Post-Harvest Life of Organic Potatoes

Project Report to Organic Sector Development Program

Fraserland Organics

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Executive Summary

Potatoes can spend as much time in storage as they do in the field, thus the post-harvest "life" of tubers needs to be considered when organic growers are determining steps to reduce losses and improve overall returns. Diseases present in the field can proliferate in storage. Tuber damage during harvest and processing can create physical damage which can increase the risk for disease development in storage. In this study, we examined the types of physical damage that occur during potato harvest (using two mechanized harvesters) and washing and bagging (along two mechanized lines). We found that more damage occurred during the washing and bagging of tubers than during harvest from the field. The majority of tuber damage was bruising and this occurred at four points along the harvester (primary and secondary chains, picking table to multisep, and as tubers are dropped into the truck). We also identified three points along the washing and bagging lines where bruising damage increased compared to the previous steps (on the picking table, belt and in bags). By focusing in on these seven areas our collaborating growers can potentially reduce their losses due to physical damage from tuber handling.

We also examined tubers at harvest and after two months of storage for the severity of common storage diseases. Severity scores for silver scurf, rhizoctonia, soft rot, and common scab were similar between freshly harvested and stored AC Peregrine variety tubers. Silver scurf severity did increase slightly on Yukon Gold tubers after two months of storage, but all other diseases were at similar levels.

Finally, we tested the efficacy of three registered organic fungicides for post-harvest disease control. Tubers were treated with Bio-Save® 10 LP (*Pseudomonas syringae*), Serenade® ASO™ (*Bacillus subtilis*), or StorOx (hydrogen peroxide) shortly after harvest, held in storage for two months and then assessed for disease. Serenade ASO and StorOx were found to suppress disease development of both silver scurf and soft rot and Bio-Save 10 LP was found to suppress silver scurf in storage compared to the water only Control treatment. None of the products were found effective in supressing rhizoctonia development. The overarching goal of this work is to increase the awareness among growers of developing best management practices geared specifically towards the harvest and post-harvest portion of potato production.

Introduction and Objectives

Potatoes are an important staple crop that requires protection from arthropods and diseases both during in-field production and post-harvest (i.e. any time between harvest and consumption). Post-harvest losses can be apparent immediately after harvest, e.g. severe cuts, or may not occur until after a period of storage, e.g. bruising and disease. Locally, the time tubers can spend in on-farm storage can vary from 1 to 10 months, depending on variety, market demand and individual grower's storage capacity (H. Meberg, E.S Cropconsult Ltd., personal communication). Regardless of when post-harvest losses occur, there are both direct (loss of tuber sales) and indirect (time spent grading, loss of consumer confidence) economic costs associated with the post-harvest phase of potato production (Potato Council 2011, NPABCPAA 1998). In this study we focused on two aspects of the post-harvest "life" of potatoes: physical damage during harvesting and post-harvest handling and tuber diseases.

Potato tubers can receive considerable physical damage during post-harvest handling - i.e. harvesting from field and during washing and bagging. In addition to making tubers more susceptible to disease physical damage also results in rejection of tubers based on visual appearance (NPABCPAA 1998). There are three main types of physical damage: skinning, bruising, and cracks/cuts. In order to reduce physical damage, regular monitoring is recommended as tubers move through the different steps along the harvesting and washing and grading equipment. This helps to identify areas where damage is occurring and thus corrective steps can be taken (British Potato Council 2011). The first objective of this study was to determine the level and types of physical damage that occur on potatoes during harvest and washing and bagging.

In addition to physical damage, diseases can be another reason for post-harvest loss of tubers. Furthermore, physical damage can make tubers more susceptible to disease development (Johnson 2008; Stark and Love 2003). Tuber diseases can be apparent either at harvest or can develop during storage. Silver scurf (*Helminthosporium solani*), Pythium leak (*Pythium* spp.), Fusarium dry rot (*Fusarium* spp.), pink rot (*Phytophtora erythroseptica*), bacterial soft rot (*Erwinia carotovora*) and late blight (*Phytophthora infestans*) are the main diseases of concern (Fig. 1). Some diseases (e.g. late blight) are issues both during in-field production and storage. In contrast, other diseases (e.g. silver scurf) are issues during storage and not during production; however, infection usually begins in the field (Al-Mughrabi *et al.* 2013). The second and third objectives of this study were to identify pathogens present on tubers at harvest and to assess disease development over the course of two months of storage.

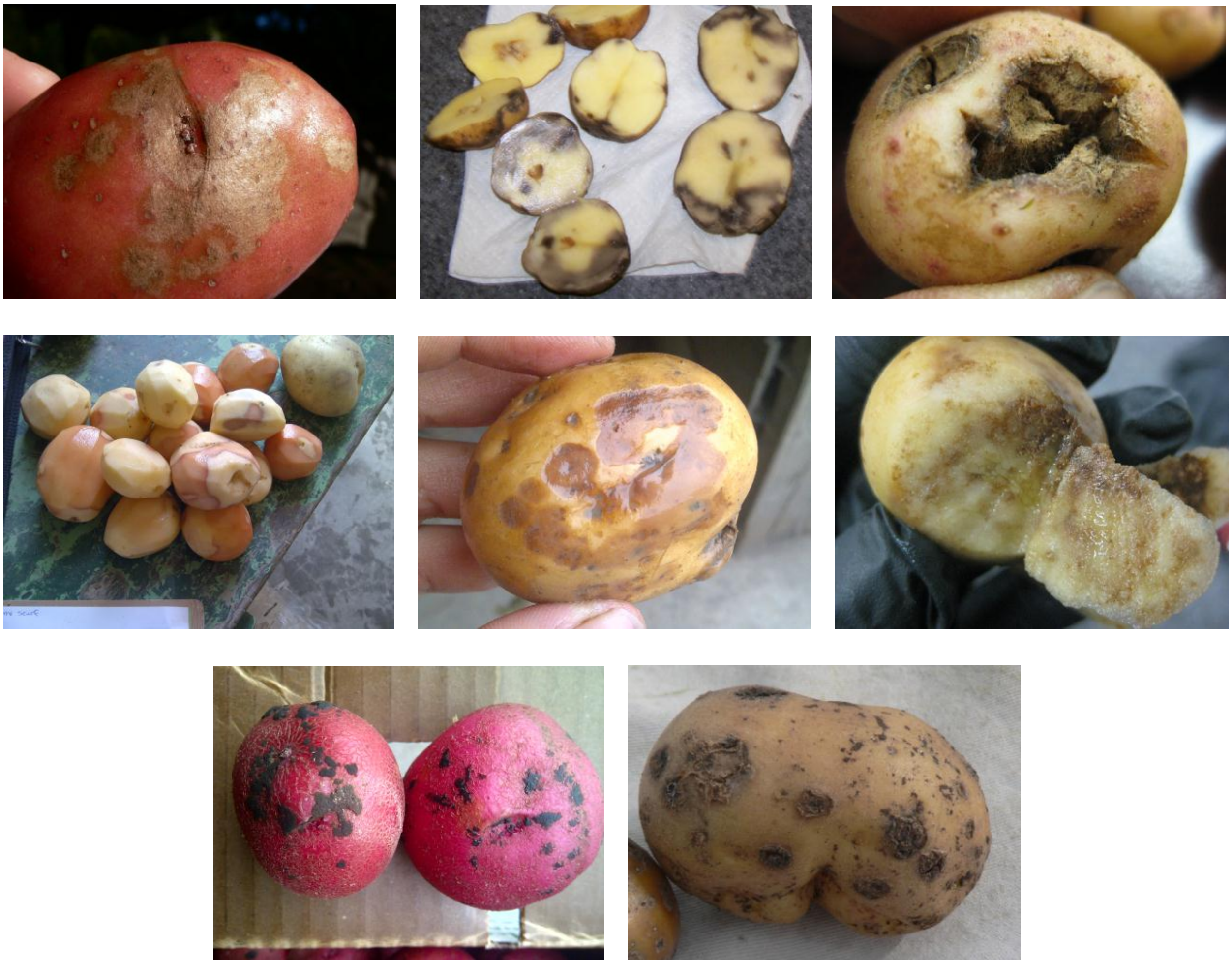


Figure 1. Symptoms of common post-harvest tuber diseases. Top row (from left): Silver scurf, Pythium leak and dry rot. Middle row (from left): Pink rot, soft rot, and late blight. Bottom row (from left): Rhizoctonia and common scab. Photo credits: K. Jack.

As organic production is increasing, more options for post-harvest treatment of commodities are becoming available. Three products, suitable for organic production, currently registered in Canada for post-harvest use on potatoes are Bio-Save® 10 LP (*Pseudomonas syringae*), Serenade® *ASO*™ (*Bacillus subtilis*), StorOx (hydrogen peroxide). In trials all three products have shown efficacy against a number of potato storage diseases including silver scurf (Al-Mughrabi et al. 2013) and rhizoctonia (Todorova and Kozhuharova 2010). However, local experience with these products is limited and in the past efficacy has not been consistent in trials (Glover and Prasad 2012, Glover and Syrovy 2011). Thus the final objective of this study was to evaluate the efficacy of currently registered products for post-harvest disease control of potatoes. We focused on three diseases for this part of the study: silver scurf, soft rot, and rhizoctonia.

Materials and Methods

All potatoes used in this study were collected from organic potato fields in Delta, BC. The fields belonged to three different growers and potatoes were produced using standard practices for organic production, with all nutrient, irrigation and pest management decisions made by individual growers.

Objective 1- Damage assessment during harvesting and washing/bagging

Collection during harvest - Between September 4 and 20, 2013 potatoes were collected from eight fields during harvest (Table 1). The eight fields were harvested by two different types of equipment (Grimme GT 170 and Grimme GZ 1700 DL) and operated by three different individuals. Harvest operators were given time to 'open up' the field (harvested in such a way that the truck would fit next to the harvester) and get used to field conditions. Six to eight sites in each field were sampled. The sites were spread out between a minimum of two and maximum of four passes of the field (a pass being the length of the field) and were not taken from the headlands. At each site, tubers were collected manually from the field and at six different locations on the harvester: 1) after the primary chain, 2) after the secondary chain, 3) after the multi-sep table, 4) after the picking table, 5) within the last three feet of the boom, and 6) in the truck (Appendix 1). At each location, in the field and on the harvester, six potatoes were collected for a total of 42 tubers collected at each site within a field. For manual collection tubers were dug up by hand from two to three rows that were, wherever possible, located in rows which were not adjacent to rows driven in by machinery during the season or at harvest. On the harvester two people were responsible for tuber collection. To minimize sampling bias these individuals each sampled an equal number of sites per location.

Table 1. Summary of fields assessed at harvest (8 fields) and their respective harvester, variety, skin color, soil type, number of replicate and time before assessment (* indicates fields for which tubers were followed from harvester to bagging line)

Date collected	Field name	Harvester	Variety collected	Skin colour	Soil type	Number of replicates per location	Time before assessment
Sep 4	2-1*	GT170	Satina	yellow	Clay	6	22.7hrs at 35^{o}C
Sep 10	1-1*	GZ1700DL1	AC Peregrine	red	Clay	8	24hrs at 22-26^{o}C
Sep 10	2-2*	GT170	Yukon Gold	yellow	Clay	8	19hrs at 22^{o}C
Sep 15	2-3	GT170	Yukon Gold	yellow	Clay	8	24hrs at 20^{o}C, 23hrs at 30^{o}C
Sep 17	1-2	GZ1700DL1	AC Peregrine	red	Clay	8	17hrs at 33^{o}C
Sep 18	2-4	GT170	AC Peregrine	red	Sand-clay	8	21hrs at 36^{o}C

					(peaty)		
Sep 20	1-3	GZ1700DL1	Yukon Gold	yellow	Sand-clay	8	24hrs at 39^{o}C and 48hrs at 17^{o}C
Sep 20	2-5	GT170	AC Peregrine	red	Sand-clay (peaty)	8	24 at 39^{o}C and 45hrs at 17^{o}C

We followed the post-harvest damage assessment protocol with regards to sample size as laid out in Wiltshire (2006) with modifications developed by E.S. Cropconsult Ltd. As soon as potatoes were collected, manually or along the harvester, tuber pulp temperature was measured using a temperature gauge. Potatoes were collected into breathable bags which were labelled with field, site and other identification information. Samples were then transported to a hot box and held for a minimum of 12 hours (Table 1). The hot box temperature was set at 35°C. A hot box can be purchased, or created using an old freezer and heater as long as it is safely set up. The hot box should be run with relative humidity at between 95-98% which can simply be accomplished by placing a dish of water in the freezer and the temperature should be between 34-36°C (Potato Council 2011) by setting the heater gauge to a pre-determined level. Details pertaining to sample date, time, field, variety, skin set, harvester, truck, operators, weather, temperature, soil type, soil moisture, tuber pulp temperature, field observations, and arrival time at the hot box were recorded per field.

Collection along washing and bagging lines - In addition to collections from the field and harvester we followed tubers from three of the eight fields (Table 1) along the washing and bagging lines. Collection locations on the washing and bagging lines were chosen to account for potatoes either dropping, or changing chains or direction. Along the washing line, samples were collected from four positions: 1) the pit conveyor, 2) after the Wyma, 3) after the picking table, and 4) in the medium sized potatoes bin (Appendix A). Along the bagging line, samples were collected from three locations: 5) the belt, 6) the feeder and 7) the bag (Appendix A). Each time a sample was collected from this combination of lines, a total of six potatoes were taken from each position by a single person, every ten minutes for a total of eight collections (Table 2). As with field and harvester samples, washing and bagging samples were collected into breathable bags which were labelled with the collection number, location along the two lines and identification code if applicable. Samples were put in a hot box for a minimum of 12 hours with the temperature set to 35°C. Details pertaining to sampling date, variety, and storage location, time in hot box, tuber pulp temperature in pit, and temperature of hot box were all recorded per variety along the two lines.

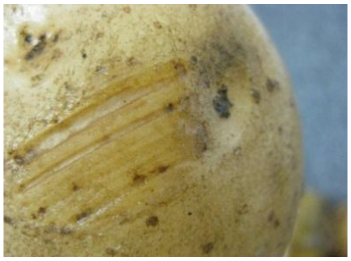
Table 2. Summary of fields assessed along the washing and bagging lines

Date collected	Field	Variety collected	Time before assessment
Sep 4	2-1	Satina	23hrs at 35^{o}C
Sep 10	1-1	AC Peregrine	27hrs at 25-35^{o}C
Sep 10	2-2	Yukon Gold	24hrs at 22-26^{o}C

Assessment procedure for harvest, washing and bagging lines - While there are slight variations in damage noted from the field and along the washing and bagging lines, potatoes were assessed in the same way for both. We followed standard post-harvest damage assessment protocols for assessing physical damage due to post-harvest handling based on the Potato Council's outline (2011) with modifications developed by E.S. Cropconsult Ltd. For each collection site - manual, six harvester and seven washing and bagging lines - five of the six tubers collected were assessed for damage (these five tubers were selected at random). Tubers were assessed for damage based on Table 3 after a period of storage in the hot box (Tables 1 and 2). If needed tubers were washed gently with warm water to remove any remaining dirt, and visually assessed with skin on and after peeling. Each potato was fully peeled to a depth of a single peeler swipe. Areas such as potato "eyes" and other indents were not peeled beyond a single swipe. An explanation of different methods for sampling and assessing damage at harvest can be found in Appendix B.

Clean

Skinning



Scuffed bruise- skin broken

Slight bruise

Severe bruise

Shatter bruise

Thumb nail crack

Black spot bruise

Slight cut **Large cut**

Figure 2. Categories of potato damage used for post harvest damage assessment. All photos: K. Jack

Table 3. Damage assessment qualifications **(**created with consideration to guidelines in Tables 1 and 2 and specific grower requirements)

Damage Category	Criteria	Record Keeping
Clean	No type of damage as identified below.	Independently totaled category
Number with skinning >10%	Skin removed or peeled on more than 10% of the surface. No damage below the surface.	Independently totaled category
Total bruise	Total number of scuffed, slight, severe, and shatter bruises.	Total of the following four bruise types
Scuffed bruise- skin broken	Noticeable marking/scuffing on skin. Damage shallowly below surface.	If a potato has more than one of these types of bruises record it as the most serious type where scuffed bruise-no broken skin is the least serious and shatter bruise is the most serious.
Slight bruise	Two or fewer strokes of a potato peeler required to remove bruise.	
Severe bruise	More than two strokes with a potato peeler required to remove a single bruise or multiple bruises.	
Shatter bruise	More than one crack or split coming from a focal point.	
Thumb nail crack	Small cracks in the skin resembling a thumb nail.	Independently totaled category
Black spot bruise	Dark grey to black coloured bruising below skin. Sometimes grainy looking.	Independently totaled category
Total cuts	Total number of slight and large cuts.	Total of the following two cut types
Slight cut	Cuts which are less than ½ an inch in length	If a potato has more than one type of cut it is recorded as the most serious where slight cut is the least serious and large cut is the most serious
Large cut	Large cuts appearing to have been caused by digging blade and cuts larger than ½ an inch in length	
Multiple types of damage	Any potato with two or more of the following types of damage: skinning, total bruise, thumb nail crack, black	Independently totaled category

	spot bruise, total cut	

Objective 2-Tuber diseases present at harvest

Disease incidence and severity were assessed on forty potatoes hand harvested in each of the 12 fields. The visibly recognizable diseases assessed were silver scurf, rhizoctonia, common scab and soft rot. Severity was scored on a 1-10 scale based on amount of surface area with visible symptoms (Table 4). Individual severity rankings for each tuber were compiled into a single severity score, for each disease, for a sample of forty tubers. The combined severity score was the sum of the number of tubers in each disease category (except 0) multiplied by the category value:

Severity score =(# tubers*1)+(# tubers*2)+ (# tubers*3)+ (# tubers*4)+ (# tubers*5)+ (# tubers*6)+ (# tubers*7)+ (# tubers*8)+ (# tubers*9)+ (# tubers*10) (1)

Where # tubers was the average number in each disease category (Table 4) based on the average of five tubers/sample/field. The maximum possible severity score for each disease was 50 for this portion of the study (for Objective 3 and 4 the maximum possible score is different because different numbers of tubers were assessed). Additionally, potatoes with suspicious symptoms that could not be visually linked to a specific disease were cultured in Petri dishes to identify pathogens at the BC Ministry of Agriculture. We followed standard plant pathology protocols (e.g. Agrios 2005), including taking samples from the interface of suspicious symptoms and healthy tissue, surface sterilizing samples, cutting samples to 0.25cm^2 pieces and plating either onto tryticase soy agar (TSA) plates or 1/4 strength potato dextrose agar (PDA) plates. Three samples were plated/dish. Plates were sealed and left in an incubator at 20°C until growth appeared or it was determined the sample was not viable.

Table 4. Disease severity grading scale used for quantifying symptoms of tuber disease

Scale	0	1	2	3	4	5	6	7	8	9	10
Percentage of surface coverage of disease	0-4	5-9	10-14	15-19	20-32	33-45	46-59	60-72	73-85	86-99	100

(Falloon *et al*. 1995**)**

Objective 3- Tuber diseases after storage

On November 12, 2013 pit samples were taken either directly from the pit or from tubers that were collected a month earlier from the pit and stored in crates in the storage facility for a total of six collections (Table 5). Regardless of when tubers were collected, they were collected along the front slope of the pit. For each of the collections 80 tubers were assessed for silver scurf, rhizoctonia, common scab and soft rot using the severity grading scale (Table 4). In this case the disease severity score was calculated using Equation 1 above but with the # tubers being the number out of 80 within each disease category (Table 4). Thus maximum possible severity score for each disease was 800. One questionable tuber sample was taken for Petri dish sampling as described in Objective 2.

Table 5. Storage conditions, prior to tuber assessment,

Pit	**Pit Temperature**	**Pit Humidity**	**Variety**	**Nov. 12 collection location**	**Number of tubers collected**	**Number of locations collected from within pit**
1	9.9°C	87%	Yukon Gold	Crate*	126	6
2	2.8°C	78%	A.C. Peregrine	Crate*	126	6
3	4.4°C	99%	Yukon Gold	Crate*	126	6
3	4.4°C	99%	Yukon Gold	Directly from pit	84	4
4	2.8°C	99%	A.C. Peregrine	Crate	126	6
4	2.8°C	99%	A.C. Peregrine	Directly from pit	84	4

* Tubers were collected directly from pit on Oct. 18 and stored in crates in the storage facility until Nov. 12. This precaution was taken to ensure tubers would not be sold.

Objective 4-Efficacy of products for post-harvest disease control

Tuber selection –The variety used for this trial was Norland which is highly susceptible to silver scurf (CFIA 2011). After treatment, tubers were stored in a commercial potato storage facility in Delta BC.

Pest infestation –Norland tubers that displayed obvious signs of silver scurf infection were selected from storage containers on September 12, 2013 (potatoes were harvested the previous day). The potatoes were stored in the same potato storage facility until September 17, 2013 when treatments were applied.

Treatment description – In order to evaluate the efficacy of organic treatments for post-harvest silver scurf control the trial examined three products and one Control (Table 8). The amount of product applied to tubers was based on weight of tubers so the amount of each product used was different for each treatment.

Table 8: Products and rates used for each treatment evaluated for control of silver scurf on tubers in storage.

Treatment	Recommended or label rate	Rate used (as per registrant recommendation)	Weight/ treatment (kg)	Amount of product applied/treatment
Serenade ASO (*Bacillus subtilis*); Bayer	85-175mL/1000kg of tubers, 2L solution/1000 kg of tubers	175mL/1000kg of tubers 2L solution/1000kg of tubers	9.70	1.7mL Serenade in 17.7mL water

CropScience Inc.				
Storox (hydrogen peroxide); BioSafe Systems LLC	1:100 dilution 4.15-8.30L solution/1000kg of tubers	1:100 dilution 4.15L solution/1000kg of tubers	9.12	0.38mL Storox in 37.46mL water
BioSave-10LP (Pseudomonas syringae); Austin Grant Inc., DBA JET Harvest Solutions	500g/136500kg using a minimum 100L water	500g/136500kg in 273L water (2L/1000kg of potatoes to allow good coverage)	9.46	0.03g in 19.40mL water
Water Control	NA	2L water/1000kg of tubers	9.48	18.96ml water

Application of treatments: All tubers treated in the trial were washed on September 17, 2013. Treatments were applied to randomly selected tubers. Each treatment was replicated 10 times (Total N = 40). A replicate consisted of 10 randomly selected tubers held together in mesh sacks for a total of 100 tubers per treatment. All treatments were applied using hand-held garden spray bottles set to a fine mist. All tubers were allowed to thoroughly air dry before each tuber was placed into a mesh sack. All treatment replicates were placed in a storage tote in a grower's potato storage facility. Storage conditions during the trial were 2.8°C and 99% RH.

Assessment and analysis– Tubers were assessed twice: 1) Pre-treatment on September 17, 2013 and 2 months post treatment on November 15, 2013. At each assessment both disease incidence (number of tubers with symptoms) and disease severity were recorded. Silver scurf, rhizoctonia and soft rot scored separately. For each tuber in each replicate disease severity was scored as one of ten categories based on the percentage of surface area affected by lesions using Falloon *et al.* (1995) severity scale (Table 4). For each disease, a combined severity score was calculated for each replicate pre and post-treatment using Equation 1 above. The maximum possible combined severity score was 100 and the change in combined severity score for each disease was calculated ((Post-treatment score - Pre-treatment score)/Pre-treatment score)*100. The effect of post-harvest fungicide treatments on the change in disease severity after two months of storage was examined using one-way ANOVA with Tukey-Kramer HSD test used for means comparison. All data were analyzed using JMP-In (Version 5.1) (SAS Institute Chicago, IL).

Results

Objective 1- Damage assessment during harvest, washing and bagging

Very little tuber damage occurred when tubers were manually harvested (i.e. 1 out of 320 tubers). By the time tubers were in the truck there was a 10% increase in damage (Fig. 3). This damage was the result of handling along the harvester. Based on our small sample size of three fields we also found that by the time tubers are bagged there was a 52% increase in damage compared to the field (with the damage ranging from 17 to 82%).

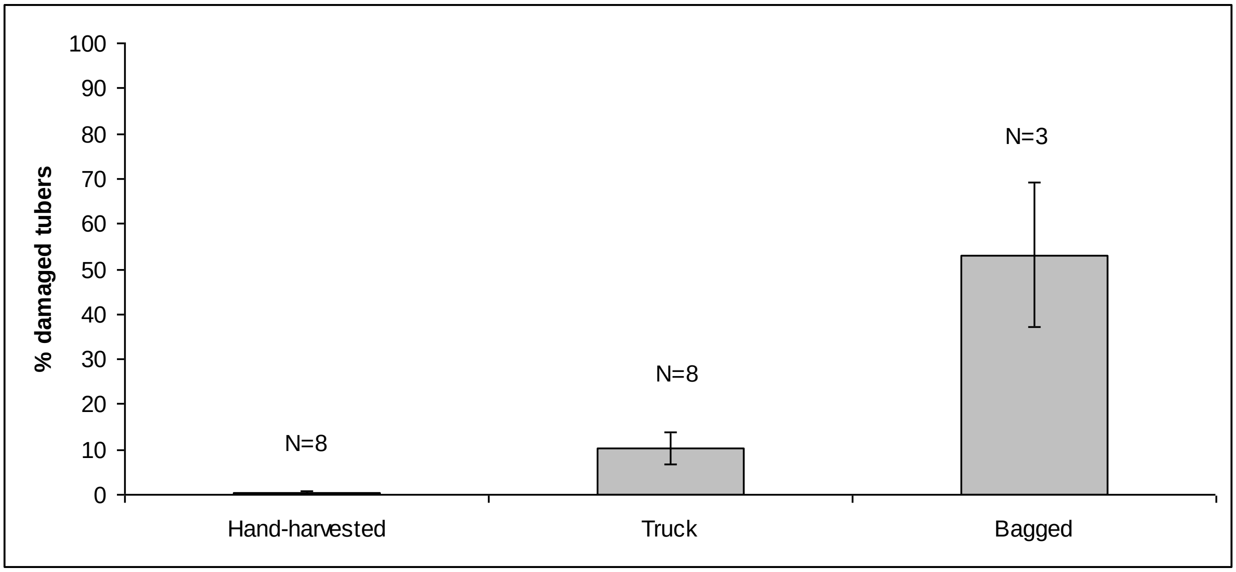
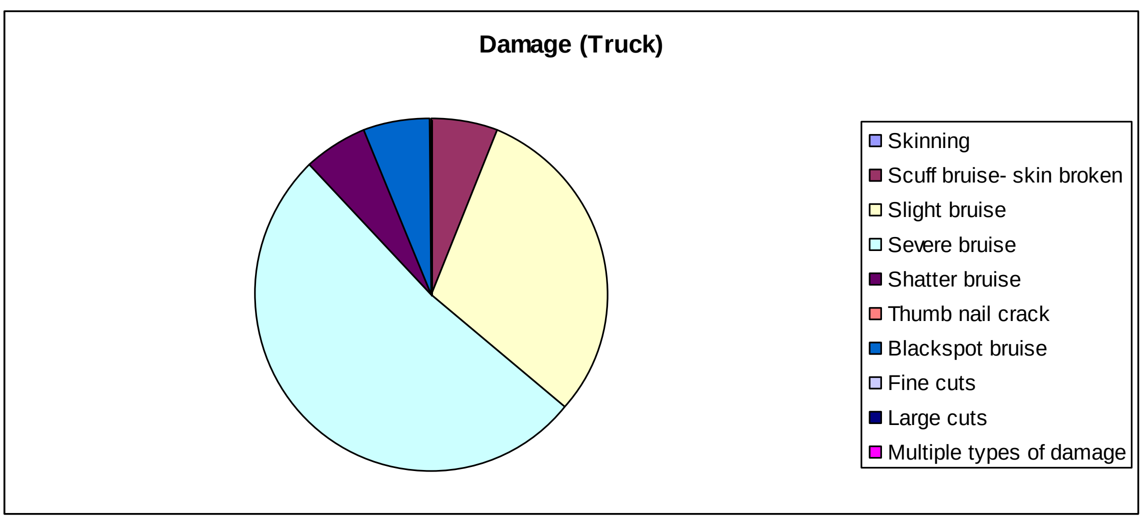


Figure 3. Percentage (mean ± s.e.m) of damaged tubers collected from the field by hand harvesting, in the truck after the harvesting line, and in bags after harvesting, washing and bagging lines. Values above bars indicate the number of fields from which tubers were collected.

The most common type of damage observed on tubers was the severe bruise - this was found when we only looked at tubers at the end of the harvesting line (i.e. in the truck) (Fig. 4A) or when we included bagged tubers as well (i.e. at the end of washing/grading/packaging line as well) (Fig. 4B). More types of damage seem to occur during the washing and bagging of tubers than during the harvesting of tubers. For example, in the eight fields surveyed no cuts were observed in the truck at the end of harvesting (Fig. 4A) but were observed in bagged tubers in all three fields that were followed along the washing and bagging lines (Fig. 4B).



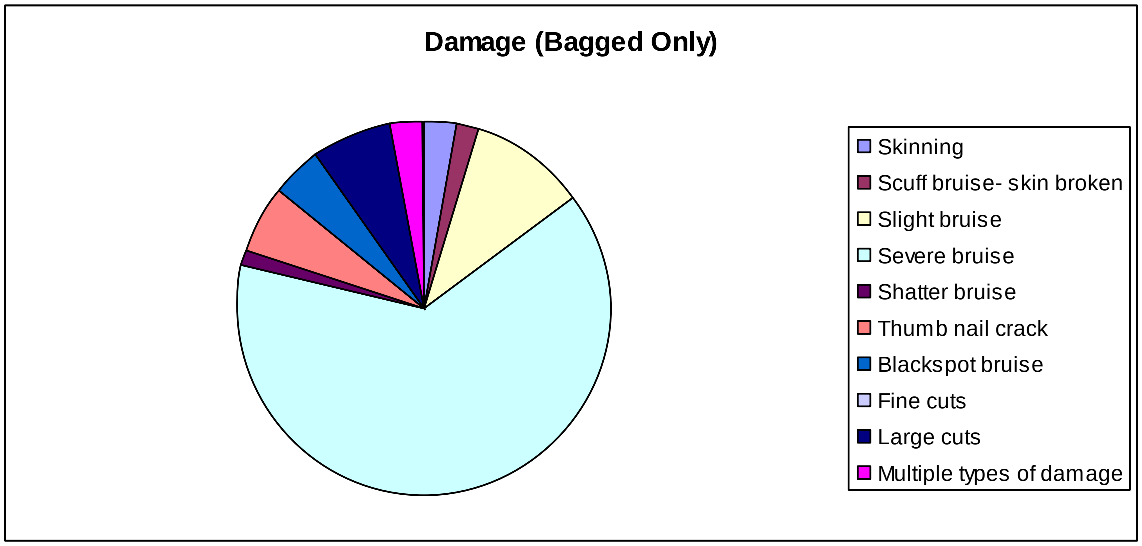
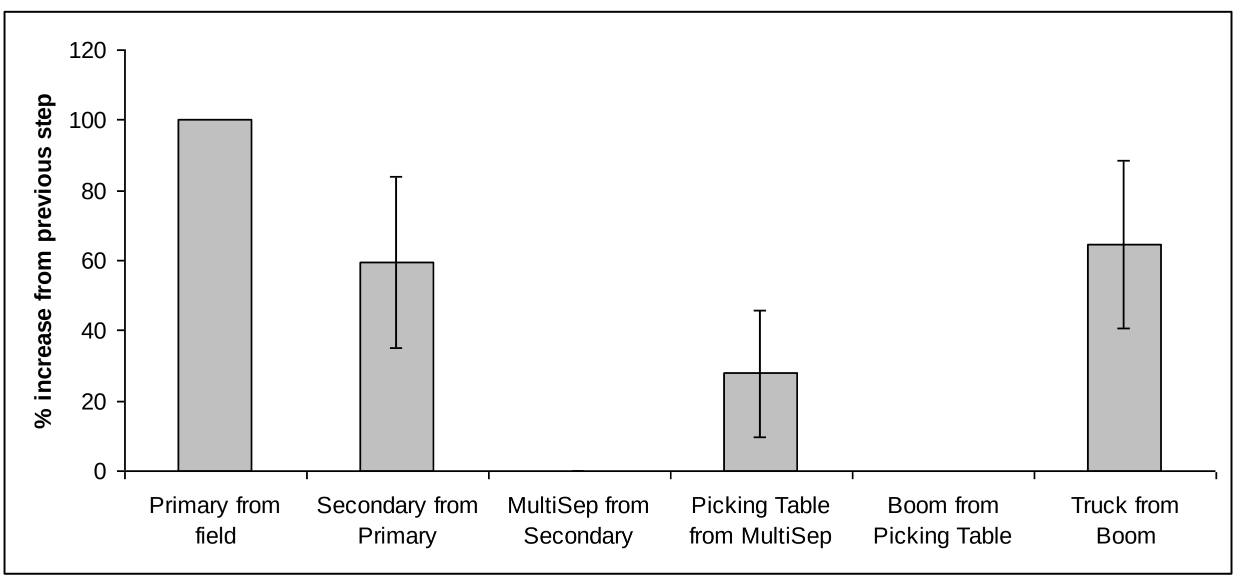


Figure 4. Relative occurrence of different types of damage on tubers assessed at A) the end of the harvesting line, i.e. in the truck (above) and B) at the end of the washing and bagging lines, i.e. in bags (bottom).

Focusing on the most common type of damage - bruising - there were four locations on the harvester where the incidence of bruising increased from the previous step: primary chain from the field, secondary chain from primary chain, picking table from multisep, and truck from boom (Fig. 5A). Of these the increase in damage between the field and the primary, the primary and secondary chain and from the boom to the truck were the sites of greatest increase in damage (Fig. 5A). Similarly, there were three locations along the grading and bagging line where bruising increased from the previous step: picking table from Wyma, belt from bin, and bag from feeder (Fig. 5B).



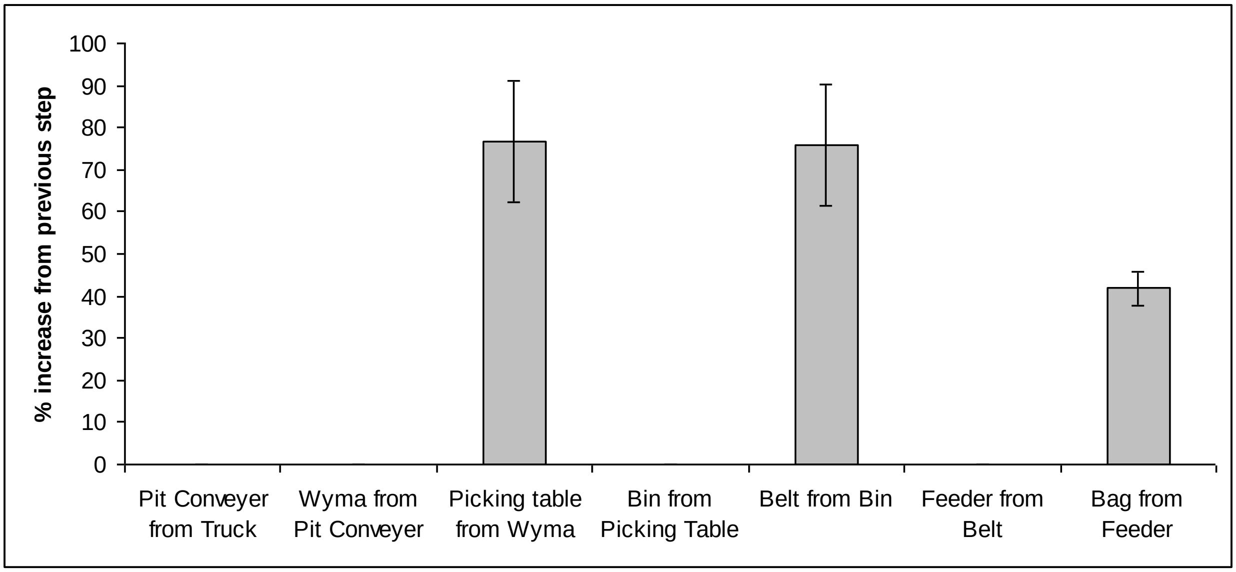


Figure 5. Locations along (A - top) harverster and (B -bottom) washing and bagging lines where the tubers with severe bruising increased compared to the previous step. For harverster, bars are the mean (± s.e.m) of eight fields and for the washing and bagging lines bars are the average of three fields. For locations with no bars damage did not increase from the previous step.

Objective 2 Tuber diseases present at harvest

The most common tuber diseases present at harvest were silver scurf and rhizoctonia (Table 9). Rhizoctonia was found in all 12 sampled fields and silver scurf in 11 of the 12 fields. Scab was found in 7/12 fields and soft rot only in the two Satina fields. For the other diseases there did not appear any difference among the three varieties in terms of severity. For some varieties, however, disease severity appeared to increase with later harvest dates. For example, the severity score for silver scurf increased with later harvest dates on AC Peregrine and to some extent on Yukon Gold (Table 9). None of the tubers samples cultured on media in Petri dishes were positive for pathogens.

Table 9. Summary of disease severity scores for tubers assessed at harvest from 12 potato fields. Data are shown as the % of the maximum possible severity score

Date	Variety	Location	Silver scurf	Rhizoctonia	Scab	Soft rot
Sep 4	Satina	Hand	0	10	0.66	0
Sep25	Satina	Hand	3	10	1.8	0
Sep10	AC Peregrine	Hand	5	8	0	0
Sep 17	AC Peregrine	Hand	12	5.5	0	0
Sep18	AC Peregrine	Hand	11	10	0.26	0
Sep20	AC Peregrine	Hand	13	6	0.26	0
Sep 7	Yukon	Hand	0	6	0.76	0

	Gold					
Sep10	Yukon Gold	Hand	6	0.3	0.26	0
Sep15	Yukon Gold	Hand	10	10	0	0
Sep20	Yukon Gold	Hand	13	10	0.26	0
Sep20	Yukon Gold	Hand	11	10	0	0
Sep25	Yukon Gold	Hand	4	3	0	0

Objective 3- Tuber diseases after storage

Overall we did not observe any major changes in the severity of the four common diseases on Yukon Gold and AC Peregrine tubers after two months of storage, compared to disease severity at harvest (Fig. 6). The only disease which appeared to have increased in storage was silver scurf on Yukon Gold tubers (Fig. 6). In addition, we observed late blight in two of the six potato storages samples (Table 10) and no late blight was observed in field samples.

Table 10. Summary of disease severity scores for tubers collected from six potato storage pits after 2 months of storage. Data are shown as the % of the maximum possible severity score.

Variety	Silver scurf	Rhizoctonia	Scab	Soft rot	Late blight
Yukon Gold	10	2	1	0.63	0
Yukon Gold	16	2	0.75	0.5	2
Yukon Gold	12	7	0	0.13	0
AC Peregrine	11	5	0	0	0
AC Peregrine	14	8	0.38	0.5	0
AC Peregrine	15	4	0	0.38	4

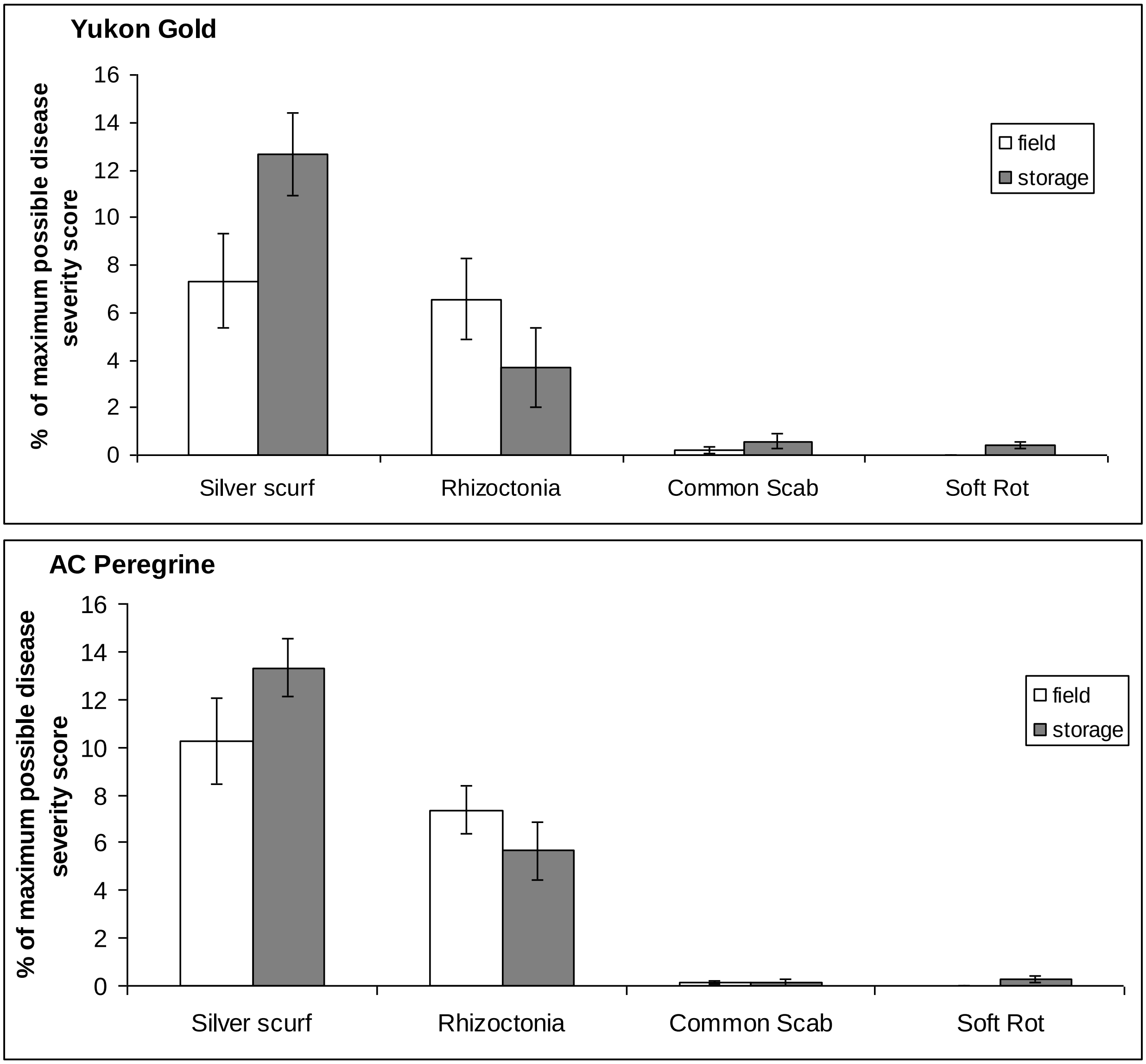


Figure 6. Disease severity scores - represented as the mean (± s.e.m) % of the maximum possible severity score - for four tuber diseases assessed on Yukon Gold and AC Peregrine varieties in the field at harvest and after two months of storage. For Yukon Gold N=6 for field and 3 for storage and for AC Peregrine N=4 for field and 3 for storage.

Objective 4-Efficacy of products for post-harvest disease control

Application of Serenade ASO, BioSave 10 LP, and StorOx post-harvest resulted in a significant reduction in silver scurf development on tubers compared to the Control (Fig. 7.; $F(3,36)=7.99$, $p=0.0003$). Application of Serenade ASO and StorOx also resulted in a significant delay in soft rot development compared to the Control (Fig. 8.; $F(3,36)=3.39$, $p=0.03$). None of the products delayed the development of Rhizoctonia on tubers, however even on Control tubers the development of this disease was quite low (Fig. 9.; $F(3,36)=1.53$, $p=0.22$).

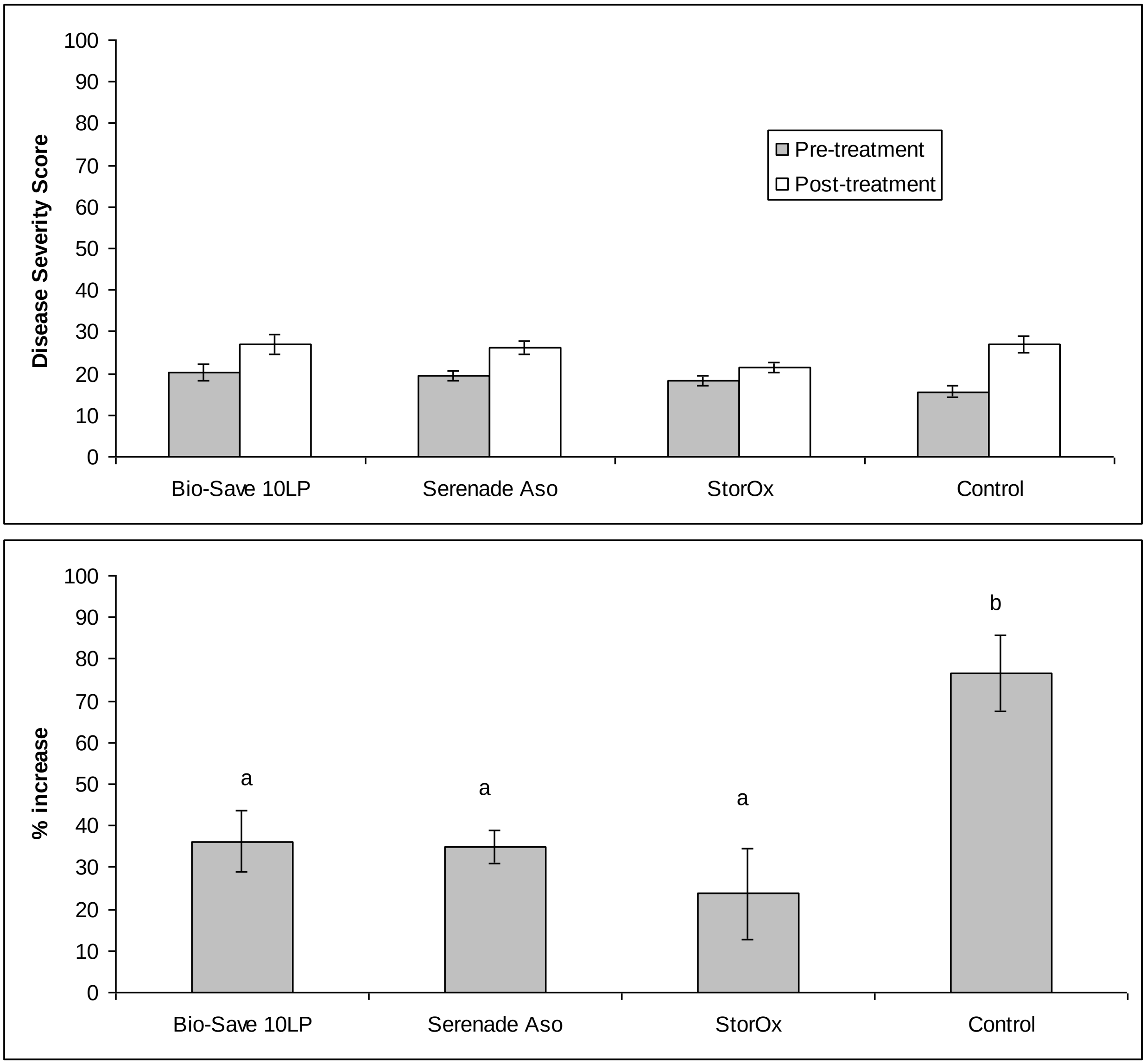


Figure 7. Effect of post-harvest fungicide treatments on silver scurf disease development in storage. Top: Mean (± s.e.m) disease severity scores pre and post-treatment (highest possible score 100). Bottom: Mean (± s.e.m) change in disease severity following two months of storage. 10 replicates/treatment. Bars with different letters are not significantly different based on Tukey-Kramer HSD test.

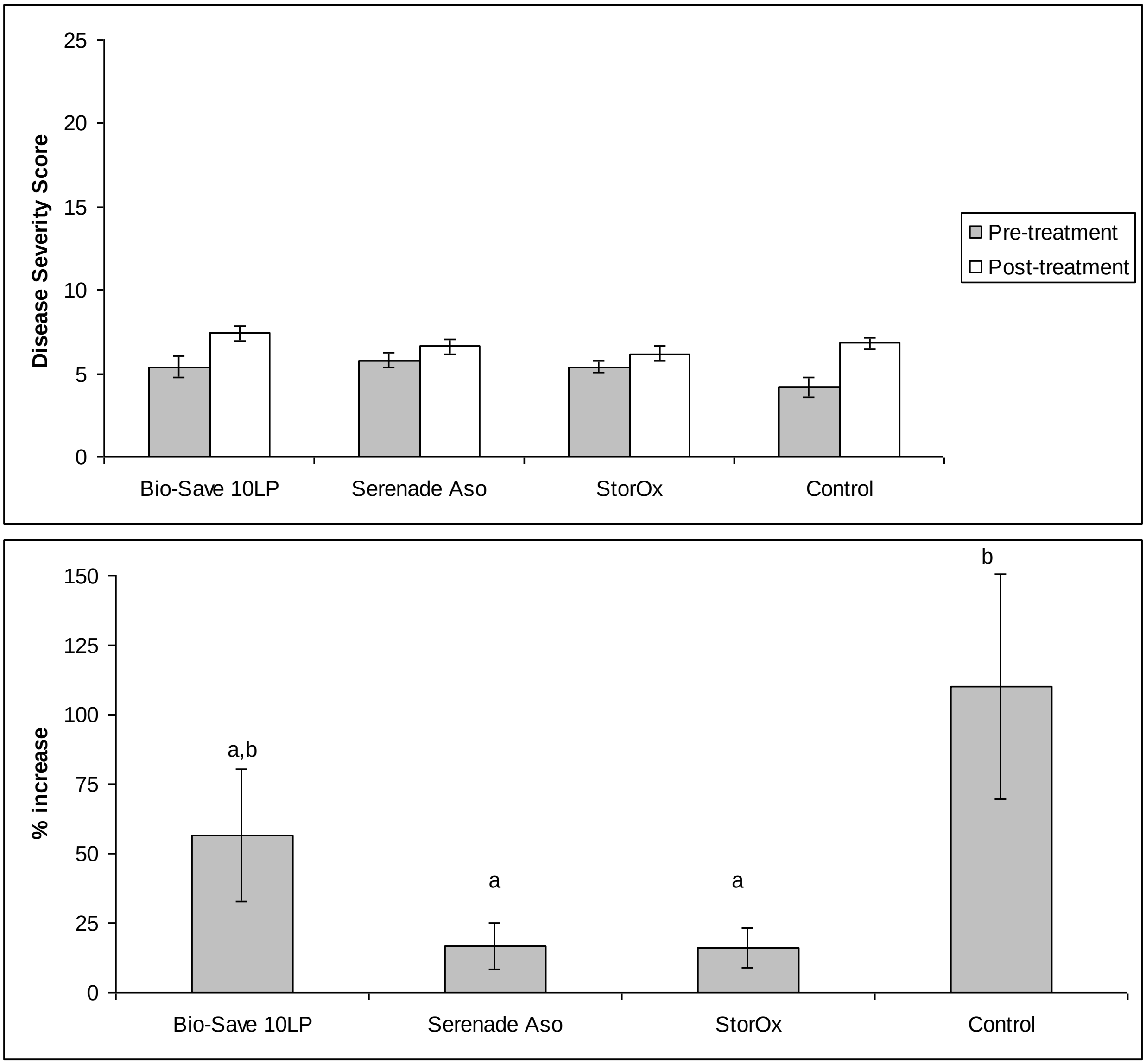


Figure 8. Effect of post-harvest fungicide treatments on soft rot disease development in storage. Top: Mean (± s.e.m) disease severity scores pre and post-treatment (highest possible score 100). Bottom: Mean (± s.e.m) change in disease severity following two months of storage. 10 replicates/treatment. Bars with different letters are not significantly different based on Tukey-Kramer HSD test.

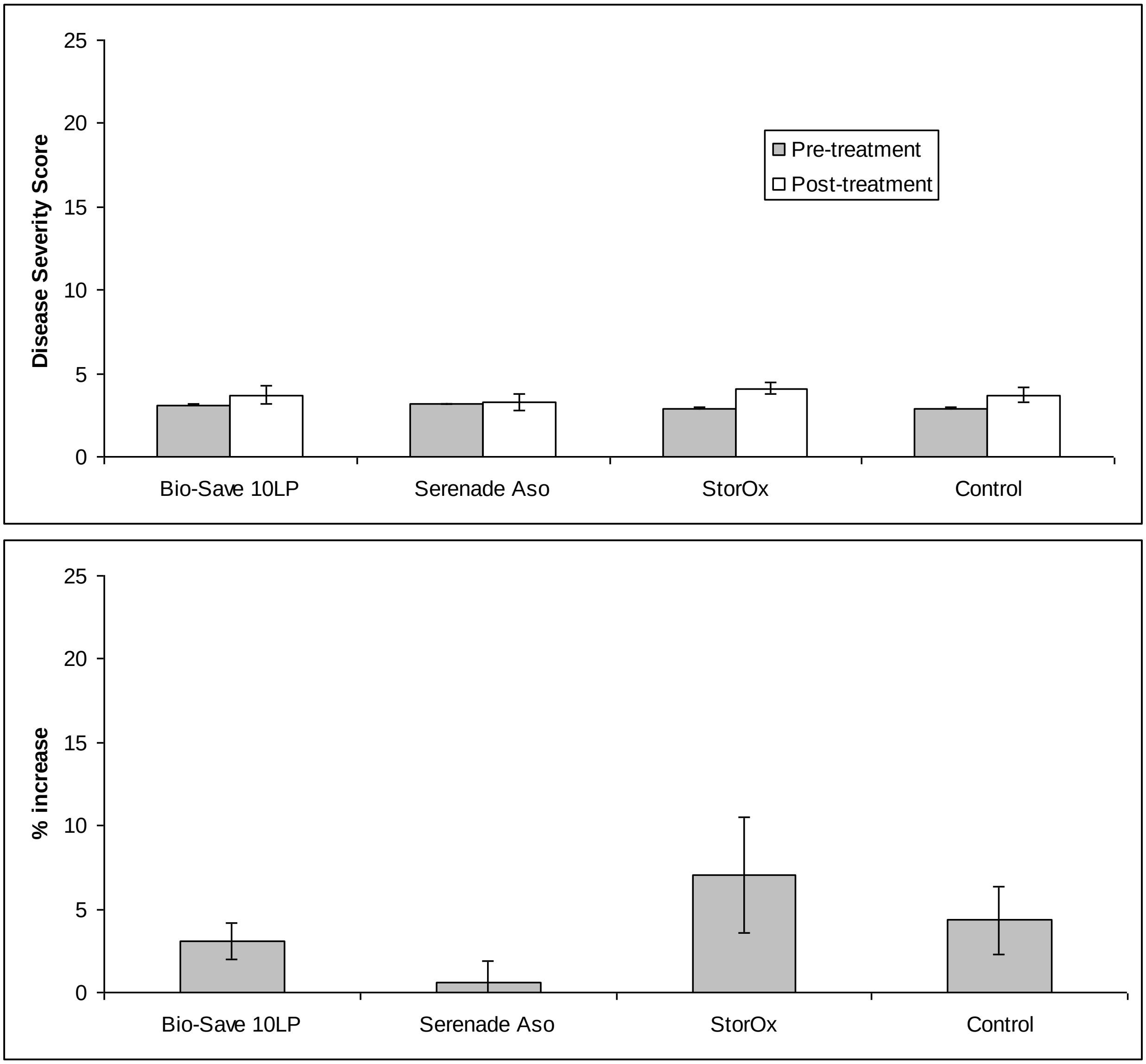


Figure 9. Effect of post-harvest fungicide treatments on Rhizoctonia disease development in storage. Top: Mean (± s.e.m) disease severity scores pre and post-treatment (highest possible score 100). Bottom: Mean (± s.e.m) change in disease severity following two months of storage. 10 replicates/treatment.

Discussion

Some estimates of post-harvest losses of food crops, on a global scale, are as high as 30 to 40% (Thomas 1999). In this study we observed losses due to physical damage could be as high as 82% by the time tubers were bagged and ready to send to wholesalers. By focusing on the most commonly occurring type of damage (i.e. bruising) and focusing in on where damage increased from the previous step, we were able to identify seven locations between the harvester and the two post-harvest washing and bagging lines where our collaborating growers should focus their efforts to reduce damage. We recommend that all growers consider a similarly detailed examination of their harvest practices to locate specific areas where changes could be made.

Typically significant damage does occur along the primary chain (Johnson 2008). Damage reduction on the primary chain is possible by minimizing rollback through adjusting the primary chain speed in relation to the forward ground speed so that it runs at full capacity and maintains soil up the main primary chain (whether this is a primary or secondary chain). Chain shakers should be avoided when removing soil as this can cause bruising and chains can be covered with a rubber casing to reduce skinning and minor bruising (Potato Council 2011, Pringle *et al.* 2009, Johnson 2008, Boswall and Glencross 2007, Bohl 2006, NPABCPAA 1998, O'Leary and Iritani 1969). We also saw an increase in bruising damage at the picking table however this was a much smaller increase than compared to the chains or boom to truck (Fig. 5A). As this is not a site where tubers are dropped, the results are not easily explained. We recommend that growers check the picking table for sharp edges or rough parts that result in excessive force against tubers as this may be the cause of damage at this location. Damage between the boom and the truck can be reduced by using soft padding on the base and sides of the truck to cushion initial drops and by always keeping the drop from boom to truck as minimal as possible- with a maximum drop of 15 cm (Potato Council 2011, Pringle *et al.* 2009, Johnson 2008, Boswall and Glencross 2007, Bohl 2006, NPABCPAA 1998, O'Leary and Iritani 1969). Finally, all machinery should frequently be checked over for sharp edges which may puncture, cut or otherwise damage tubers.

As with the harvesting line, the areas where we observed damage on the washing and bagging lines were associated with drops (Fig. 5B, belt from bin and bag from feeder) or tumbling of tubers (picking table from Wyma). Reducing damage at these three points will have a dramatic impact in reducing overall physical damage to tubers (Fig. 3). Similar steps can be taken as with the harvesting line to cushion tubers during steps involving tumbling (with rubber padding or softer brushes) or drops (reducing the height of the drop to less than six inches, adjusting the angle between the feeder and bags). As well we observed cuts only after tubers were bagged (Fig. 4B), this suggests that sharp edges along the washing and bagging lines are further contributing to tuber damage. In our research we found that the focus of advice for growers was on steps to reduce damage along the harvesting line. The results of this study suggest that the additional handling tubers experience after harvest or from storage is also a significant source of physical damage and that washing and bagging equipment should be scrutinized as much as the harvest equipment.

In addition to direct cosmetic impacts, physical damage can also make tubers more susceptible to diseases. The main diseases we found during our assessments were silver scurf, rhizoctonia, common scab, and soft rot. Of these silver scurf and rhizoctonia were the most prevalent. Common scab, silver scurf and rhizoctonia do not cause tubers to breakdown in storage but they can affect quality, increase handling costs, and significantly affect marketability with superficial defects (Stark and Love 2003). For the two varieties tested we observed no difference in disease severity of rhizoctonia, common scab or soft rot between freshly harvested field tubers and those in storage for two months. For silver scurf we did see an increase in disease severity on Yukon Gold tubers after two months of storage, but not AC Peregrine. We recommend that longer term studies continue to sample tubers of different varieties at intervals throughout storage. For larger-scale operations, with longer storage times, tuber sampling during storage maybe a beneficial practice in terms of selecting tubers for shipment. Best management practices recommended overall for reducing storage rots include: harvest when the tubers are mature and the soil is cool, minimize bruising by reducing physical impacts during harvest, encourage wounds to heal quickly by drying and cooling crops immediately after harvest, maintain adequate airflow in storage, prevent condensation in storage, maintain good storage hygiene. (Appendix C)

Of the three products tested in this trial Serenade ASO and StorOx proved to be the most effective as both delayed silver scurf and soft rot development on tubers. Further study of long term control with these products is needed to determine how long they are effective, as many potatoes are stored for more than two months before sale. Additionally, in this study tubers were treated with disease present (in order to ensure pest pressure). However, best management practices for disease control in storage include not storing diseased tubers. Further, all of the products tested are for suppression only, so they would most likely provide better control at lower levels of disease prior to application. We recommend that growers follow already established best management practices for storage rots of potatoes, when incorporating these additional chemical tools into their management program.

Summary of Recommendations

- Harvest when the tubers are mature, skin is set and pulp temperature is between 10-16°C
- Assess harvesting, washing and bagging lines regularly for areas of impact and bruising damage to tubers
- Maintain soil on the primary chains and run at full capacity
- Avoid chain shakers and cover chains with rubber casings
- Ensure that drops are less than 15 cm on all lines (harvesting, washing and bagging)
- Assess the washing and bagging line for sharp areas that may cut tubers
- To minimize the spread of disease in storage encourage wounds to heal quickly by drying and cooling crops immediately after harvest
- Maintain adequate airflow in storage and prevent condensation in storage
- Maintain good storage hygiene.
- If concerned with silver scurf or soft rot, in addition to the above recommendations, spraying with Serenade ASO or StorOx when pitting may delay the spread of disease.

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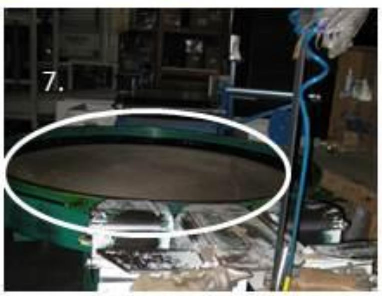
Appendix A: Sample Locations

Harvesting

1. Primary
2. Secondary
3. Multi-sep
4. Picking Table
5. Boom
6. Truck
7. Hand harvested



Processing and Storage

1. Pit conveyor
2. Wyma
3. Processing picking table
4. Bin
5. Belt
6. Feeder
7. Bag
8. Pit (storage)

Appendix B

Damage Management and Assessment Techniques

Poor skin set and, or excessive physical pressure resulting in the peeling or rubbing off of skins is the cause of skinning (NPABCPAA 1998). General bruising results from an impact between a tuber and something else which creates noticeable flesh damage, and skin damage which may or may not be visible. Black spot bruising occurs when an impact does not break through the potato skin and a dark fuzzy, grey/blue coloured spot under the skin appears. White-knot bruising is similar to a black spot bruise but white in colour. This type of bruising is only occasionally found and cause is unknown. When a potato splits or cracks from a central point due to an impact, it is referred to as a shatter bruise. A depression on a potato caused by tuber dehydration is called a pressure bruise. Thumbnail cracking is likely due to impacts and changes in temperature and is recognizable by thin lines resembling a thumbnail which barely break the surface (NPABCPAA 2006). Cuts vary in size and are created by digging blade or sharp edges along the harvesting or processing line (NPABCPAA 1998

Managing damage to potatoes must occur throughout the growing season. Potato damage and specifically bruise damage can be prevented or minimized through the use of a number of best management practices from cultivation to shipping (Table 10).

Table 10 Best management practices for minimizing damage to potatoes (Information compiled from Potato Council 2011, Pringle *et al.* 2009, Johnson 2008, Boswall and Glencross 2007, Bohl 2006, NPABCPAA 1998, O'Leary and Iritani 1969)

Stage of Production	Best Management Practices
Pre-planting	• choose fields with optimal soil conditions • cultivate in fall to break up hard pans • cultivate in spring under dry soil conditions, especially in heavy clay • remove rocks before planting • break up clods using appropriate machinery before planting • choose varieties which are least susceptible to bruising • if planting susceptible varieties avoid sandy soils • handle and transport seed carefully
Planting	• choose dates to ensure sufficient time for crop maturity • plant when soil temperature at seed depth is at least 9°C • plant with sufficient fertilizer, especially calcium and potassium • design planting to reduce turning during harvest • plant up and down slopes rather than across them • ensure planting of straight rows and proper row spacing • ensure even spacing and depth between seed • check that clods are not being brought into seed bed
Growing Season	• sufficiently irrigate and fertilize fields to avoid stress • do not spray, irrigate or go through field unless necessary in order to reduce compaction and clod formation • do not excessively fertilize as this will delay maturity and increase black spot bruising

	• assess petiole nitrate-nitrogen levels. Levels should be down to 15 000ppm or lower by mid-August
Vine Kill	• kill two to three weeks before harvesting but consider weather conditions as skins mature slower under cool or wet soil conditions • guarantee vine destruction so tubers easily separate from stolons during harvest • keep soil moisture greater than sixty percent from the time vines are killed to harvest • irrigate one week prior to harvest if soil is dry and tubers are dehydrated
Harvest	• assess a row or two of each field the day before intended harvest • assess dry matter content and specific gravity and if either are high, harvest cautiously • ensure tubers are not overly hydrated or dehydrated • harvest when tuber pulp temperature is between 10-16°C • correctly align diablo rollers over hills so as to not cut or crush tubers • angle digging blades so that tubers do not bump into primary chain • base conveyor speeds on ground speed • chains can be coated with soft materials if this will not affect soil elimination requirements for a given field • maintain a flow of soil up to the second chain • minimize tuber rollback on second chain • avoid using chain shakers if possible • ensure vine fingers prior to multi-sep table are well padded • aim to remove 60-70% of vines coming through harvester as removing more may cause excessive damage to potatoes • use tank water on red, yellow and white potatoes especially • keep drop from boom end to truck as low as feasible
Truck	• avoid stepping on potatoes in the truck when covering with tarp
Piling	• maintain minimum distance between boom end and potato pile • pile potatoes in a step manner
Storage	• complete wound healing within one to two weeks • maintain high humidity unless disease concerns require drying
Processing	• warm potatoes to 7°C prior to handling • ensure potatoes are not bagged while wet or when condensation can form inside of bags
All harvesting and processing equipment	• ensure drops are kept below fifteen centimeters • install padding wherever potatoes may be damaged • run machinery at full capacity • regularly inspect equipment for issues or sources of damage

Several scales have been created to assist in damage assessment (Table 11); for many damage types, criteria are fairly consistent between different authors. Additionally, a range of severity ratings was created for scuffing, cuts, splitting, and bruising categories using surface and depth measurements, as listed in Pringle *et al.* (2009).

Table 11. Criteria for evaluating various types of tuber damage

	Source					
Type of damage	Potato Council 2011	Pringle *et al*. 2009	Boswall 2007	NPABCPAA 1991	Robertson 1970 (as cited in Pringle *et al*. 2009)	O'Leary and Iritani 1969
Undamaged	No damage	No damage	No damage	No damage	No damage	No damage
Skinning	N/A	N/A	Flesh damage removable by one peeler stroke	Flesh damage removable by one peeler stroke	N/A	Flesh damage removable by one peeler stroke
Scuffed bruise	Broken skin with no flesh damage	N/A	N/A	N/A	Undefined	N/A
Slight bruise	Flesh damage removable by two peeler strokes	Flesh damage removable by two peeler strokes (<3mm deep)	Flesh damage removable by two peeler strokes	Flesh damage removable by two peeler strokes	<1.5mm	Flesh damage removable by two peeler strokes
Severe bruise	Flesh damage needing more than two peeler strokes for removal	Flesh damage needing more than two peeler strokes for removal (>3mm deep)	Flesh damage needing more than two peeler strokes for removal	Flesh damage needing more than two peeler strokes for removal	>1.5mm deep	Flesh damage needing more than two peeler strokes for removal

Reducing damage while harvesting and processing is possible by regularly assessing tubers and making changes to practices. Various quality control management programs can be put into effect depending on the needs of the grower. The best case scenario would be to assess potato damage susceptibility prior to harvest, however this is often not a practical option and levels found prior to harvest may not correlate with damage found at harvest (Croy 2011). Thus bruising assessments need to be made along the harvest and post-harvest processing lines when they are running with systems in place to make adjustments based on findings as quickly as possible. Sample locations should be decided based on changes in potato variety, soil type, machinery settings or when machinery adjustments are made (Potato Council 2011), or where crop management practices differed (e.g. planting date, use of row covers)(Croy 2011). Locations where potatoes drop, or change direction or chains exist are important spots for testing damage (NPABCPAA 1991, O'Leary and Iritani 1969). For instance, collection locations should include the primary chain, secondary chain, rear cross, elevator, and boom (Boswall 2007). The number of potatoes recommended to be collected per location (sample size) differs between authors (Table 12). A more detailed guide for determining sample size based on damage tolerance levels, is offered by Pringle *et al.* (2009)(Table 13). **Regardless of the sample size taken, numbers of tubers should be divided up and taken at separate intervals to form replicates**. While there is no singular standard for sample size, *frequent* and *regular* sampling is crucial in managing physical damage in any quality control program (NPABCPAA 1998). Finally, observational data is beneficial in providing additional information on the extent and severity of damage, when it is combined with data from repeated sampling under the same set of harvest or processing conditions (Pringle *et al.* 2009).

Table 12. Sample size recommendations for damage assessment during harvest.

Sample size recommended	**Source**
15-25kg (33-55lb) of potatoes per sample	Potato Council 2011
• Low risk considering variety and season: 5 samples of 5 potatoes per field • High risk considering variety and season: 10 samples of 5 potatoes per field • High risk or high variability if average bruise index of 5 samples is >5.5 or any single value is >7.5 retest field: 10 samples of 5 potatoes per field	Croy 2011
9-14kg (20-30lb) of potatoes per sample	Johnson 2008
33 potatoes per sample	Boswall 2007
10 samples of 5 potatoes per field	Wiltshire 2006
10 potatoes per sample	NPABCPAA 1991
10 or more potatoes per sample	O'Leary and Iritani 1969
25, 50 or 100 potatoes per sample	Robertson 1970 (as cited in Pringle *et al.* 2009)

Table 13. Number of randomly selected tubers required to find defective tubers in a load. (Table 12.2 from Pringle *et al.* 2009).

Maximum level of defect permitted (%)	Minimum sample size (no. of tubers) required to detect presence of defect	Minimum sample size (no. of tubers) required to estimate % level of defect
20	15	45
10	30	90
5	60	180
2	150	450
1	300	900

Various protocols have been used in order to test regularly for tuber damage at harvest. The time between sampling tubers and viewing results can be long when bruising is the main focus for testing, because some types of bruises can take two to four days at room temperature to become visible Potato Council 2011, Pringle *et al.* 2009, Boswall 2007, NPABCPAA 1991). A time saving option is to use a hot box which heats potatoes, speeds up bruising discolouration and allows for assessments to be made within six to twelve hours, although twenty-four hours is recommended (NPABCPAA 1998). A hot box can be purchased, or created using an old freezer and heater as long as it is safe. The hot box should be run with relative humidity at between 95-98% and the temperature should be between 34-36°C (Potato Council 2011). Soaking potatoes in water which is 60°C for 10 minutes and then leaving them for at least six hours is another, although not commonly used, heat related option. Regardless of how long potatoes have been left for, when they are ready, they should be peeled to include all types of bruising in assessments (NPABCPAA 1998).

In the past, testing for damage was also conducted using catechol dye. Exposed starch (through cuts and bruises) reacts with catechol and these areas would show up as discoloured for easy and rapid damage assessment (Boswall 2007, O'Leary and Iritani 1969). However, black spot bruising is not detectable with a dye as bruise development occurs below the surface without exposing any starch. Unlike catechol, tetrazolium is a chemical for rapid bruise assessment which can detect black spot bruising, yet both products are known to be toxic to animals and tetrazolium is toxic to humans (Kleinschmidt and Thornton 1991). Due to the inability of detecting black spot bruising (W. Bohl, University of Idaho personal communication 2012) and/or carcinogenic concerns (J. Dittmann, AGPower Sales Inc. personal communication 2012), these products have not been used in the past 10-20 years. Food grade dye is noted in the Prince Edward Island guide for damage assessment at harvest and is used by some growers (W. Proctor, PEI Department of Agriculture personal communication 2013). While this dye can rapidly detect damage (Boswall 2007), black spot bruises are not detectable so it may be an effective enough tool for fresh market potatoes but not processing potatoes where black spot bruising is a greater concern.

Finally, a third method which can be used to detect damage is to use an instrumental sphere (NPABCPAA Bohl 1998) such as the SmartSpud (Masitek Instruments Inc. formerly Sensor Wireless Inc.) or the TuberLog (Martn Lishman Ltd.). An electronic sphere is an electronic tool enclosed in a potato like rubber covering which can be put through any part of a production line. The device records impact levels as it travels through machinery and this data are transferred to a hand held computer or laptop where they can be compared to already developed thresholds. This technique can provide the quickest results however sometimes tubers need to be visually assessed because the impact levels as measured by the device may have varying effects on different tuber varieties. Grower uptake of this technique is very limited, especially locally even though the technology has been available for many years. Limited use maybe due to the cost as the SmartSpud has an initial hardware cost of approximately $4 995 US and an annual software fee of approximately $995 US, and older versions of the technology are not all compatible with current operating systems (D. McNally, Masitek personal communication 2012). While less expensive, the TuberLog still has an upfront cost of about $2 230 US (G. Lishman, Martin Listman Ltd personal communication 2013). While these tools are expensive, their use in reducing tuber damage through production lines could make them well worth the initial cost.

Considering that losses from the field to the bag can be as high as 82% , regardless of the method chosen, assessing potatoes along harvesting and processing lines for bruising is highly recommended for all growers.

Appendix C

Summary of selected diseases and potential management strategies (Johnson 2008)

Disease	Management Practices
All disease types	• plant certified, clean seed potatoes • sanitize and clean all equipment and storage areas and maintain farm hygiene
Diseases caused by Viruses, Viroids, and Phytoplasmas	• control aphid, nematode and leafhopper vectors • control volunteer potatoes and destroy cull piles • plant disease resistant varieties
Seedborne and Soilborne pathogens	• inspect, even certified, seed for diseases • ensure a minimum of 2-3 years of crop rotation in between potato plantings and if possible use crops which will suppress the diseases found in particular fields • plant disease resistant varietes • warm seed potatoes prior to cutting • encourage rapid emergence through seed piece treatments, successful wound healing, and shallow planting in warm soil • hill rows to reduce risk of late blight infection • wait at least 2 weeks after incorporating vegetation before planting to reduce the risk of Pythium seed piece decay • some work suggests green manure crops can suppress diseases themselves and also increase soil microorganisms which can also suppress diseases • carefully manage temperature, relative humidity, and airflow in storage
Blackleg	• plant short-generation seed potatoes • use a fungicide seed piece treatment • warm seed potatoes before planting • choose fields with well-drained soil
Aerial Stem Rot	• increase spacing between plants • prevent over irrigating • prevent over fertilizing • prevent stem damage while working in field
Tuber Soft Rot	• let tubers mature before harvest • harvest when soil is cool • encourage wounds to heal in storage • keep conditions cool in long term storage • provide airflow in storage • prevent condensation in storage
Bacterial Ring Rot	• plant short-generation seed potatoes • test seed potatoes for ring rot • disinfect all equipment, storage areas, and trucks
Early Blight	• choose fields which have not been growing potatoes in at least 2-3

	years • choose resistant varieties • ensure crop has sufficient nitrogen and phosphorus • avoid over irrigating • control pests which stress plants as this increases susceptibility to early blight • scout fields and follow a disease forecasting system to know when to start fungicide treatments and determine an treatment schedule • use the recommended amount of effective fungicides at the ideal time • wait for skins to be well set and avoid damage at harvest
Late Blight	• control volunteer potatoes and destroy cull piles • choose resistant varieties • use a fungicide seed piece treatment • plan irrigation to minimize time when plants will be wet • scout the crop at least weekly for earliest possible detection • follow the weather and a disease forecasting system to know when to start fungicide treatments and determine an treatment schedule • keep using fungicides until plants are completely dead • in many farming areas, leave 2-3 weeks of plants being entirely dead before harvesting • monitor potatoes in storage closely to detect problems early and adjust storage
White Mold	• choose fields which have not been growing potatoes in at least 2-3 years • prevent over fertilizing • ensure plants have sufficient water during and after bloom but prevent over irrigating • think about using a biocontrol agent to decrease survival of the mold's sclerotia