Postharvest Storage Losses Associated with Aphanomyces Root Rot in Sugarbeet

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ABSTRACT

Because of its persistence in the soil and the ineffectiveness of control measures, *Aphanomyces cochlioides* (causal organism of Aphanomyces root rot) is one of the more problematic pathogens attacking sugarbeet (*Beta vulgaris*). As a consequence, diseased roots often are included in storage piles; however, information on the consequences of storing roots with Aphanomyces root rot is lacking. Roots from six commercial fields with chronic root rot problems were divided into groups based upon root rot severity. Prior to measuring storage respiration rate, sucrose concentration, and extractable sucrose concentration, a root rot index (0 = no rot to 100 = completely rotted) was determined for each sample. Regression analyses were used to characterize relationships among root rot index, postharvest respiration rate, and extractable sucrose losses during storage for 120 days. Below rot indices of 35, Aphanomyces had little or no effect on respiration rate or extractable sucrose loss during storage. Sucrose losses associated with rot indices of 65 and 80 were 1.8 and 2.8 times those associated with a rot index of 35, respectively. Aphanomyces root rot has the potential to significantly increase losses during storage; however, field by Aphanomyces severity interactions and variability in the observed response patterns indicate that accurately predicting these losses prior to harvest will be difficult. This report provides information that will assist in determining the Aphanomyces root rot severity that would justify not harvesting a field or if roots from diseased fields should be processed early in the campaign.

Additional key words: *Aphanomyces cochlioides, Beta vulgaris,*

extractable sucrose, respiration

After harvest, most of the sugarbeet (*Beta vulgaris* L.) crop is stored in piles for up to 200 days, during which respiration, rotting, and physical deterioration decrease extractable sucrose. This loss represents a substantial decrease in revenue for the sugar industry and even small reductions in storage losses can have significant economic impact, when multiplied over the volume of roots processed and the time in storage. Much of the previous storage research has dealt with minimizing deterioration by modifying harvest operations and storage conditions after the crop has been piled (Campbell and Klotz, 2006); however, crop management and environmental conditions during the growing season also affect subsequent storage losses (Smith and Ruppel, 1971; Bugbee, 1979; Wiltshire and Cobb, 2000).

The detrimental effects of rots caused by storage rot pathogens have been evaluated (Bugbee, 1982); however, information on the consequences of storing roots attacked by root rot pathogens during the growing season is lacking. Because of its persistence in the soil and the absence of effective control methods, *Aphanomyces cochliodes* Drechsl. (causal organism of Aphanomyces root rot) is especially threatening in areas where it has become established (Dyer et al., 2004; Duffus and Ruppel, 1993; Schneider and Whitney, 1986; Windels, 2000). In a study of three fields in 2000 (Campbell and Klotz, 2003), the storage respiration rate of roots with severe Aphanomyces rot was four times the respiration rate of healthy roots. Roots classified as having moderate Aphanomyces symptoms had respiration rates 1.6 times those of healthy roots. The elevated respiration rate in diseased roots was apparent soon after they were placed in storage and relative respiration rates between diseased and healthy roots were constant throughout the trial. After storage for 85 days, healthy roots had extractable sucrose concentrations of 159 kg Mg^{-1}; in contrast to 57 kg Mg^{-1} for roots that had severe Aphanomyces root rot at harvest.

The objective of this study was to obtain information on the effects of Aphanomyces root rot severity on storability of sugarbeet. This information would assist growers and agriculturalists who must decide when disease severity justifies not harvesting a field or if roots from fields with Aphanomyces root rot should be piled separately and processed early in the campaign.

MATERIALS AND METHODS

Roots were harvested from six commercial production fields, three each in 2001 and 2002, in three contiguous counties in western Minnesota (Clay and Norman) and eastern North Dakota (Traill). All six fields had severe chronic root rot problems with *A. cochlioides* being the predominant causal agent. Roots were hand harvested in late September, washed, and placed in perforated plastic produce bags for storage. All roots exhibited symptoms commonly associated with Aphanomyces root rot although severity of symptoms ranged widely within each field. Roots were stored at 4.5 C and 90 – 95% relative humidity for the duration (120 days) of the trials.

One hundred forty-four roots from a small area of each field (< 0.25 ha) were divided into four groups of 36 with roots within a group exhibiting similar disease symptoms. The 36 roots within a group were randomly assigned to three, 12-root samples, which comprised the experimental units for subsequent observation and analysis. Each root within a sample was assigned a rating based upon root rot severity (0 = no apparent rot to 7 = completely rotted) at the time of harvest (Windels and Nabben-Schnidler, 1996). A rot index for each sample was calculated by dividing the sum of the ratings for all roots in the sample by the number of roots in the sample times seven and multiplying by 100. The resulting index values range from 0 for no rot to 100 when all roots in a sample are severely rotted.

Respiration rate was measured 20 and 120 days after harvest in 2001 and 20, 60, and 120 days after harvest in 2002. Each 12-root sample was placed in a 23-liter sealed bucket equipped with inlet and outlet tubes through which a regulated flow of ambient air was continually pumped. After 24 hours, the CO_2 concentration of air from the exit tube of each bucket was determined with an infrared analyzer. The CO_2 concentration of ambient air from the exit tube of an empty bucket was subtracted from this measurement and respiration rate expressed as mg CO_2 per kg of roots per hour (Campbell, 2005). All three samples representing a group within a field were used to determine respiration rates 20 days after harvest (DAH). Two samples per group were used to estimate 60 and 120-DAH respiration rates.

Sucrose concentration, clear juice purity, and dry matter concentration were determined 20 and 120 DAH. Sucrose was determined polarimetrically (McGinnis, 1982). Clear juice purity was calculated using the procedures described by Dexter et al. (1967). Sucrose concentration and clear juice purity were used to calculate extractable sucrose concentration 20 DAH and after storage for 120 days and to estimate extractable sucrose losses during storage. Twenty-gram brei samples

were oven dried at 80 C to determine dry matter concentration. Sucrose concentrations for the samples obtained 20 DAH were expressed on a fresh weight basis. To eliminate the effect of changes in water content during storage, sucrose concentrations for the later sampling date were adjusted to the dry matter concentration of the corresponding sample obtained 20 DAH. One sample representing each group within a field was used to determine sucrose concentration, purity, and dry matter concentration 20 DAH. Two samples were used to estimate these traits 120 DAH.

Fields and disease severity groups were assumed to be fixed effects for the analysis of variance. LSD's were calculated only when the corresponding F-test indicated significance at the 0.05 probability level. Because of differences between years in disease severity of the disease groupings, a combined analysis of variance over years was not performed. Regression analyses were used to examine relationships among the root rot index, respiration rate, and percent sucrose loss during storage. Data from the two years were combined for the regression analyses. The respiration rates used in the regression analyses were the average of the 20 and 120-DAH respiration rates in 2001 and the 20, 60, and 120-DAH respiration rates in 2002. Roots with severe Aphanomyces root rot symptoms, but with no apparent active rot at the time of the 2002 harvest, were not included in the regression analyses. These roots were severely malformed, scarred, and stunted (Windels and Lamey, 1998). Relatively dry, fibrous woody tissue had replaced much of the typical healthy root tissue.

RESULTS AND DISCUSSION

Disease severity, as measured by the root-rot index, was less in 2001 (Table 1) than in 2002 (Table 2). In 2001, samples with rot indices in the twenties were readily available for evaluation but in 2002, the groups with the least root rot had ratings in the thirties and forties (Table 2). Similarly, the most severely damaged groups in 2001 had rot indices in the mid-eighties, compared to 2002 where ratings were near 100. Severely damaged roots with no apparent active root rot were frequent in the fields sampled in 2002. Inactivity of the pathogen was a response to the relatively dry August and early September in this locality. Roots with conspicuous rot activity and those with inactive rot were evaluated as separate groups (Table 2).

The detrimental effect of disease severity on storage respiration rate is most striking in comparisons between groups with severe rot and those with relatively low rot indices. In 2001, the average

Table 1. Root rot index, respiration rate, sucrose concentration, and extractable sucrose concentration of roots from three Clay County, Minnesota fields with Aphanomyces root rot, after storage for 20 and 120 days after harvest (DAH), 2001.

Field	Group	Root rot index	Respiration rate		Sucrose		Extractable sucrose	
			20 DAH	120 DAH	20 DAH	120 DAH	20 DAH	120 DAH
		(0-100)	- - - mg CO_2 kg^{-1} h^{-1} - - -		- - - g kg^{-1} - - -		- - - kg Mg^{-1} - - -	
Clay-1	1	20	4.3	5.0	172	168	159	139
	2	33	3.8	4.3	178	172	158	136
	3	59	9.3	6.5	175	157	157	132
	4	84	37.9	26.2	115	62	80	23
Mean		49	13.9	10.5	160	140	138	108
Clay-2	1	26	4.9	10.9	150	123	142	84
	2	40	5.3	14.1	148	121	133	80
	3	67	6.4	13.8	137	103	124	56
	4	85	17.8	17.4	111	97	89	52
Mean		54	6.6	14.0	136	111	122	68
Clay-3	1	23	3.6	3.8	173	175	155	152
	2	37	3.5	4.0	184	171	174	141
	3	58	3.6	4.1	155	157	136	128
	4	86	15.8	27.2	126	55	102	25
Mean		51	6.6	9.8	159	139	141	112
Mean(3 fields)	1	23	4.3	6.5	164	155	152	125
	2	36	4.2	7.5	170	155	155	119
	3	61	6.4	8.1	155	139	139	105
	4	85	23.8	23.6	117	71	90	34
Mean		51	9.7	11.4	152	130	134	96
LSD(0.05)[†]								
	Fields	2	2.4	3.6	15	16	NS	15
	Groups	2	2.8	4.2	18	18	24	17
	Field X Group	4	4.7	6.7	--	29	--	27

Table 2. Root rot index, respiration rate, sucrose concentration, and extractable sucrose concentration of roots from three fields with Aphanomyces root rot in Clay and Norman County, Minnesota and Triall County North Dakota, after storage for 20, 60, and 120 days after harvest (DAH), 2002.

Field	Group	Root rot index	Respiration rate			Sucrose		Extractable sucrose	
			20 DAH	60 DAH	120 DAH	20 DAH	120 DAH	20 DAH	120 DAH
		(0-100)	mg CO_2 kg^{-1} h^{-1}			g kg^{-1}		kg Mg^{-1}	
Clay-4	1	46	4.3	3.8	4.5	165	151	146	135
	2	53	3.7	3.9	5.3	163	153	145	138
	3	93(D)†	4.4	4.5	3.7	185	127	162	105
	4	99	33.3	35.6	27.1	80	44	67	28
Mean		73	11.4	12.0	10.2	148	119	130	102
Norman-1	1	31	3.8	4.2	4.3	168	159	159	146
	2	63	3.3	3.6	4.0	154	151	143	127
	3	95(D)	5.0	4.5	4.7	153	139	139	123
	4	99	27.4	29.9	25.0	114	34	109	29
Mean		73	9.9	10.6	9.5	147	121	138	106
Traill-1	1	32	4.0	4.3	5.7	161	141	150	127
	2	69	4.4	4.5	5.0	164	144	150	130
	3	94(D)	5.9	5.0	6.5	156	138	145	107
	4	100	24.0	19.7	13.5	120	51	97	44
Mean		74	9.5	8.4	7.7	150	119	136	102
Mean(3 fields)	1	36	4.0	4.1	4.9	165	150	152	136
	2	62	3.8	4.0	4.8	160	149	146	132
	3	94(D)	5.1	4.6	5.0	165	135	149	112
	4	99	28.3	28.4	21.9	104	43	91	33
Mean		73	10.3	10.3	9.1	149	120	134	103
LSD(0.05) ‡									
	Fields	NS	NS	NS	NS	NS	NS	NS	NS
	Groups	4	4.9	4.4	3.9	33	9	28	14
	Field X Group	6	NS	6.9	6.3	- -	14	- -	NS

respiration rate of roots with a rot index of 85 (Group 4) was 5.5 times the respiration rate of roots with a rot index of 23 (Group 1), twenty days after harvest (Table 1). An even larger contrast was observed in 2002 where the average respiration rate for roots with a 99 rot index was seven times that recorded for roots with a rot index of 36 (Table 2). Differences in respiration rate between groups with the lowest disease ratings and groups with disease indices less than 70 were small and almost always not significant ($P = 0.05$), in both years. Roots with no apparent rot activity but obvious severe Aphanomyces damage prior to harvest (Table 2, Group 3) had respiration rates significantly lower than comparable groups with severe symptoms and active rot and similar to groups with less rot.

Correlation coefficients of 0.80 and 0.96 for respiration rates

Table 3. Correlation coefficients (r) for root rot index, storage respiration rate, and sucrose loss during storage of sugarbeet roots from three fields in Clay County, MN, with Aphanomyces root rot, 2001.

	Respiration Rate			Sucrose loss	
	20 DAH	120 DAH	Average	Actual	Percent
Rot index	0.73**	0.77**	0.79**	0.50*	0.70**
Respiration rate:					
20 DAH†	- -	0.80**	- -	0.42	0.69**
120 DAH	- -	- -	- -	0.80**	0.95**
Average	- -	- -	- -	0.62*	0.86**

* and ** indicate correlation coefficient is significant at the 0.05 and 0.01 level, respectively.
† DAH = Days after harvest.

Table 4. Correlation coefficients (r) for root rot index, storage respiration rate, and sucrose loss during storage of roots from three fields in Traill County, North Dakota and Clay and Norman County, Minnesota, with Aphanomyces root rot, 2002.

	Respiration Rate				Sucrose loss	
	20 DAH	60 DAH	120 DAH	Average	Actual	Percent
Rot index	0.88**	0.85**	0.81**	0.85**	0.79**	0.88**
Respiration rate:						
20 DAH†	- -	0.99**	0.96**	- -	0.82**	0.96**
60 DAH	- -	- -	0.99**	- -	0.80**	0.94**
Average	- -	- -	- -	- -	0.82**	0.95**

** indicates correlation coefficient is significant at the 0.01 level.
†DAH = Days after harvest.

measured 20 and 120 days after harvest in 2001 (Table 3) and 2002 (Table 4), respectively indicate relative respiration rates remain constant during storage. Moreover, the absolute respiration rates changed only slightly over time in the stable environment in which the samples were stored and evaluated. The Clay-2 site is an exception to this general pattern (Table 1). In this field, the 120-day respiration rates for all groups except the group with the highest disease index were approximately double the rate 20 days after harvest. The cause of this apparent anomaly is unknown, but could be due to soilborne storage rot pathogens that were not prevalent in the other fields or subtle differences in environmental conditions or crop production practices. Based upon the above observations, it appears that single respiration rate measurements early in the storage period generally provide a reliable characterization of the respiration rate for the duration of storage. This response pattern is similar to that of healthy roots, which generally have high respiration rates immediately after harvest and decrease the first few days in storage to a relatively stable level (Wyse and Peterson, 1979).

Although a small amount of sucrose would have been consumed during the first 20 days in storage, differences among groups in sucrose concentration 20 days after harvest primarily reflect differences in the severity of Aphanomyces root rot prior to harvest. The response pattern for sucrose concentration 20 days after harvest was similar to that observed for respiration rate (Tables 1 and 2). Within a field, roots with low and intermediate levels of Aphanomyces differed only slightly, if at all, in sucrose concentration 20 days after harvest; whereas, severe active rot at the time of harvest resulted in sucrose concentrations substantially below all other groups.

Differences in sucrose concentration among groups after 120 days in storage are the sum of differences in sucrose concentration at harvest and differences in the rate sucrose is consumed during storage. Twenty days after harvest in 2002, the average sucrose concentration of groups with an average rot index of 36 was 1.6 times the sucrose concentration of roots with a rot index of 99 (Table 2). After 120 days in storage, there was a 3.5-fold difference between these groups. Differences between 20 and 120-day sucrose concentrations were smaller in 2001 (Table 1) than in 2002 (Table 2); roots with a rot index of 23 in 2001 had 1.4 times the sucrose of roots with a disease index of 85, 20 days after harvest. After being stored for 120 days, there was a 2.2-fold difference between these groups.

Sucrose concentration is the predominant factor in extractable sucrose calculations, so similarities in response patterns for sucrose concentration and extractable sucrose concentration are not unusual.

Except for the group with the most severe active rot at harvest, differences among the groups 20 days after harvest were generally small and not significant, in both years. Average differences between roots with the most severe symptoms (group 4) and the group with the next lowest extractable sucrose were 49 and 55 kg Mg^{-1} in 2001 (Table 1) and 2002 (Table 2), respectively. In comparisons between the most severe groups and the groups with the lowest disease indices, the differences were 62 and 61 kg Mg^{-1} in 2001 and 2002, respectively. After storage for 120 days in 2001 (Table 1), the group with an average disease index of 85 had a significantly lower extractable sucrose concentration (34 kg Mg^{-1}) than all the others and roots with an average rot index of 61 had significantly lower extractable sucrose concentrations (105 kg Mg^{-1}) than roots with an index value of 23 (125 kg Mg^{-1}). During the 100 days between sampling, roots with a rot index of 23 lost extractable sucrose at a rate of 0.27 kg Mg^{-1} d^{-1}; losses corresponding to rot indices of 61 and 85 were 0.34 and 0.56 kg Mg^{-1} d^{-1}, respectively (Table 1).

In 2002 (Table 2), the relationship between root rot severity and extractable sucrose concentration after 120 days in storage was similar to that noted for 2001. Roots with active severe Aphanomyces root rot at harvest had significantly less extractable sucrose than all other groups and roots for which the rot appeared inactive at harvest had less extractable sugar than the two groups with lower rot indices. In addition to having the lowest extractable sucrose concentration at harvest, the most severely rotted roots lost sucrose at the highest rate, 0.58 kg Mg^{-1} d^{-1}, and as a result 60% of the sucrose available 20 days after harvest was consumed during the 100-day interval between sampling dates. During this same interval, roots with a rot index of 36 lost extractable sucrose at a rate of 0.16 kg Mg^{-1} d^{-1} and roots characterized as having severe but inactive rot lost extractable sucrose at a rate of 0.37 kg Mg^{-1} d^{-1}.

The positive correlation coefficients for Aphanomyces root rot severity and respiration rate in both years (Tables 3 & 4) are consistent with reports demonstrating a strong association between storage rot pathogen activity and substantially elevated respiration rates (Mumford and Wyse, 1976). Correlations involving percent extractable sucrose loss were higher than those calculated with actual sucrose loss. Using percent loss instead of actual loss reduces the effect of differences among fields that are unrelated to disease severity and also provides a more useful predictor of storage losses for use by agriculturalists and sugar processors.

Regression analysis was used to characterize relationships among Aphanomyces root rot severity, postharvest respiration rate,

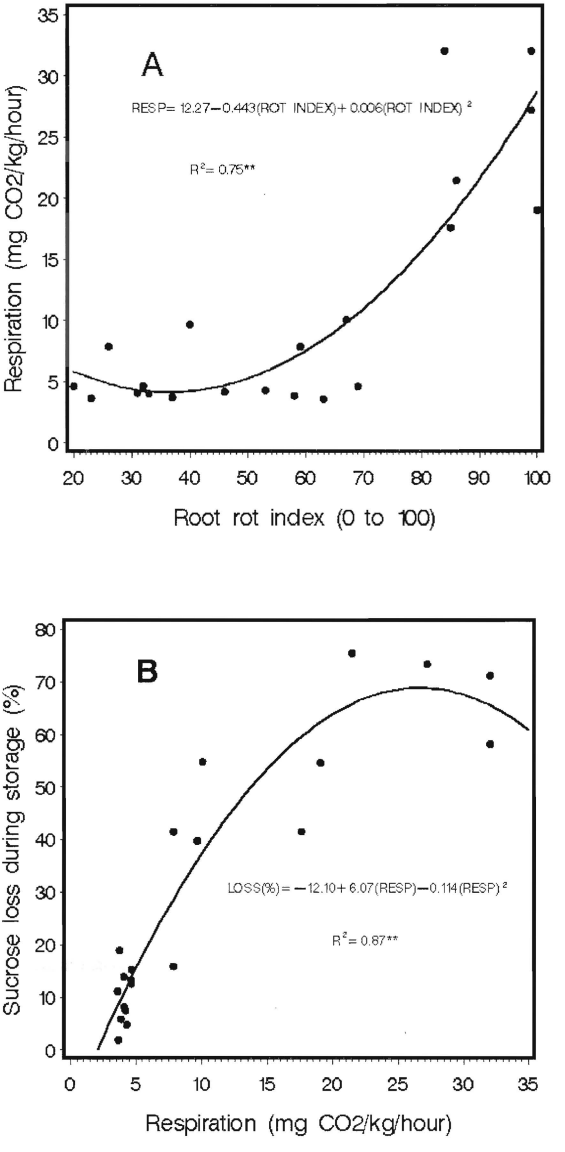

Fig. 1A and 1B. Relationships among Aphanomyces root rot severity (root rot index) and postharvest respiration rate (A) and storage respiration rate and extractable sucrose loss (B) during postharvest storage (120 days) of roots from six fields with Aphanomyces root rot, 2001-2002.

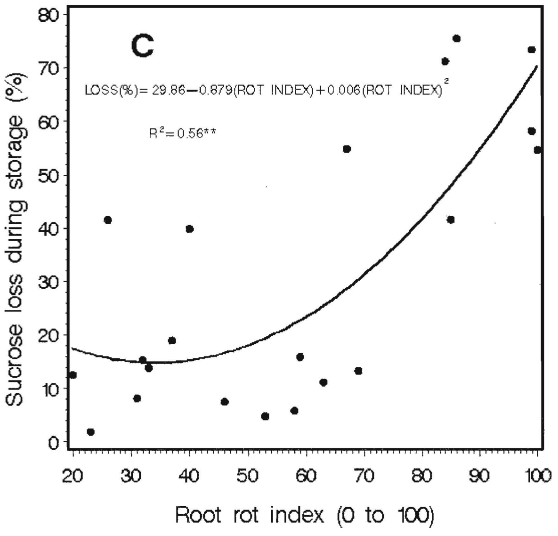

Fig. 1C. Relationship between Aphanomyces root rot severity and extractable sucrose loss (C) during postharvest storage (120 days) of roots from six fields with Aphanomyces root rot, 2001-2002.

sucrose loss during the 120 days in storage (Fig. 1A-1C). These analyses indicate that respiration rate increases as root rot severity (root rot index) increases (Fig. 1A), respiration rate is closely associated with sugar loss during storage (Fig. 1B), and therefore as root rot severity increases sucrose losses during storage increase (Fig. 1C). The R^2 (0.87) value associated with the regression of sucrose loss on respiration rate (Fig. 1B) was greater than the R^2 values for the other two regression analyses. This did not seem unusual since many factors other than Aphanomyces severity influence respiration rate and consequently sucrose loss. The R^2 (0.56) value for the relationship between root rot index and sucrose loss (Fig. 1C) was the lowest of the three. This again indicated that something other than Aphanomyces may be affecting sucrose loss. This also appears to be the case with the samples from the Clay-2 field, which had unusually high respiration rates and sucrose losses for their respective Aphanomyces root rot indices (Table 2).

While it is apparent that Aphanomyces root rot has the potential to substantially increase postharvest respiration rates and sucrose losses during storage, accurately predicting these losses based upon Aphanomyces severity prior to harvest is difficult. Significant field by disease severity interactions, the uncharacteristically high 120-day res-

disease severity interactions, the uncharacteristically high 120-day respiration rates for roots with low and moderate Aphanomyces symptoms from the Clay-2 field, the relatively low respiration rates for roots that had been severely damage by Aphanomyces but appeared to have no active rot, and the scatter of the data points around the regression lines in Fig. 1A-1C indicate that projections of storage losses will always be imprecise and should only be viewed as guidelines. Planned well-designed replicated field studies would generally provide more precision than the commercial field sampling upon which this report is based. However, reliable inoculation techniques are not available for extensive Aphanomyces root rot trials and identifying sites prior to planting that have sufficient natural inoculum and where local weather conditions will favor disease development is difficult (Beale et al., 2002; Windels and Nabben-Schnidler, 1996). Furthermore, the field X disease severity interactions, differences between years, and the influence of other factors (most of which are unidentified) on storage losses would remain and complicate the forecasting of storage losses. In addition, relative and actual respiration rates and sucrose losses incurred while roots are waiting processing will be affected by conditions within the storage pile where considerable variation among years and piling sites is likely.

In spite of these limitations, the observed relationships provide some guidance for those making decisions regarding the disposition of roots from fields with Aphanomyces root rot. Respiration rate is a more accurate predictor of sucrose loss than rot index (Fig. 1B, 1C). However, it generally is impossible to obtain the large number of respiration measurements required for evaluation of many commercial fields. Thus, decisions almost always must be based upon visual disease symptoms. The slope of the regression equation characterizing the relationship between the root rot index and respiration rate is zero when the rot index equals 36.9 (Fig. 1A). Similarly, the slope of the regression line relating sucrose loss to root rot index is zero at an index value of 34.3 (Fig. 1C). The similarity of these two values indicates that below index values of approximately 35, Aphanomyces severity has only a slight affect, if any, on storage respiration rate or sucrose loss. With a rot index of 35 or lower, 15% of the extractable sucrose available 20 days after harvest was lost during storage for 100 days. With a rot index of 50, an additional 3.4% was lost, bringing the total to 18% during the 100 days between measurements. The 28% sucrose loss associated with an index value of 65 was 1.8 times that of roots with a 35 root rot index and with a rot index of 80, 43% of the sucrose was consumed while in storage, a 2.8-fold increase over the loss associated with an index of 35. In addition to the relatively high sucrose loss

during storage, severely diseased roots had relatively low extractable sucrose concentrations 20 days after harvest. This low initial sucrose concentration combined with the increased sucrose consumption during storage produced roots with extractable sucrose concentrations only slightly above 30 kg Mg^{-1}, 120 days after harvest.

The samples upon which the relationships documented in this report are based were stored in a refrigerated room with fans for circulation. This would minimize contrasts between healthy and diseased roots to the extent it negates any temperature increase associated with elevated respiration rates in storage piles. A Mg of roots producing 5 mg CO_2 kg^{-1} h^{-1} generates 1,296 kJ of respiratory heat energy per day (Kays, 1997); 6,484 kJ would be generated by roots respiring at a rate that produced 25 mg CO_2 kg^{-1} h^{-1}. In a storage pile where healthy and diseased roots are mixed, the temperature increase due to the presence of diseased roots would increase respiration rates in surrounding healthy roots. The magnitude of detrimental effects of diseased roots on nearby healthy roots would depend upon the extent heat is dissipated from the pile.

CONCLUSIONS

The associations documented in this report are consistent with those noted in a similar study conducted in 2000 (Campbell and Klotz, 2003). Both studies demonstrate the risks associated with storing roots with Aphanomyces root rot and provide information that will aid agriculturalists and growers in decisions regarding whether fields should not be harvested or if roots from localities with severe Aphanomyces should be processed as early in the campaign as possible. Decision makers also must recognize that factors other than Aphanomyces severity will impact storage losses, and attempt to balance competing risks.

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