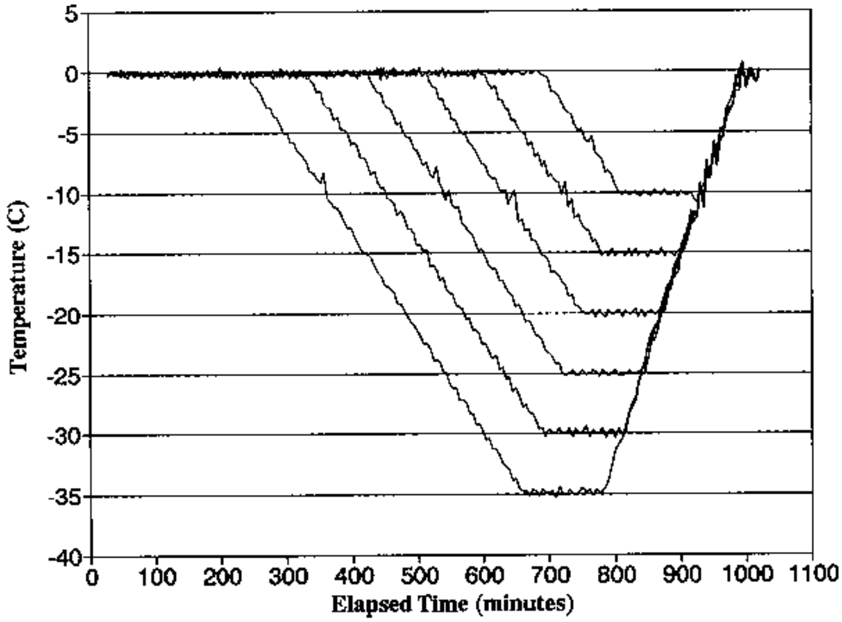

Fig. 3. *Sample temperatures of dormant raspberry canes cooled at 5C/h and warmed at 10C/h. Variations in sample temperatures in the –5 to –15C range are exotherms caused by ice formation in the samples.*

Sample temperatures from a controlled freezing run are shown in Fig. 3. Six raspberry floricane samples were cooled at 5C / h to minimum temperatures of from –10 to –35C. Each sample consisted of a bundle of five 2-cm-long internode sections banded together and wrapped in aluminum foil. Samples were held at their minimum temperatures for 2 h and then warmed to 0C at 10C / h. Initial holding times at 0C were staggered so that all samples reached their final holding temperature of 0C simultaneously. This protocol is used to eliminate artifacts caused by some samples remaining thawed longer than others, and makes it possible to load all samples into the freezer in the late afternoon, and have them reach their final holding temperatures by the beginning of the next work day.

The system described above could be improved by using proportional voltage control on heater inputs to reduce heating overshoot and the minor sample temperature fluctuations shown in Fig. 3. Thermistors would give greater temperature sensor accuracy, but are significantly more expensive than the thermocouples described here. An uninterruptible power supply (UPS) backup to the computer would help avoid data and sample loss in the event of brief power outages.

Samples of the software used for the controlled freezing chambers and electrical conductivity meter may be obtained by writing to D.L. Barney.

Literature Cited

Finkle, B.J., E. Sa B. Pereira, and M.S. Brown. 1974. Freezing of nonwoody plant tissues I. Effect of rate of cooling on damage to frozen beet root sections. Plant Physiol. 53:705–708.

Gilreath, P.R., L.W. Rippetoe, and D.W. Buchanan. 1982. Computer-controlled temperature chambers for plant environment studies. HortScience 17(1):39.

James, E.R. 1979. A portable apparatus for controlled slow, or 2-step, cooling of small volumes. Cryo-Letters 1(2):47–50.

Pogosayan, K.S. 1971. Effect of freezing rate on survival of grapevine tissues. Soviet Plant Physiol. 18:145–150.

Pogosayan, K.S. and A. Sakai. 1973. Effect of thawing speed on survival of grape vine plants. Soviet Plant Physiol. 19:1023–1028.

Sakai, A. 1965. Survival of plant tissue at super-low temperatures III. Relation between effective pre-freezing temperatures and the degree of frost hardiness. Plant Physiol. 40:882–887.

Schneider, G.W., D.R. Walker, and F.E. Correll. 1958. A controlled temperature chamber for hardiness studies with young fruit trees. Proc. Amer. Soc. Hort. Sci. 72:23–26.

Scott, K.R. and L.P.S. Spangelo. 1964. Portable low temperature chamber for winter hardiness testing of fruit trees. Proc. Amer. Soc. Hort. Sci. 84:131–136.

Weiser, C.J. 1970. Cold resistance and injury in woody plants. Science 169 (3952):126–1278.

Wolf, T.K. and R.M. Pool. 1986. Microcomputer-based differential thermal analysis of grapevine dormant tissue. HortScience 21(6): 1447–1448.

Comparison of Packing Systems for Injury and Bacterial Soft Rot on Bell Pepper Fruit

Sergio J. Carballo[1],
Sylvia M. Blankenship[2],
Douglas C. Sanders[3],
David F. Ritchie[4], and
Michael D. Boyette[5]

Additional index words. *Erwinia carotovora, Capsicum annuum,* chlorination, storage, postharvest handling, pathology

Summary. Commercial packing lines in Sampson County, N.C., were surveyed during two growing seasons to study handling methods on susceptibility of bell pepper fruits (*Capsicum annuum* L.) to bacterial soft rot (*Erwinia carotovora* subsp. *carotovora*). Samples were taken from two field packers and one packing house in 1991 and from two field packers and four packing houses in 1992. One field packer and one packing house were common to both years. Fruits were either inoculated with bacteria or untreated and stored at 10 or 21C. Damaged fruits were counted and classified as crushed, cut, bruised, abraded, and other injuries. Fruit

North Carolina State University, Raleigh, NC 27695.

[1]*In partial fulfillment of MS degree. Former graduate student, now Researcher, Estacion Experimental Las Brujas, INIA, Ruta 48-km. 10-Rincon del Colorado C.P. 90.200-C.C. 33085, Canelones-Uruguay.*

[2]*Associate Professor, Dept. of Horticultural Science, Box 7609.*

[3]*Professor, Dept. of Horticultural Science, Box 7609.*

[4]*Associate Professor, Dept. of Plant Pathology, Box 7616.*

[5]*Assistant Professor, Dept of Biological and Agricultural Engineering, Box 7625.*

The use of trade names in this publication does not imply endorsement by the North Carolina Agricultural Research Service of the products named, nor criticism of similar ones not mentioned. Partial funding for this research is from Instituto Nacional de Investigacion Agropecuaria of Uruguay (I.N.I.A.). Andes 1365 P.12, Montevideo, Uruguay, and the North Carolina Agricultural Experiment Station. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked advertisement *solely to indicate this fact.*

injury was less dependent on whether the operation was a packing house or a field packing line than on the overall handling practices of the individual grower. In general, packing peppers in packing houses resulted in an increased number of bruises, whereas fruit from field packing lines had more abrasions. More open skin injuries resulted in greater fruit decay. In both years, fruits stored at 10C had less top rot than fruits stored at 21C. In 1992, they also had less pod rot. Dry and chlorinated lines often had equivalent rot problems.

Bell peppers (*Capsicum annuum* L.) may incur mechanical damage during harvest and postharvest handling. Injuries affect fruit appearance, and increase water loss and susceptibility to postharvest diseases.

In North Carolina, field packing lines and packing houses are common postharvest handling systems. Field packing is usually less expensive and enables growers to avoid injuries caused by handling fruit in bulk bins (Boyette et al., 1990). However, packing houses have the ability to maintain cleaner conditions, and cultural practices are not required to accommodate the harvest operation.

A spray of chlorinated water is an option either in field packing lines or in packing houses. The need for chlorination is controversial because chlorine is dynamic and may lose its bactericidal action quickly. When chlorination fails, water increases the susceptibility of peppers to decay. Bartz (1988) reported that chlorination of water decreased disease incidence in tomato, but also resulted in greater water intake than with the nonchlorinated control treatment. Because peppers are prone to water infiltration, it has been recommended they be handled dry (Bartz and Eckert, 1987).

Bacterial soft rot (BSR) caused by *Erwinia carotovora* subsp. *carotovora* (*Ecc*) is the most destructive postharvest disease of bell peppers (Coplin, 1980; Johnson, 1966). *Ecc* is common on the aerial surfaces of plants and in the root zone and soil (Coplin, 1980). Bacterial inoculum may accumulate on packing lines. Johnson (1966) reported that the brush-waxer in packing sheds was the primary source of inoculum because of accumulation of bacteria on the brushes.

Reduction of inoculum and fruit injury are the main goals in all operations (Coplin, 1980). *Ecc* is an opportunistic pathogen able to initiate disease only under certain conditions that impair host resistance and favor multiplication of bacteria (Klement et al., 1990). Skin injuries, peduncle wounds, high moisture content, and high temperature are major factors in predisposing peppers to rot. Crop rotations, chemical treatments, cultural practices, and harvest time also may affect pepper susceptibility to BSR (Sherf and MacNab, 1986).

Our objective was to survey some typical commercial operations for various characteristics of postharvest handling systems, and determine their effect on injuries and rot incidence. First, we were interested in the types of injuries that occurred and how these affected the occurrence of BSR. Second, we wanted to determine the effectiveness of chlorination under commercial conditions. Third, we wanted to examine the effect of cold storage on development of BSR.

Materials and methods

In 1991 and 1992, three and six commercial packing lines, respectively, were surveyed to determine the effect of handling methods on susceptibility of bell pepper fruit to bacterial soft rot (BSR) caused by *Erwinia carotova* subsp. *carotovora*. The study took place in Sampson County, N.C. Two field-operated packing lines (B and C) and one packinghouse operation (A) were evaluated in 1991. In 1992, two field-operated packing lines (B and F) and four packinghouse operations (A, D, E, and G) were evaluated. Operations A and B were sampled in both years. Peppers were harvested by hand in all operations. In a typical packing house, bulk bins from the field were dumped into stationary bins with conveyor belts to transport fruits to a dumping location, where they were conveyed across a packing line. In typical field packing units, harvested fruits were placed on conveyor belts, which transported fruits to a mobile unit for sorting and packing. Basic descriptions of the overall operations evaluated are presented in Table 1.

In all packing operations, random samples of 40 fruits were taken at three sampling sites through the packing process. In a packinghouse operation, samples were taken from bulk bins (site 1), from the conveyor after dumping (site 2), and from U.S. No. 1 packed boxes (site 3). In field-operated packing lines, samples were taken from the plant (site 1), from the conveyor after dumping (site 2), and U.S. No. 1 packed boxes (site 3). Fruits from the second commercial harvest were sampled. In 1991, samples were taken on 25 June. In 1992, samples were taken on 10 July at packing operations A, B, E, and G; and on 21 July at packing operations D and F. Fruits from each sampling location were inoculated by immersion up to fruit

Table 1. *Basic description of packing operations surveyed at the time of evaluation.*

Variable	1991 Packing operation			1992 Packing operation					
	A	B	C	A	B	D	E	F	G
Date of sampling	25 June	25 June	25 June	10 July	10 July	21 July	10 July	21 July	10 July
Cultivar used	Camelot	Jupiter	Capistrano	Camelot	Jupiter	Bell Captain	Capistrano & Jupiter	Jupiter	Jupiter
Plastic mulch	Yes	No	No	Yes	No	Yes / no	No	No	No
Irrigation system	Drip	Overhead	Overhead	Drip	Overhead	Overhead	Overhead	Overhead	None
Harvest no.	Second	Second	Second	Second	Second	Third	Second	Fourth	Second
Packing line type	House	Field	Field	House	Field	House	House	Field	House
Chemical treatment	Not used	Sprays, chlorinated water	Not used	Not used	Sprays, chlorinated water	Automatic chlorinated system	Automatic chlorinated system	Sprays, chlorinated water	Not used

shoulder in a solution of 10^6 colony-forming units (cfu)/ml of *Ecc* and stored in boxes at 21C for 1 week or 10C for 3 weeks.

Injuries were classified into the following categories: a) crushed, when cracks were produced by fruit compression; b) cut, when any object broke the fruit skin; c) bruised, when tissue damage was observed without a breaking of the fruit skin; d) abrasion, when a scraping was observed on fruit skin; and e) other, when injury did not fit any of the preceding categories. The "other" category included insect and pathogen damage, corky areas, and cracks. The number of injured fruits in each category were counted. Decayed fruits were categorized as rotted on the side (pod rot) or rotted on the pod top near the stem (top rot), counted, and evaluated as a percentage of total fruits.

The experiment was set up as a completely randomized split-plot design of three (1991) and six (1992) packing operations as whole units and a 3 × 2 × 2 factorial arrangement of sampling site, inoculated or non-inoculated, and storage temperature as subunits for each year. Analyses of variance were calculated and, where F tests warranted, LSDs were calculated. Because each commercial operation was different (fertilization, cultivars, packing line design, etc.), it was impossible to truly replicate the study.

Results and discussion

Fruits from packing house operation A had a high number of bruises in both years and a high number of cuts in 1992 (Table 2). Many of the bruises occurred by sampling site 1, indicating rough picking and handling in bulk bins (data not shown). Other packing house operations in 1992 (D, E, and G) had significantly fewer injuries, indicating that it is possible to reduce bruising. However, even in these packing houses, bruises were >20% and cuts >4%, which are high figures and may result in rotten fruits. In 1991, fruits from field-packing operations (B and C) had more abrasions than fruits from the packinghouse operation (A) (Table 2). In 1992, operation B had high abrasion incidence compared to other operations; however, operation F, also a field packer, did not have high abrasion incidence.

Table 2. *Percentage of fruits with various injuries found among several packing operations, 1991 and 1992.*

Packing operation	Injury: Crush	Cut	Bruise	Abrasion	Other
			1991		
A	3.4 a[z]	3.4 a	61.6 a	5.6 b	12.5 a
B	0.7 ab	10.8 a	24.2 b	38.2 a	20.1 a
C	0.0 b	8.3 a	29.8 b	36.1 a	13.9 a
LSD 5%[y]	3.0	12.5	9.5	11.5	8.8
			1992		
A	0.0 a	22.3 a	53.4 a	0.0 b	11.8 cb
B	0.0 a	2.1 b	12.5 c	4.2 a	56.3 a
D	0.0 a	4.2 b	35.4 b	0.0 b	3.5 c
E	0.7 a	5.6 b	39.6 b	0.7 b	18.8 b
F	0.0 a	3.5 b	33.3 b	0.7 b	8.3 c
G	0.0 a	4.8 b	20.2 c	0.7 b	20.1 b
LSD 5%	0.8	7.3	8.3	2.8	73.3

[z]*Means within a year and column not having a letter in common are different at the 5% level of probability by* LSD.
[y]LSD *5% = least significant difference at the 5% level of probability performed when F-test warranted.*

Packing operations that had higher numbers of pod-rotted fruits also had more top-rotted fruits (Table 3). More injuries did not necessarily mean more rotted fruits. Packing operation A, which had a high percentage of bruises on fruits in 1991 (Table 2), had less pod and top rot than other packing operations (Table 3). In 1992, with a similar percentage of bruised fruits, this packing operation had more rot problems. This may be explained by the fact that conditions that predispose peppers to BSR could change for the same packing operation over time. In packing operation A in 1991, pod rot percentage was greater in inoculated fruit than in control fruit, indicating that the actual inoculum concentration in this packing line was low (22% control, 63% inoculated, LSD 5% = 33). In 1992, pod rot percentages were not statistically different (42% control, 62% inoculated, LSD 5% = 33). This difference is probably due to poor sanitary conditions in 1992. Packing operation D had high amounts of BSR (Table 3), but injuries were not excessive compared to other operations (Table 2). Operations E, F, and G, with low total injury level in 1992, also had a low number of decayed fruits (Table 3). Operations A, C, and G did not chlorinate and had both high and low levels of pod rot in both years. Operations D and E had automatic chlorinators, which should have maintained an active chlorine concentration. Pod rot was high to medium in these two operations. Bacterial soft rot problems seemed to have little to do with whether the packing was done dry or with chlorinated water. In 1991, Operations B (chlorinated spray) and C (dry) had equivalent rot problems. In 1992, Operation D, with automatic chlorination, had rot problems equivalent to a dry line (A) and a chlorinated spray line (B) (Table 3.)

Table 3. *Percentage of fruits with pod rot and top rot found among packing operations in 1991 and 1992.*

Packing operation	Pod rot	Top rot
	1991	
A	35.8 b[z]	15.0 b
B	45.0 a	26.6 a
C	49.2 a	33.3 a
LSD 5%[y]	9.6	11.2
	1992	
A	43.1 a	28.5 ab
B	41.7 a	34.0 a
D	45.0 a	41.0 a
E	22.9 bc	12.5 c
F	27.1 b	11.1 c
G	13.9 c	16.7 bc
LSD 5%	14.5	14.3

[z]*Means within a year and column not having a letter in common are different at the 5% level of probability by* LSD.
[y]LSD *5% = least significant difference at the 5% level of probability performed with F-test warranted.*

Cuts, bruises and abrasions increased as the fruit went through the packing process (Table 4). In 1991, there was a large increase in bruises, cuts, and abrasions at sampling site 2 (after dumping). In 1992, injury levels were much lower, but significant bruising and to a lesser extent cuts and abrasions were detected at site 2 and in the packed boxes (site 3). The amount

Table 4. *Percentage of fruits with various injuries found among sampling sites, 1991 and 1992.*

Sampling site	Injury Crush	Cut	Bruise	Abrasion	Other
			1991		
1	0.7 a	3.3 b	24.2 b	8.3 b	15.0 a
2	2.7 a	12.5 ab	41.6 a	39.6 a	14.5 a
3	0.7 a	19.4 a	50.0 a	31.7 a	16.6 a
LSD 5%[z]	3.0	12.5	9.5	11.6	8.8
			1992		
1	0.2 a	2.4 b	8.2 c	0.0 b	8.3 a
2	0.0 a	2.9 ab	17.5 b	0.5 ab	10.6 a
3	0.0 a	5.2 a	22.9 a	1.0 a	10.8 a
LSD 5%	0.3	2.5	3.0	1.0	3.1

[z]*LSD 5% = least significant difference at the 5% level of probability performed when F-test warranted.*

of BSR may depend on the type of injury (when the skin is broken the pathogens can penetrate) and the inoculum concentration present in the packing line.

The growing season was cold and wet in 1992, which may have caused greater susceptibility of fruits to BSR. Johnson (1966) reported that fruits with higher peduncle moisture content developed 75% infection, compared with 40% infection in those with lower peduncle moisture. Other factors besides injury level obviously are involved.

Fruits stored at 10C for 3 weeks had less top rot than fruits stored at 21C for 1 week in both years (Table 5). A reduction in pod rot under 10C storage was observed in 1992, but not in 1991. Cold storage seems to be more effective in reducing rot in calyx and peduncle tissue (top) than in pod tissue. Sherman et al. (1982) compared the effect of precooling methods on untreated and inoculated fruits, and concluded that thorough precooling to 10C soon after harvest delays, but does not prevent, soft rot decay caused by *Erwinia carotovora* in peppers. Our data suggest that, for inoculum concentration of 10^6 cfu / ml, not only a delay, but also a reduction, of top rot is observed on peppers stored at 10C immediately after harvest compared to storage at 21C. Pod tissue has a higher water concentration than top tissue—this may increase susceptibility to BSR. Bacteria require a water film on the surface of the plant cells in the intercellular spaces for vigorous multiplication (Klement et al., 1990). Another possibility is that pod tissue is more susceptible to physiological deterioration than peduncle tissue. Lurie et al. (1986) reported loss of weight; a decrease in firmness, water potential, and water-insoluble pectin; and an increase in water-soluble pectin in pepper cell walls during storage.

Table 5. *Percentage of fruits with pod and top rot found among peppers stored 1 week at 21C and 3 weeks at 10C, 1991 and 1992.*

Temperature (°C)	Pod rot	Top rot
	1991	
21	31.6 a[z]	25.5 a
10	26.1 a	8.3 b
LSD 5%[y]	7.5	6.0
	1992	
21	13.7 a	9.8 a
10	7.8 b	6.2 b
LSD 5%	2.8	2.8

[z]*Means within a year and column not having a letter in common are different at the 5% level of probability by LSD.*
[y]*LSD 5% = least significant difference at the 5% level of probability performed with F-test warranted.*

We have seen that reducing injuries and maintaining good sanitary conditions after harvest have tremendous impact on pepper susceptibility to BSR. Each individual case is worthy of study to reduce potential problems, because general recommendations are not always valid. Sampling fruits in different places from field to packing, and counting injuries, as was done in this work, could be a simple and useful tool that growers may use to monitor their overall handling practices. Placing fruit samples at room temperature for 4 or 5 days and counting the number of rotten pods after that period may give an indication of the packing line sanitary conditions. If chlorinated water is sprayed, periodic monitoring of water pH and active chlorine concentration should be done to ensure its efficacy (Boyette et al., 1992). Some growers think no water on the packing line is best, but it appears BSR problems are equivalent in dry and chlorinated-water packing lines. There appears to be little difference in rot problems between field packing and using a packing house.

Literature Cited

Bartz, J.A. 1988. Potential for postharvest disease in tomato fruit infiltrated with chlorinated water. Plant. Dis. 72:9–13.

Bartz, J.A. and J.W. Eckert. 1987. Bacterial diseases of vegetable crops after harvest, p. 351–376. In: J. Weichmann (ed.). Post harvest physiology of vegetables. Marcel Dekker, New York.

Boyette, M.D., D.F. Ritchie, S.J. Carballo, S.M. Blankenship, and D.C. Sanders. 1992. Maintaining the quality of North Carolina produce: Chlorination and postharvest disease control. N.C. Coop. Ext. Serv. Bul. AG-414-6.

Boyette, M.D., L.G. Wilson and E.A. Estes. 1990. Maintaining the quality of North Carolina fresh produce. Postharvest cooling and handling of peppers. N.C. Coop. Ext. Serv. Bul. No. AG-413-3.

Coplin, D.L. 1980. Erwinia carotovora var. *carotovora* on bell peppers in Ohio. Plant Dis. 64:191–194.

Johnson, H.B. 1966. Bacterial soft rot in bell peppers. Cause and commercial control. USDA Market Res. Dept. 738.

Klement, Z., K. Rudolph, and P.C. Sands. 1990. Methods in Phytobacteriology. Akadémiai Kiadó, Budapest.

Lurie, S., B. Shapiro, and S. Ben-Yehoshua. 1986. Effects of water stress and degree of ripeness on rate of senescence of harvested bell pepper fruit. J. Amer. Soc. Hort. Sci 111(6):880–885.

Sherf, A.F. and A.A. MacNab. 1986. Vegetable diseases and their control. 2nd ed. Wiley, New York.

Sherman, M., R.F. Kasmire, K.D. Shuler, and D.A. Botts. 1982. Effect of precooling methods and peduncle lengths on soft rot decay of bell peppers. HortScience 17(2):251–252.