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Effect of Insecticide Seed Treatments on Sugarbeet Storability

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ABSTRACT

Sucrose loss in sugarbeet storage is a concern for all roots, but particularly those stored under ambient conditions. In order to control or suppress insect pests in sugarbeet production and consequently improve root storability, two neonicotinoid seed treatments, Poncho Beta (60 g a.i. [active ingredient] clothianidin + 8 g a.i. beta-cyfluthrin/100,000 seeds) and Cruiser Tef (60 g a.i. thiamethoxam + 8 g a.i. tefluthrin/100,000 seeds), were used to produce roots from four commercial sugarbeet cultivars grown in Declo, ID. At harvest, eight-beet samples from each cultivar x treatment combination were collected and placed inside an outdoor pile. Samples were removed on approximately 30-day intervals beginning on December 6 and 8 in 2008 and 2009, respectively. Discolored and frozen root area, weight and percent sucrose reduction, and sucrose recovery were evaluated. Across six-sampling dates, Poncho Beta was always ranked first for recoverable sucrose and performed well for the other variables assessed. Over the three sampling-dates when Poncho Beta was significantly better ($P \leq 0.10$) than the non-treated check, recoverable sucrose was increased by an average of 17% with only insect pest pressure and no disease pressure. Cruiser Tef tended to rank intermediate between Poncho Beta and the non-treated check for recoverable sucrose and other variables. The insecticide seed treatments not only have the potential to limit yield losses and increase profits in the field, but also to improve sucrose recovery in storage.

Additional key words: neonicotinoid, clothianidin, thiamethoxam, beet storage

The loss of sugarbeet root tonnage and sucrose in storage costs the industry tens of millions of dollars annually (Bugbee, 1982; Bugbee and Cole, 1976; Karnik et al., 1970; Strausbaugh et al., 2008b). The best way to control sucrose losses in sugarbeet roots under ambient storage conditions will be an integrated approach. Some of the major factors influencing sucrose loss in sugarbeet roots include temperature, root health at harvest, respiration, excessive microbial growth and moisture loss, damage during harvest and transport, and the amount of soil, weeds, and debris going into piles (Akeson and Stout, 1978; Bugbee, 1982; Bugbee, 1993; Dexter et al., 1966; Kenter and Hoffman, 2006; Kenter and Hoffman, 2008; Kenter and Hoffman, 2009; Klotz and Finger, 2004; Lafta and Fugate, 2009; Mumford and Wyse, 1976; Wyse, 1978a; Wyse, 1978b). These factors are particularly important for the outer meter of the pile (Bugbee, 1993). Therefore, some of the primary responses of the sugarbeet industry to control losses in storage have been the following: split piles, air ventilation, tarp coverings, storage sheds, insulation, and refrigeration (Bernhardson, 2009; Peterson et al., 1980; Peterson et al., 1984). These physical responses to control storage losses are helpful, but only address part of the problem. Additional integrated controls such as selecting roots for less respiration, improving resistance to microbial growth, and storing only healthy roots also need consideration (Akeson and Widner, 1981; Campbell and Bugbee, 1988; Cole and Bugbee, 1976; Klotz and Campbell, 2009; Strausbaugh et al., 2009; Wyse and Dexter, 1971).

In Idaho, sugarbeet roots are commonly stored outdoors in piles 37 m wide at the base, 24 m wide at the top, and 8 m high (Peterson et al., 1984). About two-thirds of the roots harvested are stored in this manner, with half being held for short-term storage (less than 90 days) and the other half subjected to long-term storage (up to 160 days). Thus, to enhance storability beyond physical control measures, improving sugarbeet germplasm for reduced respiration and microbial resistance would be desirable. Some lines with reduced respiration and resistance to *Phoma betae* Frank, *Botrytis cinerea* Pers. ex Fr., and *Penicillium claviforme* Bainier have been released (Akeson and Widner, 1981; Bugbee, 1978; Bugbee, 1979; Bugbee and Campbell, 1990; Campbell and Bugbee, 1985; Campbell and Bugbee, 1988; Campbell and Bugbee, 1989). However, incorporating these traits into commercial germplasm takes additional breeding and selection. Once storability is incorporated into commercial cultivars , conducting trials to reliably identify the best cultivars has also been problematic.

Recently, the influence of field disease problems on sugarbeet root storability has received considerable attention. Field disease problems such as rhizomania (Campbell et al., 2008; Strausbaugh et al., 2008b; Strausbaugh et al., 2009), Aphanomyces root rot (Campbell and Klotz, 2006; Klotz and Campbell, 2009), Rhizoctonia root rot (Kenter et al., 2006), Cercospora leaf spot (Smith and Ruppel, 1971), and curly top (Strausbaugh et al., 2008a) can all have a negative influence on the storability of sugarbeet roots. The influence of *Beet necrotic yellow vein virus* (BNYVV), the causal agent of rhizomania, has been identified to be particularly damaging (Campbell et al., 2008; Strausbaugh et al., 2008b; Strausbaugh et al., 2009). In long term storage, sucrose losses from sugarbeet roots infested with BNYVV can approach 90% (Strausbaugh et al., 2008b; Strausbaugh et al., 2009). Given the potential for cultivar separation with BNYVV infested roots in long-term storage, this approach was investigated for its potential as a tool for cultivar selection for storability (Strausbaugh et al., 2009). By combining the use of BNYVV-infested roots with indoor storage, good consistent cultivar separation for storability can be achieved (Strausbaugh et al., 2009). This new approach to cultivar selection may lead to more widespread incorporation of storability into commercial germplasm.

Although the influence of field disease problems has been under investigation, the influence of pest pressure in the field on the sugarbeet storability has been given limited attention. Recently the use of clothianidin, the active ingredient in Poncho, as a seed treatment proved effective in controlling the beet leafhopper (*Circulifer tenellus* Baker) sufficiently to limit curly top so that storability could be improved (Strausbaugh et al., 2008a). Given the wide influence of clothianidin on numerous pest problems (Strausbaugh et al., 2010), this insecticide applied as a seed treatment could potentially allow for improved root health going into storage. The objective of this study was to investigate the possibility that insecticidal seed treatments, without the influence of disease, could provide enough control and/or suppression of insect pests throughout the growing season to improve the storability of sugarbeet roots.

MATERIALS AND METHODS

Treatments.

The experimental design was randomized complete block with four replications. The study involved three seed treatments and four commercial sugarbeet cultivars (B-13, B-22, C-12, and HM070002; for more information on the coded cultivars contact the respective seed companies: B = Betaseed Inc., C = ACH Seeds Inc., and HM = Hilleshog) for a total of 12 treatments. The seed treatments included a non-insecticide-treated check, Cruiser Tef (60 g a.i. thiamethoxam + 8 g a.i. tefluthrin /100,000 seed), and Poncho Beta (60 g a.i. clothianidin + 8 g a.i. beta-cyfluthrin/100,000 seed). The non-insecticide-treated checks and Poncho Beta treated seed had an Allegiance FL (15.6 g a.i. metalaxyl/100 kg seed) and Thiram 42S (250 g a.i. thiram/100 kg seed) fungicide seed treatment to limit the influence of fungal pathogens and allow for good stand establishment. The seed treated with Cruiser Tef had Apron XL (7.5 g a.i. mefenoxam/100 kg seed) + Maxim 4FS (2.5 g a.i. fludioxonil/100 kg seed) as a fungicide seed treatment. The non-insecticide-treated checks and Poncho Beta treatments were applied by Bayer CropScience (Research Triangle Park, NC) and the Cruiser Tef treatment was applied by Syngenta (Stanton, MN). The trial was planted in Declo, ID to a density of 352,123 seeds/ha on 16 April 2008 and thinned to 117,374 plants/ha on 13 June. Plots were four rows wide (56-cm row spacing) and 7.3 m long. Trials were managed using standard crop production practices described previously (Strausbaugh et al., 2006), except no insecticides were used other than the seed treatments.

Root samples.

The center two rows were mechanically topped and a two-row plot harvester was used to harvest the topped rows on 7 October. Two eight-beet sugar samples per plot were collected for sugar analysis during harvest. At the same time, three additional eight-beet samples per plot were collected and placed in a nylon mesh onion bag. The storage samples were piled inside a metal corrugated ventilation pipe (0.9 m diameter) on top of plywood in the same experimental design and blocks as they were arranged in the field. The samples inside the pipe covered an area of 6.1 m in length with the initial 6.1 m of the open end of the pipe near the edge of the pile remaining unused. The open end of the pipe was covered with straw bales. The pipe was located on top of a 30 cm layer of beet. The pipe was covered by roots piled to a height of 8 m. The pile was ventilated using the same perforated pipe placed 3.7 m on center. The storage pipe with the samples was placed in between the two ventilation pipes. The roots surrounding the pipe were from commercial cultivars and healthy in appearance (no visible rhizomania or rot symptoms). The samples were retrieved 6 December 2008, 4 January 2009, and 5 February 2009 after 60, 90, and 120 days in storage (DIS), respectively. Temperature inside the storage tube was recorded on a Hobo temperature sensor (Onset Computer Corp., Bourne, MA) at 1 h intervals.

The trial was repeated during the 2009 growing season with the same cultivars and seed treatments. The crop was planted on 21 April in Declo, ID and harvested on 13 Oct. The samples were retrieved 8 December 2009, 6 January 2010, and 5 February 2010 after 56, 85, and 115 DIS, respectively.

Disease and Pest Ratings.

The center two rows of the plots were evaluated for curly top just prior to harvest using a disease index of 0 to 9 described by Strausbaugh et al. (2006). During harvest roots were evaluated for rhizomania on a scale of 0 to 9 as described by Strausbaugh et al. (2008b). In both disease ratings 0 represented a healthy plant and 9 represented a dead plant. Both scales were applied in a continuous manner rather than categorically. Cultivar B-22 is very susceptible to curly top pressure and would show symptoms at any exposure level, while the other three cultivars contain moderate resistance/tolerance based observations in the BSDF Curly Top nurseries (unpublished data). All four cultivars contain resistance/tolerance to rhizomania based on observations in rhizomania nurseries (unpublished data). Evaluations for leafminer (*Pegomya* spp.), black bean aphid (*Aphis fabae* Scopoli), and root aphid (*Pemphigus betae* Doane) were conducted as described by Strausbaugh et al. (2010). In addition, the plots were scouted approximately every three weeks throughout the growing season for the presence of other diseases and pests.

Ratings for discoloration and freeze damage.

After being retrieved from the storage pile on each sampling date, the roots were evaluated for surface discoloration as the percentage of root area associated with rot damage such as dry black rot, wet bacterial rot, and/or tissue covered with fungal growth. The percentage of root area associated with freeze damage (frost on root surface and translucent tissue) was also established at the time of retrieval from storage.

Weight analysis.

Prior to placing the storage samples in the pile, each sample was weighed. The samples were reweighed when retrieved from the storage pile. These weights were used to determine reduction in root weight.

Sugar analysis and yield.

Two eight-beet samples collected from each plot at harvest were submitted to the Amalgamated Tare Lab in Paul, ID. Percent sucrose was determined using an Autopol 880 polarimeter (Rudolph Research

Analytical, Hackettstown, NJ) and a half-normal weight sample dilution and aluminum sulfate clarification method [ICUMSA Method GS6-3 1994] (Bartens, 2005). Conductivity was measured using a Foxboro conductivity meter Model 871EC (Foxboro, Foxboro, MA) and nitrate was measured using a multimeter Model 250 (Denver Instruments, Denver, CO) with Orion probes 900200 and 9300 BNWP (Krackler Scientific, Inc., Albany, NY). Percent sucrose for samples coming out of storage was determined by Amalgamated Research Inc. in Twin Falls, ID using gas chromatography, since polarimeter readings can be affected by impurities that accumulate during storage (Buczys, 2007; Shore et al., 1983). The gas chromatographic method was similar to ICUMSA Method GS4/7/8/5-2 [2002] with the following modifications: the internal standard used is D(-)- salicin [2-(hydroxymethyl)phenyl-ß-D-glucopyranoside] and equal volumes (to ± 0.01 ml) of a solution of internal standard in dimethylformamide were dispensed into weighed samples and standards using a volumetric dispenser (Bartens, 2005). The gas chromatography analysis averaged 1.395% higher than the polarimeter reading on samples evaluated in previous work (Strausbaugh et al., 2008b). To establish percent reduction in sucrose at harvest versus storage, only samples from within the same plot were compared. Percent sucrose reduction was established using the following equation: % reduction in pounds of sucrose = $(1-(((\%\ \text{Sucrose}_{\text{storage sample}} - 1.395) \times \text{Weight}_{\text{storage sample}})/(\%\ \text{Sucrose}_{\text{harvest sample}} \times \text{Weight}_{\text{harvest sample}}))) \times 100$. Recoverable sucrose yield per ton of roots was estimated using [(extraction)(0.01)(gross sucrose/ha)]/(t/ha) , where extraction = 250 + [[(1255.2)(conductivity) – (15000)(percent sucrose - 6185)]/[(percent sucrose)(98.66 – [(7.845)(conductivity)])]] and gross sucrose = [[(t/ha)(percent sucrose)](0.01)](1000 kg/t).

Data Analysis.

Data were analyzed in SAS (SAS Institute Inc., 2008) using the Proc Mixed procedure. The Tukey-Kramer multiple comparison test ($P < 0.05$) was used for mean comparisons. Linear regression analyses (Proc Reg) were also conducted in SAS.

RESULTS

Temperature.

During the 2008/2009 storage season, temperatures began above 0°C and attained freezing after 61 days in storage (Fig. 1, Plate A). The temperature remained below freezing for the remainder of the storage period with the lowest average daily temperature being -8.3°C after 73

DIS. During the 2009/2010 storage season, temperatures were lower than the previous year with freezing temperatures beginning after roots were in storage for only 34 days (Fig. 1, Plate B). Temperatures remained below freezing except for day 45 in storage when the average daily temperature reached 0.2°C. The lowest average daily temperature was -10.6°C after 65 days in storage.

Disease and pest ratings.

No damping off was evident both years, which allowed all plots to have equal plant numbers after thinning. No curly top or rhizomania was evident in the plot areas both years, so data are not presented for these disease problems. Other diseases were also not evident on plants in the plot areas during both growing seasons or on the roots during harvest. In 2008 leafminer, black bean aphid, and sugarbeet root aphid were present on 18%, 15%, and 85% of the non-treated check plants in the field, respectively (Strausbaugh et al., 2010). In 2009 leafminer and black bean aphid were present on 76% and 5% of the non-treated check plants in the field, respectively (Strausbaugh et al., 2010). No sugarbeet

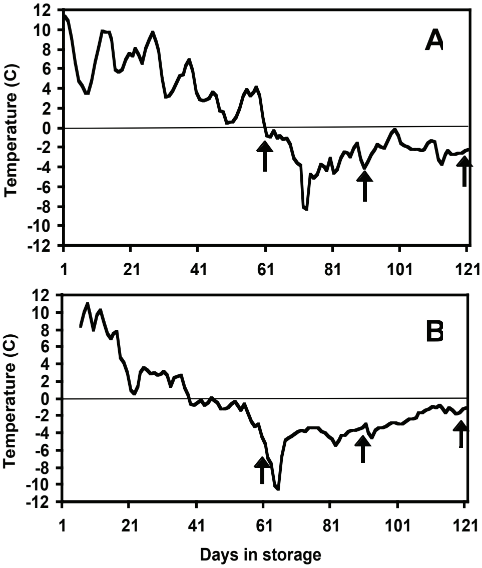

Fig. 1. Average daily temperature (°C) next to sugarbeet storage samples inside the storage tube from 7 October 2008 to 5 February 2009 (A) and from 13 October 2009 to 5 February 2010 (B) in an outdoor pile in Twin Falls, ID. Arrows designate when storage samples were retrieved.

root aphids were observed on roots in 2009. Other pest problems were not evident on plants in the plot area during the two growing seasons or on the roots at harvest.

Surface discoloration.

In 2008 overall treatment means were compared (Table 1) because of a non-significant treatment by cultivar interaction for roots after 60, 90, and 120 DIS (*P* = 0.723, 0.863, and 0.511, respectively) . With 2009 roots after 56 DIS, there was no surface discoloration on the roots and consequently no analysis was conducted. In 2009 overall treatment means were compared (Table 1) because of non-significant treatment by cultivar interaction for roots after 85 and 115 DIS (*P* = 0.453 and 0.851, respectively). When comparing seed treatments, there were no significant differences among means within the six sampling-dates. However, Poncho Beta always ranked first or equal to other treatments for less discolored root surface area across all six sampling-dates. When comparing cultivars, the only differences were with the 2008 roots after 120 DIS (Table 1). HM070002 (29% discoloration) had less surface discoloration than C-12 (53%) and B-13 (57%). A similar trend was evident after 60 and 90 DIS with 2008 roots and after 115 DIS with 2009 roots. In the first two 2009 sampling-dates, roots could not be compared with the 2008 roots, because the optimal storage conditions did not allow for fungal or lesion development on the 2009 roots.

Based on regression analysis with data from 2008 roots on all sampling-dates, there was a strong positive relationship between surface discoloration and frozen root area, since r^2 ranged from 0.75 to 0.91 (Table 2). With 2009 roots there was only a positive relationship ($r^2 = 0.33$) between surface discoloration and frozen root area on the last sampling (Table 2). With 2008 roots, there was a weak negative relationship (r^2 ranged from 0.15 to 0.31) between surface discoloration and estimated recoverable sucrose (ERS) on all three sampling dates (Table 2). With 2009 roots there was weak negative relationship ($r^2 = 0.08$) between surface discoloration and ERS on the last sampling (Table 2). With 2008 roots there was a weak positive relationship between surface discoloration and weight reduction in the December and February samplings ($r^2 = 0.10$ and 0.13, respectively; Table 2). With 2009 roots there was a weak positive relationship between surface discoloration and weight reduction in the last sampling ($r^2 = 0.19$, Table 2).

Frozen root area.

In 2008 overall treatment means (Table 3) were compared because of a non-significant treatment by cultivar interaction for roots

Table 1. The percentage of discolored surface area as influenced by cultivars and insecticide seed treatments in sugarbeet storage in an outdoor commercial pile at Twin Falls, ID.

Variable[†]	**Surface discoloration (%)**[‡]					
	2008 roots			**2009 roots**		
	60 DIS	90 DIS	120 DIS	56 DIS	85 DIS	115 DIS
Seed treatment						
Non-treated check	10	20	47	0	2	12
Cruiser Tef	5	21	49	0	3	13
Poncho Beta	5	12	38	0	2	8
$P > F$[§]	0.177	0.163	0.131	NA	0.156	0.480
Cultivar						
B-13	10	26	57 a	0	2	13
B-22	7	19	39 ab	0	2	7
C-12	8	15	53 a	0	3	17
HM070002	2	11	29 b	0	2	5
$P > F$[§]	0.112	0.067	0.001	NA	0.230	0.110

[†] Non-treated check = no insecticide seed treatment, Cruiser Tef = 60 g a.i. thiamethoxam + 8 g a.i. tefluthrin/100,000 seed, and Poncho Beta = 60 g a.i. clothianidin + 8 g a.i. beta-cyfluthrin/100,000 seed. For more information on the coded cultivars contact the respective seed companies: B = Betaseed Inc., C = ACH Seeds Inc., and HM = Hilleshog.

[‡] Surface discoloration = percentage of root surface area associated with fungal growth or dark root rot lesions. DIS = days in storage.

[§] $P > F$ was the probability associated with the F value. Data were analyzed in SAS (SAS Institute Inc., 2008) using the Proc Mixed procedure. Means followed by the same letter did not differ significantly based on the Tukey-Kramer multiple comparison test ($P < 0.05$). NA = no analysis was necessary since there was no fungal growth or lesions on the root surface. With 2008 roots after 60, 90, and 120 DIS, there was no treatment by cultivar interaction (P = 0.723, 0.863, and 0.511, respectively), so the overall treatment means were compared. With 2009 roots after 56, 85, and 115 DIS, there was no treatment by cultivar interaction (P = NA, 0.453, 0.708, and 0.851, respectively), so the overall treatment means were compared.

Table 2. Regression analysis for storage and yield variables in sugar beet storage studies conducted in an outdoor commercial pile at Twin Falls, ID.

		December		January		February	
Independent variable[†]	**Dependent variable**	**r^2**	**P**	**r^2**	**P**	**r^2**	**P**
2008							
Surface discoloration	ERS	0.1473	0.007	0.3146	<0.001	0.2970	<0.001
Frozen root area	ERS	0.1588	0.005	0.3537	<0.001	0.3613	<0.001
Weight reduction	ERS	0.2133	0.001	0.0116	0.467	0.2380	<0.001
Sucrose at harvest	ERS	0.1760	0.003	0.1386	0.009	0.2074	0.001
Nitrate at harvest	ERS	0.0064	0.588	0.1226	0.015	0.0040	0.670
Cond. at harvest	ERS	0.0000	0.988	0.0630	0.085	0.0245	0.288
Frozen	Surface discoloration	0.8536	<0.001	0.9086	<0.001	0.7520	<0.001
Surface discoloration	Weight reduction	0.1020	0.027	0.0116	0.466	0.1335	0.011
Frozen root area	Weight reduction	0.0464	0.142	0.0080	0.546	0.1294	0.012
2009							
Surface discoloration	ERS	NT	NT	0.0054	0.620	0.0825	0.048
Frozen root area	ERS	0.0518	0.120	0.0477	0.136	0.1121	0.020
Weight reduction	ERS	0.1227	0.015	0.0132	0.436	0.2082	0.001
Sucrose at harvest	ERS	0.0449	0.148	0.0063	0.590	0.0439	0.153
Nitrate at harvest	ERS	0.0117	0.464	0.0214	0.321	0.0024	0.741
Cond. at harvest	ERS	0.0807	0.050	0.0568	0.103	0.0181	0.362
Frozen	Surface discoloration	NT	NT	0.0000	0.977	0.3304	<0.001
Surface discoloration	Weight reduction	NT	NT	0.0099	0.501	0.1884	0.002
Frozen root area	Weight reduction	0.3904	<0.001	0.0446	0.150	0.1652	0.004

[†] Surface discoloration = the percentage of root surface area covered by dark lesions or fungal growth. ERS = estimated recoverable sucrose at the end of storage. Frozen root area = root surface area frozen. Weight reduction = percent reduction in root weight after storage when compared to that determined at harvest. Cond. = conductivity measured at harvest. NT = not tested since there was no surface discoloration evident on the roots in the December sampling.

Table 3. The frozen root surface area as influenced by cultivars and insecticide seed treatments in sugarbeet storage in an outdoor commercial pile at Twin Falls, ID.

	Frozen root surface area (%)[‡]					
	2008 roots			**2009 roots**		
Variable[†]	**60 DIS**	**90 DIS**	**120 DIS**	**56 DIS**	**85 DIS**	**115 DIS**
Seed treatment						
Non-treated check	4	15	27	54	91	35
Cruiser Tef	2	14	30	60	93	43
Poncho Beta	1	8	19	39	80	20
$P > F$[§]	0.109	0.165	0.229	0.408	0.157	0.210
Cultivar						
B-13	5 a	19	39 a	70	90	36
B-22	2 ab	13	20 ab	46	97	33
C-12	2 ab	9	30 ab	57	88	38
HM070002	0 b	8	12 b	32	80	25
$P > F$[§]	0.050	0.085	0.010	0.210	0.196	0.844

[†] Non-treated check = no insecticide seed treatment, Cruiser Tef = 60 g a.i. thiamethoxam + 8 g a.i. tefluthrin/100,000 seed, and Poncho Beta = 60 g a.i. clothianidin + 8 g a.i. beta-cyfluthrin/100,000 seed. For more information on the coded cultivars contact the respective seed companies: B = Betaseed Inc., C = ACH Seeds Inc., and HM = Hilleshog.

[‡] Frozen root surface area = percentage of root surface area associated with frozen tissue. DIS = days in storage.

[§] $P > F$ was the probability associated with the F value. Data were analyzed in SAS (SAS Institute Inc., 2008) using the Proc Mixed procedure. Means followed by the same letter did not differ significantly based on the Tukey-Kramer multiple comparison test ($P < 0.05$). With 2008 roots after 60, 90, and 120 DIS, there was no treatment by cultivar interaction ($P = 0.331$, 0.717, and 0.664, respectively), so the overall treatment means were compared. With 2009 roots after 56, 85, and 115 DIS, there was no treatment by cultivar interaction ($P = 0.862$, 0.062, and 0.211, respectively), so the overall treatment means were compared.

after 60, 90, and 120 DIS (P = 0.331, 0.717, and 0.664, respectively). In 2009 overall treatment means (Table 3) were compared because of a non-significant treatment by cultivar interaction for roots after 56, 85, and 115 DIS (P = 0.862, 0.062, and 0.211, respectively). When comparing seed treatments, there were no significant differences among means within the six sampling-dates (Table 3). However, Poncho Beta always ranked first for less frozen root surface area across all six sampling-dates. When comparing cultivars, the only differences among cultivars were with the 2008 roots after 60 and 120 DIS (Table 3). HM070002 always ranked first for less frozen root surface area across all six sampling-dates and at times was significantly different from B-13.

Based on regression analysis with data from 2008 roots, there was a weak negative relationship between frozen root area and ERS, since r^2 ranged from 0.16 to 0.36 (Table 2). With 2009 roots there was only a weak negative relationship ($r^2 = 0.11$) between frozen root area and ERS on the last sampling-date (Table 2). With 2008 roots there was a weak positive relationship ($r^2 = 0.13$) between frozen root area and weight reduction on the last sampling-date (Table 2). With 2009 roots there was a weak positive relationship between frozen root area and weight reduction in the December and February samplings (r^2 = 0.39 and 0.17, respectively; Table 2).

Root weight reduction.

In 2008 overall treatment means (Table 4) were compared because of a non-significant treatment by cultivar interaction for roots after 60, 90, and 120 DIS (P = 0.616, 0.366, and 0.735, respectively). In 2009 overall treatment means (Table 4) were compared because of a non-significant treatment by cultivar interaction for roots after 56, 85, and 115 DIS (P = 0.071, 0.708, and 0.059, respectively). With 2008 roots after 60 DIS, Poncho Beta and Cruiser Tef had less weight reduction than the non-treated check (Table 4). With the other five sampling dates, no consistent trends were evident. Relative to C-12, HM070002 had less weight reduction with 2009 roots after 115 DIS (Table 4). On the other five sampling-dates, HM070002 ranked first or at least equal to other cultivars for the least weight reduction.

Based on regression analysis with data from 2008 roots there was a weak negative relationship between weight reduction and ERS in the December and February samplings (r^2 = 0.21 and 0.24, respectively; Table 2). With the 2009 roots there was also a weak negative relationship between weight reduction and ERS in the December and February samplings (r^2 = 0.12 and 0.21, respectively; Table 2).

Table 4. Root weight reduction as influenced by cultivars and insecticide seed treatments in sugarbeet storage in an outdoor commercial pile at Twin Falls, ID.

	Weight reduction (%)[‡]					
	2008 roots			**2009 roots**		
Variable[†]	**60 DIS**	**90 DIS**	**120 DIS**	**56 DIS**	**85 DIS**	**115 DIS**
Seed treatment						
Non-treated check	12 a	12	16	8	9	8
Cruiser Tef	10 b	12	15	8	8	9
Poncho Beta	9 b	10	16	7	9	8
$P > F$[§]	0.005	0.209	0.703	0.654	0.055	0.668
Cultivar						
B-13	10	12	16	8	9	9 ab
B-22	11	11	16	7	8	8 ab
C-12	10	11	16	8	9	9 a
HM070002	9	10	15	7	8	7 b
$P > F$[§]	0.414	0.515	0.989	0.694	0.117	0.028

[†] Non-treated check = no insecticide seed treatment, Cruiser Tef = 60 g a.i. thiamethoxam + 8 g a.i. tefluthrin/100,000 seed, and Poncho Beta = 60 g a.i. clothianidin + 8 g a.i. beta-cyfluthrin/100,000 seed. For more information on the coded cultivars contact the respective seed companies: B = Betaseed Inc., C = ACH Seeds Inc., and HM = Hilleshog.

[‡] Weight reduction = percent reduction in root weight after storage when compared to that determined at harvest. DIS = days in storage.

[§] $P > F$ was the probability associated with the F value. Data were analyzed in SAS (SAS Institute Inc., 2008) using the Proc Mixed procedure. Means followed by the same letter did not differ significantly based on the Tukey-Kramer multiple comparison test ($P < 0.05$). With 2008 roots after 60, 90, and 120 DIS, there was no treatment by cultivar interaction ($P = 0.616$, 0.366, and 0.735, respectively), so the overall treatment means were compared. With 2009 roots after 56, 85, and 115 DIS, there was no treatment by cultivar interaction ($P = 0.071$, 0.708, and 0.059, respectively), so the overall treatment means were compared.

Sucrose reduction.

In 2008 overall treatment means (Table 5) were compared because of a non-significant treatment by cultivar interaction for roots after 60, 90, and 120 DIS (*P* = 0.066, 0.609, and 0.473, respectively). In 2009 overall treatment means (Table 5) were compared because of a non-significant treatment by cultivar interaction for roots after 56, 85, and 115 DIS (*P* = 0.687, 0.346, and 0.250, respectively). With the 2008 roots after 60 DIS, Poncho Beta and Cruiser Tef had less sucrose reduction than the non-treated check (Table 5). The other two sampling-dates for the 2008 roots showed a similar trend, particularly for Poncho Beta, but there were no significant differences. No significant differences or trends were evident with the 2009 roots (Table 5). After 60 and 90 DIS with 2008 roots, C-12 and HM070002 had less sucrose reduction. With 2009 roots after 56 and 115 DIS, B-22 had the lowest sucrose reduction.

Estimated recoverable sucrose.

With 2008 roots after 60 DIS, there was a significant interaction (*P* = 0.0108) and thus treatments were compared within each cultivar. With cultivar B-13 roots after 60 DIS significant differences (*P* = <0.001) were present among the treatments. Cruiser Tef (7723 kg/ha) and Poncho Beta (7260 kg/ha) were not significantly different from each other, but both led to more recoverable sucrose than the non-treated check (4769 kg/ha). With cultivar B-22 roots after 60 DIS, significant differences were not (*P* = 0.297) present among the treatments [Cruiser Tef (6714 kg/ha), Poncho Beta (7237 kg/ha), and non-treated check (6063 kg/ha)]. With cultivar C-12 roots after 60 DIS, significant differences (*P* = 0.005) were present among the treatments. Cruiser Tef (7741 kg/ha) and Poncho Beta (8614 kg/ha) were not different from each other, but both led to more recoverable sucrose than the non-treated check (4734 kg/ha). With cultivar HM070002 roots after 60 DIS, significant differences (*P* = 0.018) were present among the treatments. Poncho Beta (8099 kg/ha) was not different from Cruiser Tef (7186 kg/ha) but did lead to more recoverable sucrose than the non-treated check (6438 kg/ha). Cruiser Tef did not have more recoverable sucrose than the non-treated check.

With 2008 roots after 90 and 120 DIS, there was no treatment by cultivar interaction (*P* = 0.687 and 0.460, respectively), so the overall treatment means were compared (Table 6). With 2009 roots after 56, 85, and 115 DIS, there was no treatment by cultivar interaction (*P* = 0.120, 0.349, and 0.071, respectively), so the overall treatment means were compared (Table 6). When the treatments were compared across the five storage-sampling-times, there was only one sampling-date (2009

Table 5. Sucrose reduction as influenced by cultivars and insecticide seed treatments in sugarbeet storage in an outdoor commercial pile at Twin Falls, ID.

	Sucrose reduction (%)[‡]					
	2008 roots			**2009 roots**		
Variable[†]	**60 DIS**	**90 DIS**	**120 DIS**	**56 DIS**	**85 DIS**	**115 DIS**
Seed treatment						
Non-treated check	35 a	75	89	19	23	25
Cruiser Tef	23 b	74	88	20	27	26
Poncho Beta	19 b	63	82	19	26	25
$P > F$[§]	<0.001	0.170	0.345	0.527	0.222	0.731
Cultivar						
B-13	31 a	85 a	94	20 a	26	25 ab
B-22	31 a	71 ab	84	15 b	21	22 b
C-12	23 b	61 b	85	22 a	28	29 a
HM070002	18 b	66 ab	82	21 a	26	24 b
$P > F$[§]	<0.001	0.041	0.150	0.003	0.106	0.006

[†] Non-treated check = no insecticide seed treatment, Cruiser Tef = 60 g a.i. thiamethoxam + 8 g a.i. tefluthrin/100,000 seed, and Poncho Beta = 60 g a.i. clothianidin + 8 g a.i. beta-cyfluthrin/100,000 seed. For more information on the coded cultivars contact the respective seed companies: B = Betaseed Inc., C = ACH Seeds Inc., and HM = Hilleshog.

[‡] Sucrose reduction = percent reduction in sucrose after storage when compared to that determined at harvest. DIS = days in storage.

[§] $P > F$ was the probability associated with the F value. Data were analyzed in SAS (SAS Institute Inc., 2008) using the Proc Mixed procedure. Means followed by the same letter did not differ significantly based on the Tukey-Kramer multiple comparison test ($P < 0.05$). With 2008 roots after 60, 90, and 120 DIS, there was no treatment by cultivar interaction ($P = 0.066$, 0.609, and 0.473, respectively), so the overall treatment means were compared. With 2009 roots after 56, 85, and 115 DIS, there was no treatment by cultivar interaction ($P = 0.687$, 0.346, and 0.250, respectively), so the overall treatment means were compared.

Table 6. Estimated recoverable sucrose as influenced by cultivars and insecticide seed treatments in sugarbeet storage in an outdoor commercial pile at Twin Falls, ID.

	Estimated recoverable sucrose (kg/ha)[‡]					
	2008 roots			**2009 roots**		
Variable[†]	**60 DIS**	**90 DIS**	**120 DIS**	**56 DIS**	**85 DIS**	**115 DIS**
Seed treatment						
Non-treated check	5501	2167	1032	9982	9418	9197 b
Cruiser Tef	7340	2506	1181	10423	9490	9667 ab
Poncho Beta	7803	3584	1742	10497	9685	9838 a
$P > F$[§]	NC	0.100	0.296	0.086	0.710	0.040
Cultivar						
B-13	6585	1494	603	10525 ab	9684	9887 a
B-22	6671	2887	1666	10828 a	10087	9923 a
C-12	7030	3559	1397	9858 b	9086	8895 b
HM070002	7241	3068	1608	9992 b	9268	9565 ab
$P > F$[§]	NC	0.071	0.200	0.004	0.060	0.004

[†] Non-treated check = no insecticide seed treatment, Cruiser Tef = 60 g a.i. thiamethoxam + 8 g a.i. tefluthrin/100,000 seed, and Poncho Beta = 60 g a.i. clothianidin + 8 g a.i. beta-cyfluthrin/100,000 seed. For more information on the coded cultivars contact the respective seed companies: B = Betaseed Inc., C = ACH Seeds Inc., and HM = Hilleshog.

[‡] Estimated recoverable sucrose = sucrose recoverable from roots after storage. DIS = days in storage.

[§] $P > F$ was the probability associated with the F value. Data were analyzed in SAS (SAS Institute Inc., 2008) using the Proc Mixed procedure. Means followed by the same letter did not differ significantly based on the Tukey-Kramer multiple comparison test ($P < 0.05$). NC = not compared because of a significant cultivar by seed treatment interaction. With 2008 roots after 60 DIS, there was a significant interaction ($P = 0.011$) and thus treatments were compared within each cultivar in the Results section. With 2008 roots after 90 and 120 DIS, there was no treatment by cultivar interaction ($P = 0.687$ and 0.460, respectively), so the overall treatment means were compared. With 2009 roots after 56, 85, and 115 DIS, there was no treatment by cultivar interaction (P = 0.200, 0.349, and 0.071, respectively), so the overall treatment means were compared.

roots after 115 DIS) with a significant difference. On this sampling-date, Poncho Beta ranked first for yield but was not different from Cruiser Tef. Poncho Beta was significantly different from the non-treated check, but Cruiser Tef was not. In the other sampling-dates, Poncho Beta always ranked first for recoverable sucrose (Table 6). Cultivars were significantly different in two of the three sampling-dates with 2009 roots (Table 6), with cultivar B-22 having the most recoverable sucrose. Treatments with 2009 roots after 85 DIS were significantly different at the 10% level with cultivar B-22 having the highest yield. Cultivar trends were not consistent among the sampling-dates with the 2008 roots.

Based on regression analysis with data from 2008 roots there was a weak positive relationship between ERS and percent sucrose in roots at harvest, since r^2 ranged from 0.18 to 0.21 (Table 2). With 2009 roots there was no relationship between ERS and percent sucrose in roots at harvest (Table 2). When comparing ERS versus nitrates in roots at harvest, there was only a weak negative relationship ($r^2 = 0.12$) in the January sampling with 2008 roots. When comparing ERS versus conductivity in roots at harvest, there was only a weak negative relationship ($r^2 = 0.08$) in the December sampling with 2009 roots.

DISCUSSION

With natural pest pressure and the absence of visible plant disease, the insecticide seed treatment Poncho Beta and at times Cruiser Tef allowed for the production of sugarbeet roots that frequently stored (significantly and/or in ranking) better than the non-treated check for most storage variables measured. Across six sampling-dates, Poncho Beta was always ranked first for recoverable sucrose and was better than the non-treated check when significant differences were present. Poncho Beta also always ranked first or equal to other treatments across the six sampling-dates for less surface discoloration (fungal growth or dark lesions) and less frozen root surface area. When significant differences were present for weight reduction and sucrose reduction, Poncho Beta performed well. Cruiser Tef at times was not significantly different from Poncho Beta for the storage variables assessed, but tended to rank between Poncho Beta and the non-treated check.

In trials conducted under moderate curly top pressure, Poncho Beta increased root yield from 3.8 to 36.7 t/ha compared to the non-treated check, depending on cultivar susceptibility (Strausbaugh et al., 2006). In trials conducted under low curly top pressure, Poncho Beta and Cruiser Tef had more root yield than the non-treated check by 3.4 to 15.1 t/ha, depending on cultivar susceptibility (Strausbaugh et al., 2010). In trials conducted without curly top pressure, Poncho Beta and Cruiser Tef resulted in root yield increases of 3.1 to 6.7 t/ha over that of the non-treated check (Strausbaugh et al., 2010). Thus, Poncho Beta (costs approximately $57 per ha) has demonstrated the ability to pay for itself in the field even in the absence of disease pressure. However, Poncho Beta may also pay for itself through less sucrose reduction in storage. By reducing curly top symptoms in the field through the use of Poncho Beta, 5.0 to 8.5% more sucrose was present in the roots after long-term storage (Strausbaugh et al., 2008). In the present study without disease pressure in the field, roots produced with Poncho Beta always ranked first for recoverable sucrose (Table 6). On three of the six sampling-dates, Poncho Beta was significantly better ($P \leq 0.10$) than the non-treated check, with an average recoverable sucrose increase of 17%. Thus, Poncho Beta would appear to have the potential to increase profits in both storage and the field even without the influence of disease. Cruiser Tef always ranked better than the non-treated check, but less than Poncho Beta.

When considering all crops, neonicotinoids represent the most effective chemical class for the control of sucking insects such as aphids, whiteflies, leafhoppers, and planthoppers, as well as thrips, some microlepidoptera, and a number of coleopteran insect species (Elbert et al., 2008). The sugarbeet plants that produced the 2008 and 2009 roots were subjected to natural leafminer and black bean aphid pressure during the growing season (Strausbaugh et al., 2010). The plants associated with the 2008 roots also had some natural root aphid pressure (Strausbaugh et al., 2010). Thus given the broad spectrum of control provided by neonicotinoid seed treatments, we cannot state the seed treatments had a direct affect on the roots since pest control during the season may have contributed to improved root health at harvest time and consequently improved storability.

If sugarbeet roots lose more than 25 to 30% of their weight, then vital root functions are disrupted and the root cannot resist microbial development (Bugbee, 1993; Vajna, 1962). Weight reduction was significant both years, but mean values were less than 17%, so roots should have maintained the ability to resist microbial development. Nevertheless, the 2008 roots averaged 7, 18, and 45% of the root surface area discolored (fungal growth and dark lesions) after 60, 90, and 120 DIS, respectively (Table 1). Previous studies have shown that if 20% or more of the root surface is affected by fungal growth, root respiration increases 100% (Mumford and Wyse, 1976). These data likely explain some of the considerable loss in recoverable sucrose (Table 6) with the 2008 roots. This opinion is also supported by the regression analysis that shows a relationship (r^2 ranged from 0.15 to 0.31; Table 2) between surface discoloration and ERS over the sampling-dates. There was also a considerable relationship (r^2 ranged from 0.75 to 0.91; Table 2) between surface discoloration and frozen root area. With the 2009 roots, surface discoloration averaged just 0, 2, and 11% after 60, 90, and 120 DIS, respectively (Table 1). The warmer start to the storage season with 2008 roots combined with freezing temperatures later, likely led to considerably more surface discoloration and sucrose loss when compared with the 2009 roots. With the 2009 roots, sustained freezing temperatures were encountered after only 34 DIS, while the 2008 roots took 27 days longer to reach a similar condition.

In previous studies, sucrose was lost at the rate of 0.2 to 0.5 lb per ton of sugarbeet roots per day (Cole and Bugbee, 1976; Peterson et al., 1980). Based on these data, sugar companies could expect to lose from 8 to 17% of their sucrose in 100 days with healthy roots under good storage conditions in an outdoor pile. Under unfavorable conditions, both direct sucrose losses by respiration and indirect losses due to the accumulation of non-sucrose substances which impair sucrose recovery strongly increase (Kenter and Hoffmann, 2009). The warm temperatures when first placed in storage along with fluctuating cold temperatures likely led to less than optimal storage in 2008 and consequently considerable sucrose losses. On the other hand, the 2009 roots experienced more optimal storage conditions and performed considerably better than the 2008 roots.

Freezing and thawing cause considerable changes in the chemical composition of a sugarbeet root and thus hinder the factories' processing ability (Kenter and Hoffmann, 2006). Previous research indicated that storage life was reduced and sucrose loss and reducing sugars increased when sugarbeet roots were exposed to fluctuating temperatures or temperatures of -1°C or below (Wyse, 1978a). Irreversible damage, as demonstrated by loss of cellular contents and increased respiration rates, results from exposure to temperatures below -2°C (Wyse, 1978a). Respiration in sugarbeet roots does not stop until the root temperature reaches -18°C, at which point the roots will be frozen solid (Wyse, 1978a). The lowest average daily temperatures during the 2008/2009 and 2009/2010 storage periods were -8.3°C and -10.6°C, respectively. Thus, freezing temperatures were low enough to damage root tissue but not to stop respiration in both storage seasons. However, the early and continuous cold temperatures in 2009/2010, led to much more freeze damage than the previous season (Table 3). Nevertheless, some of the roots must have been able to recover, since the 2009 roots showed a reduction in frozen tissue after 115 DIS. In the field if a sugarbeet is not frozen too badly, it can recover in three to five days and be harvested (Bernhardson, 2009).

On sugarbeet, Poncho Beta and Cruiser Tef have been shown to be effective at controlling or at least suppressing beet leafhopper (subsequently also reducing curly top), black bean aphid, sugarbeet root aphid, and leafminer (Strausbaugh et al., 2006; Strausbaugh et al., 2010). Other investigations with sugarbeet indicate some efficacy exists against sugarbeet root maggot (unpublished data), wireworms (unpublished data), and springtail (Thorsness et al., 2007). In Idaho, the broad spectrum of pest control or suppression provided by Poncho Beta and Cruiser Tef may allow these seed treatments to serve as the only insecticides (areas with heavy root maggot and/or cutworm pressure or late season issues may need additional control options) needed for pest control during the growing season with identifiable yield benefits both in the field and storage (Strausbaugh et al., 2010). Another positive associated with these seed treatments is the small environmental footprint they leave. Nevertheless, host resistance for storability, pests, and diseases should continue to be identified and incorporated into commercial cultivars whenever possible.

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DISCLAIMER

Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

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