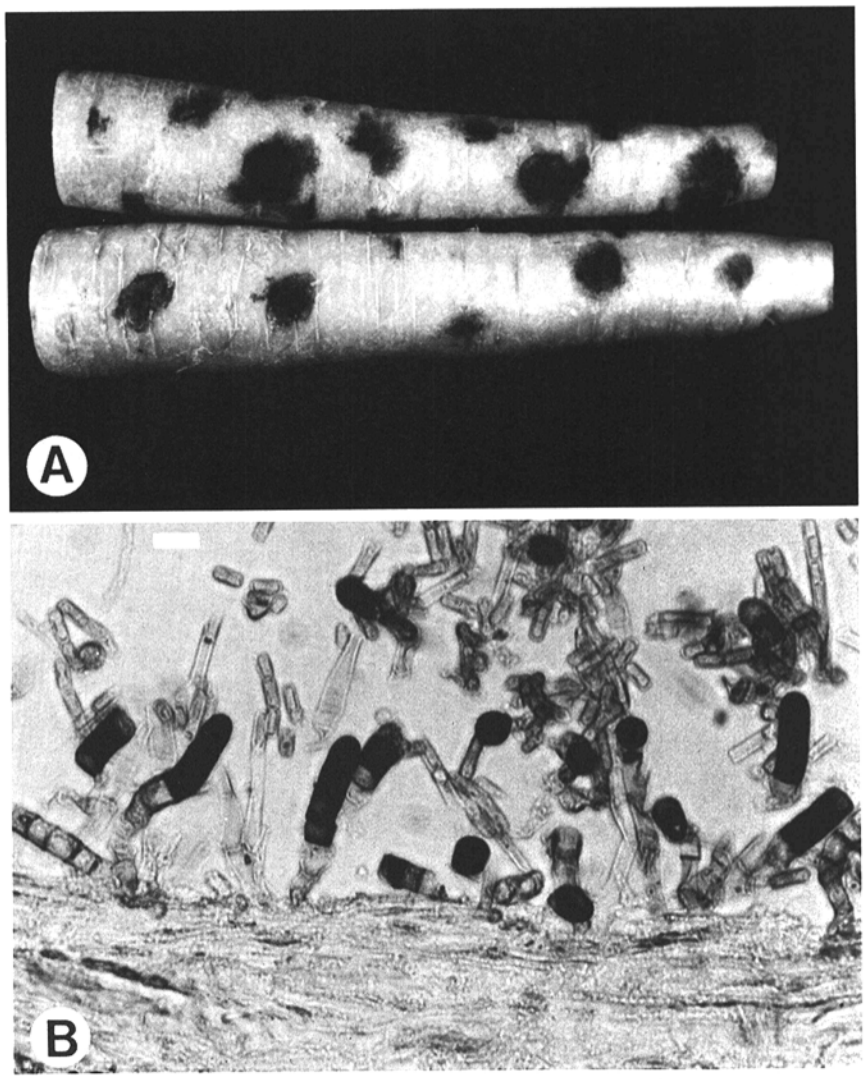

Fig. 6. Development of black root rot on artificially wounded and inoculated carrot roots. **(A)** Dark lesions with growth and sporulation of the pathogen at sites of wounding only. **(B)** Chlamydospores and phialospores produced from a wound site. Photographs were taken after 10 days of incubation at 25 C.

Table 1. Effect of dip treatments on colonization of carrot root disks by *Chalara elegans* at two different inoculum concentrations and treatment times

	Surface area infected (%) at two inoculum levels[w]			
	5.5×10^2 spores/ml[x]		1.4×10^5 spores/ml	
Treatment[v]	Preinoculation[y]	Postinoculation	Preinoculation	Postinoculation
Water, pH 6.5	84.0 a[z]	81.3 a	91.6 a	90.9 a
Bleach, pH 9.5	95.3 a	60.4 b	91.0 a	94.0 a
Bleach, pH 6.8	68.7 b	28.0 c	87.0 a	92.5 a
NH_4HCO_3, pH 8.3	73.6 ab	59.3 b	91.8 a	88.9 a
$NaHCO_3$, pH 8.3	52.1 c	55.6 b	93.6 a	93.3 a
K_2CO_3, pH 11.2	72.0 b	50.2 b	91.9 a	72.3 b
K_2-sorbate, pH 6.0	30.5 d	15.0 d	63.5 b	53.0 c
Ca-propionate, pH 8.0	90.0 a	81.0 a	98.0 a	93.3 a
Ca-propionate, pH 4.2	32.1 d	3.7 e	47.7 c	27.6 d
LSD	11.9	10.3	13.1	12.4

[v] Treatments were applied as a dip treatment for 2 min at 25 C. Bleach was tested at a concentration equivalent to 100 μg/ml chlorine. Chemical salts were tested at a concentration of 0.05 M.

[w] Percentage of surface area of carrot root disks colonized by *Chalara elegans* was rated after 6 days (for 5.5×10^2 spores per milliliter) or 4 days (for 1.4×10^5 spores per milliliter) of incubation at 25 C.

[x] Inoculum was comprised of a suspension of phialospores from a 14–21 day old culture on V8 agar; a volume of 0.5 ml was atomized onto carrot root disks.

[y] For preinoculation treatment, root slices were dipped 1 hr prior to inoculation; for postinoculation treatment, root slices were dipped 24 hr after inoculation.

[z] Means within a column followed by the same letter are not significantly different ($P = 0.05$). Data were analyzed using the least significant difference (LSD) method. Values represent the means of four replications in each treatment. The experiment was conducted three times.

disease incidence (Z. K. Punja and M.-M. Gaye, *unpublished*).

Minimizing wounds and abrasions during mechanized washing and grading is difficult. Occasionally, roots may be subjected to vertical drops of up to 0.5 m, which result in visible injury to the periderm. The inclusion of a postwounding treatment with a protectant chemical could prevent such wounds from becoming infected. At present, roots are exposed to hydrocooled water containing sodium hypochlorite during washing and prior to sizing and grading, where most of the wounds are incurred. From our laboratory experiments, postinoculation treatments were found to be more effective than preinoculation (protectant) treatments, because the spores and germ tubes come into direct contact with the chemical. Thus, modification of the current grading system to include a dip treatment after grading should further reduce the incidence of black root rot.

Sodium hypochlorite (at approximately 80 μg/ml of chlorine, pH 7.0) is currently the only recommended treatment for carrots, but it appears to be ineffective in reducing black root rot development. Frequently, the concentration of chlorine in the hydrocooler may drop below 50 μg/ml because of sequestration by organic matter present in the water (Z. K. Punja and M.-M. Gaye, *unpublished*). From our laboratory experiments, colonization of carrot disks by *C. elegans* was significantly reduced only when sodium hypochlorite was used at 100 μg/ml of chlorine (pH 6.8) as a postinoculation treatment. When applied prior to inoculation, the treatment was not effective even at 200 μg/ml of chlorine. Salts containing carbonate and bicarbonate anions reduced disease development compared to the water control, but not to levels that would be considered commercially acceptable. These compounds provide effective control of a number of other fungal diseases (12, 23,30).

As an alternative to sodium hypochlorite, both Ca-propionate (pH 4.2) and K_2-sorbate significantly reduced the development of black root rot. At a concentration of 0.1 M (about 0.8%), Ca-propionate completely inhibited development of the pathogen; at 0.05 M, disease was reduced to 3.7%. Propionic acid is widely used to inhibit the growth of molds and for the preservation of grain (11,15,22,27), hay (5,17), and breads (2), and has broad utility in the preservation of other foods (2). The effective concentrations used ranged from 0.4 to 1.0%. Similarly, potassium sorbate is widely used as a preservative in foods such as cheeses, cakes, and breads (2). Therefore, the adoption of either chemical as a postharvest dip treatment for the prevention of black root rot on carrots could be readily implemented. The pH of the solutions should be maintained within the range of 4.0–4.2, at which these organic acids occur in their undissociated forms and are most toxic to fungi (1,2,7,8,22).

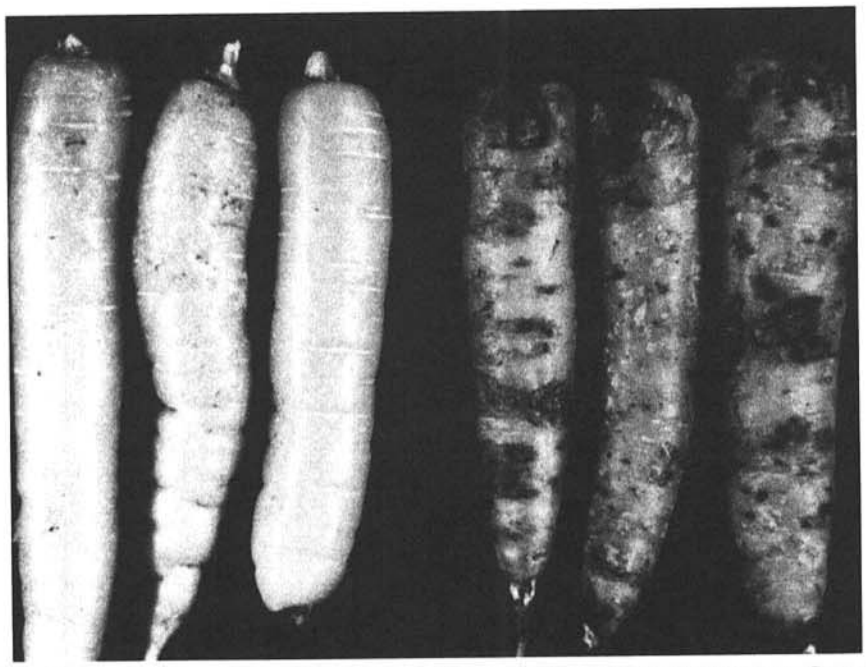

Fig. 7. Effect of harvesting and handling procedures on black root rot development. Carrots on the left were harvested by hand, while those on the right were harvested, washed, and graded mechanically. Both groups of carrots were artificially inoculated and incubated at 25 C for 10 days. Note the absence of disease development on hand harvested carrots.

Table 2. Effect of dip treatments on colonization of carrot root disks by *Chalara elegans* at two different inoculum concentrations and treatment times

	Surface area infected (%) at two inoculum levels[w]			
	6×10^2 spores/ml[x]		1.1×10^5 spores/ml	
Treatment[v]	Preinoculation[y]	Postinoculation	Preinoculation	Postinoculation
Water, pH 6.5	91.1 a[z]	97.0 a	91.2 a	90.0 a
Bleach, pH 10.3	91.4 a	28.5 d	96.9 a	31.5 bc
Bleach, pH 6.8	60.0 b	13.8 e	94.0 a	12.1 d
NH_4HCO_3, pH 8.3	64.3 b	50.1 c	95.6 a	94.0 a
$NaHCO_3$, pH 8.6	51.5 c	43.6 c	97.3 a	94.0 a
K_2CO_3, pH 11.8	69.1 b	27.0 d	92.5 a	33.1 b
K_2-sorbate, pH 6.0	27.2 d	10.1 e	42.3 b	21.6 c
Ca-propionate, pH 8.5	84.4 a	81.6 b	85.0 a	86.4 a
Ca-propionate, pH 4.0	0.0 e	0.0 f	0.3 c	0.1 e
LSD	11.7	9.4	12.6	10.2

[v] Treatments were applied as a dip treatment for 2 min at 25 C. Bleach was tested at a concentration equivalent to 200 μg/ml chlorine. Chemical salts were tested at a concentration of 0.1 M.

[w] Percentage of surface area of carrot root disks colonized by *Chalara elegans* was rated after 6 days (for 6×10^2 spores per milliliter) or 4 days (for 1.1×10^5 spores per milliliter) of incubation at 25 C.

[x] Inoculum was comprised of a suspension of phialospores from a 14–21 day old culture on V8 agar; a volume of 0.5 ml was atomized onto carrot root disks.

[y] For preinoculation treatment, root slices were dipped 1 hr prior to inoculation; for postinoculation treatment, root slices were dipped 24 hr after inoculation.

[z] Means within a column followed by the same letter are not significantly different ($P = 0.05$). Data were analyzed using the least significant difference (LSD) method. Values represent the means of four replications in each treatment. The experiment was conducted three times.

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