Project Title: Effect of dump tank composition on lenticel breakdown disorder

Report Type: Final Project Report

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Item	2019	2020	2021
Salaries	20,480	10,240	5,120
Benefits	325	163	81
Supplies	3,000	2,000	
Travel	2,500	1,000	1,000
Miscellaneous			

Total	26,305	13,403	6,201

Footnotes: Salaries: Temporary personnel to assist in fruit evaluations and analysis in years 1, 2, and 3.
Benefits: $325, $163, and $81 are requested for benefits tied to the temporary personnel.
Supplies: Supply costs of $3,000 in year 1, $2,000 in year 2 are requested to pay for boxes, trays and supplies for fruit maturity evaluation. Travel: $2,500, $1,000, and $1,000 is requested in years 1, 2, and 3, respectively, for mileage and associated travel costs at a rate of $0.535/mi and adhering to all university policies for per diem associated with overnight travel.

OBJECTIVES

1. Assess the progression of lenticel browning disorder (LBD) incidence and severity on different lots of fruit and packing operations with different water makeups.
2. Correlate mineral and organic composition of water sources from different packing operations with LBD development.
3. Evaluate the effect of chlorine, peroxyacetic acid, chlorine dioxide, and ozone concentrations on LBD development on apples under controlled environment.

SIGNIFICANT FINDINGS

- LBD incidence and severity kept increasing after 96 h at 68°F and it was the highest after 1 week in air plus 7 days at 68°F. Fruit from all lots developed LBD after this time and after being packed or presized (including the least susceptible fruit).
- Phosphorus accumulation in the processing water was positively correlated with high LBD incidences. Calcium, Boron, and Potassium may also be playing a role.
- High free chlorine was not correlated with elevated LBD incidence.
- There was no evidence that neither chlorine or peracetic acid (at 50 ppm) in simulated washing conditions (COD) can cause LBD development.
- Water management (filtering, replacement) is critical when processing susceptible fruit.

Objective 1. Assess the progression of LBD incidence and severity on different lots of fruit and packing operations with different water makeups.

Activities

Different commercial lots of apples cv. Gala were sampled between 1 and 3 months, 4-6 months, and 7-9 months during the storage season. For each Lot, fruit was retrieved prior and after processing in the packing line (presizer and/or confection line). LBD incidence (# fruit affected/# total fruit) and severity (0-3, where 1=mild, 1-3 lesions per fruit, 2=moderate, 4+ lesions per fruit, and 3=severe, 50% area affected by lesions; Picture 1) were evaluated visually after 24 h, 96 h, after 1week in air (33°F), and 1 week in air ply 7 days at room temperature (RT, 68°F) of retrieving the sample. Fruit quality was determined for each sample at the time of retrieval. Three replicates per lot were used with a sample of 100 fruit per replicate.

Picture 1. LBD severity

RESULTS

LBD incidence and severity increased from the evaluation at time zero (0 h, right after processing) until 1 week (in cold storage) plus 7 days at 20°C ('shelf-life') in presized and/or packed fruit from all lots and time-points during storage (Tables 1 & 2).

When fruit from the same lot was evaluated during the storage season (#6780, #7961, #6520), LBD incidence progressively increase over time (Table 1, Figure 1).

Fruit maturity at harvest and after the packaging or presizing is shown in Table 2. Maturity indices at harvest and postharvest (considering that all fruit was treated with 1-MCP) cannot explain differences on LBD susceptibility observed on pre-process LBD incidences. Preharvest factors such as, weather before harvest (dehydration pressure, etc.), nutritional levels, tree vigor and others affecting LBD development, were not considered in this study.

Table 1. Mean LBD incidence (%) observed at different evaluation times after warehouse sampling. Asterisks indicate significant statistical differences (Kruskal-Wallis, P≤0.05) between sample means (Pre-line/Post-line) at each evaluation time.

			Mean LBD incidence (%)				
Lot	Processing date	Sample	0 h	24 h	96 h	1wRA	1w+7d
	10/19/2020	Pre-line	0.0	1.5	3.0	3.0	4.0
#6780		Presized	0.0	2.3	4.0	3.0.0	4.0
	11/5/2020	Pre-pack	0.6	1.0	1.0	1.0	2.3
		Packed	3.0 *	4.0 *	15.0 *	21.0 *	24.0 *
	11/12/2020	Pre-pack	0.0	0.0	0.0	0.3	1.0
		Packed	1.0	1.0	3.0	14.0 *	23.7 *

	11/19/2020	Pre-pack	1.7	3.0	5.3	7.0	11.0
		Packed	9.3 *	21.3 *	27.0 *	37.0 *	49.7 *
	1/15/2021	Pre-pack	1.0	1.7	2.7	4.0	5.0
		Packed	1.7	1.3	2.0	2.7	6.7
	1/26/2021	Pre-pack	0.7	4.7	6.7	8.7	22.0
		Packed	22.7 *	35.0 *	48.7 *	53.7 *	64.7 *
	2/2/2021	Pre-pack	0.7	1.0	1.3	3.3	5.0
		Packed	8.7 *	15.0 *	20.3 *	22.7 *	31.3 *
#7961	12/7/2020	Pre-pack	0.0	0.0	0.0	3.0	4.0
		Packed	0.0	0.0	0.0	2.0	2.7
	12/11/2020	Pre-pack	0.0	0.0	0.0	0.0	0.0
		Packed	1.3 *	1.3 *	3.0 *	3.0 *	3.0 *
#6520	12/7/2020	Pre-pack	0.0	0.0	0.3	0.7	0.7
		Packed	0.0	0.0	0.3	1.3	1.3
	12/11/2020	Pre-pack	0.0	0.0	0.0	0.0	0.0
		Packed	0.0	0.0	0.3	2.3 *	3.0 *
#2750	12/11/2020	Pre-pack	0.0	0.7	1.3	2.3	3.3
		Packed	2.3	2.3	4.0	5.0	7.7
#2670	12/7/2020	Pre-pack	0.0	0.0	0.3	1.3	3.3
		Packed	0.0	0.0	0.6	1.7	3.3
#G-434	1/7/2021	Pre-pack	0.0	0.3	1.3	2.0	3.0
		Packed	0.0	0.5	0.5	0.8	1.5

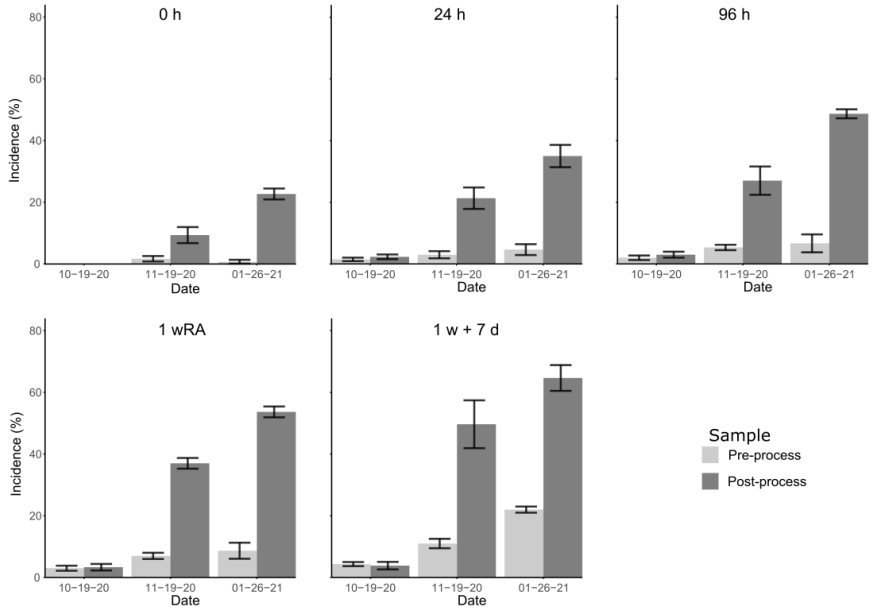

Figure 1. LBD incidence (%, average) pre and post-process in lot #6780 during different time during the storage season. Inside bars indicate standard error (n=3).

Table 2. Mean LBD severity (0-3) observed at different evaluation times after warehouse sampling. Asterisks indicate significant statistical differences (Kruskal-Wallis, $P \leq 0.05$) between sample means (Pre-line/Post-line) at each evaluation time.

Lot	Processing date	Sample	**Mean LBD severity**				
			0 h	24 h	96 h	1wRA	1w+7d
#6780	10/19/2020	Pre-line	0.00	0.00	0.02	0.03	0.05
		Presized	0.00	0.00	0.03	0.03	0.04
	11/5/2020	Pre-pack	0.03	0.04	0.04	0.04	0.10
		Packed	0.10	0.13	0.67*	0.97*	1.21*
	11/12/2020	Pre-pack	0.02	0.02	0.07	0.34	0.55
		Packed	0.00	0.00	0.00	0.01	0.04
	11/19/2020	Pre-pack	0.11*	0.33*	0.43*	0.67*	0.97*
		Packed	0.02	0.04	0.06	0.09	0.14
	1/15/2021	Pre-pack	0.01	0.02	0.02	0.03	0.06
		Packed	0.02	0.02	0.03	0.05	0.06
	1/26/2021	Pre-pack	0.27*	0.46*	0.69*	0.86*	1.11*
		Packed	0.01	0.05	0.08	0.10	0.26
	2/2/2021	Pre-pack	0.12*	0.21*	0.27*	0.30*	0.43*
		Packed	0.01	0.01	0.02	0.04	0.06
#7961	12/7/2020	Pre-pack	0.00	0.00	0.00	0.03	0.04
		Packed	0.00	0.00	0.00	0.05	0.06
	12/11/2020	Pre-pack	0.00	0.00	0.00	0.00	0.00
		Packed	0.03	0.05	0.05	0.06	0.06
#6520	12/7/2020	Pre-pack	0.00	0.00	0.00	0.02	0.02
		Packed	0.00	0.00	0.00	0.01	0.01
	12/11/2020	Pre-pack	0.00	0.00	0.00	0.00	0.00
		Packed	0.00	0.00	0.00	0.03	0.03
#2750	12/11/2020	Pre-pack	0.01	0.02	0.02	0.03	0.05
		Packed	0.03	0.05*	0.05*	0.06*	0.10*
#2670	12/7/2020	Pre-pack	0.00	0.00	0.01	0.02	0.03
		Packed	0.00	0.00	0.00	0.02	0.04
#G-434	1/7/2021	Pre-pack	0.00	0.00	0.01	0.01	0.03
		Packed	0.00	0.01	0.01	0.01	0.02

Table 2. Harvest maturity and postharvest treatments of fruit from different Gala apples (information provided by the warehouse).

Lot	Harvest	Treatments	Flesh firmness (lb)	Starch Index (1-8)
#6780	9/1/2020	1-MCP+Sch[Z] (9/3/2020)	19.46±2.28[Y]	2.3
#7961	9/6/2020	1-MCP+Sch (9/2, 3, 14/2020)	18.82±1.97	3.0

#6520	9/4/2020	1-MCP+Sch (9/2,13/2020)	19.49±1.72	2.3
#2670	9/1/2020	1-MCP+Sch (9/3,14/2020)	18.48±2.36	2.9

[Z] Scholar Max fogging, commercial rate.

[Y] Mean ± standard deviation

Table 3. Fruit maturity at the time of sampling during the storage period in Gala lots #6780, #7961, #6520, #2750, #2670, #G434.

Lot	Processing date	Sample	+1 days at 20°C			+7 d at 20°C		
			Firmness (lb)	SS (Brix)	SI (1-8)	Firmness (lb)	SS (Brix)	SI (1-8)
#6780	10/19/2020	Pre-line	15.3±1.7[Z]	13.6±0.7	6.0±0.0	15.0±1.6	14.2±0.8	7.7±0.4
		Presized	14.6±1.8	13.2±0.9	6.4±0.8	14.5±1.9	14.0±1.0	7.6±0.3
	11/5/2020	Pre-pack	12.8±1.2	13.4±0.8	7.6±0.7	15.0±1.6	13.9±0.6	7.9±0.2
		Packed	14.4±1.8	14.6±0.9	7.2±1.1	14.5±1.9	13.9±1.3	7.8±0.3
	11/12/2020	Pre-pack	15.9±1.4	13.1±1.1	7.5±0.8	14.8±1.8	13.6±1.4	8.0±0.1
		Packed	15.0±1.5	13.2±1.0	7.4±0.9	15.2±1.9	13.2±1.2	8.0±0.1
	11/19/2020	Pre-pack	14.9±1.4	13.5±0.8	7.9±0.3	14.2±1.6	13.8±1.1	8.0±0.0
		Packed	13.2±3.6	13.9±1.6	7.7±0.5	13.7±1.0	13.6±0.9	8.0±0.0
	1/15/2021	Pre-pack	16.0±1.2	14.8±0.7	6.0±0.0	15.9±1.8	15.1±0.9	6.0±0.0
		Packed	13.8±3.2	14.3±1.2	6.0±0.0	15.6±1.3	14.9±1.0	6.0±0.0
	1/26/2021	Pre-pack	14.0±2.1	13.6±1.0	6.0±0.0	13.2±1.6	13.9±0.6	6.0±0.0
		Packed	13.4±1.5	14.0±0.8	6.0±0.0	13.3±2.5	14.0±1.0	6.0±0.0
	2/2/2021	Pre-pack	15.9±1.4	13.6±1.6	6.0±0.0	15.2±2.2	14.7±0.8	6.0±0.0
		Packed	15.7±1.0	14.1±0.9	6.0±0.0	16.0±1.3	14.9±1.1	6.0±0.0
#7961	12/7/2020	Pre-pack	13.7±1.3	13.8±0.8	6.0±0.1	14.5±1.2	14.1±1.0	7.8±0.4
		Packed	13.4±0.9	13.2±0.9	6.0±0.1	13.3±1.9	13.4±0.9	7.9±0.3
	12/11/2020	Pre-pack	13.1±1.5	12.1±0.7	6.0±0.1	13.9±1.3	12.7±0.7	8.0±0.0
		Packed	13.8±1.1	12.9±1.0	6.0±0.1	13.5±2.2	12.5±0.9	8.0±0.0
#6520	12/7/2020	Pre-pack	13.1±2.3	12.7±1.1	5.9±0.2	13.0±2.1	12.5±0.9	6.0±0.0
		Packed	12.7±1.9	12.5±1.0	6.0±0.1	14.0±1.7	13.1±1.1	6.0±0.0
	12/11/2020	Pre-pack	12.7±2.4	11.9±0.7	6.0±0.1	13.0±1.7	12.3±1.0	6.0±0.0
		Packed	12.7±1.3	11.9±1.2	6.0±0.1	13.3±2.5	12.7±0.9	8.0±0.0
#2750	12/11/2020	Pre-pack	15.4±1.2	12.5±1.5	5.9±0.2	14.4±2.2	12.7±1.0	8.0±0.0
		Packed	13.9±1.1	12.1±1.0	5.9±0.2	15.1±1.8	12.8±1.2	7.9±0.2
#2670	12/7/2020	Pre-pack	14.8±1.3	15.9±2.1	6.0±0.1	14.7±1.6	12.7±1.1	8.0±0.0
		Packed	15.1±1.5	13.0±0.8	5.9±0.1	15.1±1.8	12.8±1.2	7.9±0.2
#G-434	1/7/2021	Pre-pack	15.1±0.5	13.5±0.8	6.0±0.0	13.7±1.2	13.4±0.8	6.0±0.0
		Packed	13.5±1.0	12.9±1.2	6.0±0.0	14.1±1.0	13.5±1.1	6.0±0.0

[Z] Mean ± standard deviation

Objective 2. Correlate mineral and organic composition of water sources from different packing operations with LBD development.

Activities

The water makeup (carbohydrate, protein, mineral content, chemical oxygen demand (COD), oxidation reduction potential (ORP), and turbidity) was determined for all water sources during the processing of each fruit lot, and later correlated with their LBD incidence differences (Δ LBD) between pre-process and post-process, both after 1 week in cold storage plus 7 days at 20°C.

RESULTS

The highest ORP, conductivity, temperature, turbidity, free chlorine and minerals were observed at the dump tank or first flume in the confection line in one of the operations. In the second operation, this was not the case and mineral content varied between flumes 1, 2 and 3 (data not shown).

Combining all lots, sampling dates, Δ LBD from each of them, and water in a multivariate statistical analysis (Principal Component Analysis, PCA; Figure 2), we were able to see four clusters which separation was driven by different water components, e.g. cluster 1, lot with high Δ LBD, was highly correlated with P content (highest content, Fig. 3). Furthermore, the level of P in the processing waters was also highly correlated with LBD incidence when all lots were combined (R^2=0.72; Fig. 4). Cluster 1 was also negatively correlated with free chlorine, Mg, Na, COD and pH. Although P content appeared to be critical for LBD development post processing, cluster 2, which has the same lot as cluster 1 but processed in different dates (with slightly less Δ LBD) was positively correlated with Ca, B, and K contents (Fig. 2). Nevertheless, this was also true for cluster 3 which grouped lots with low LBD incidence (Fig. 2). On the other hand, cluster 4 grouped the lot with the lowest Δ LBD and was positively correlated with free chlorine levels (highest levels, Fig. 3). The level of each water component for each cluster is shown in Figure 3.

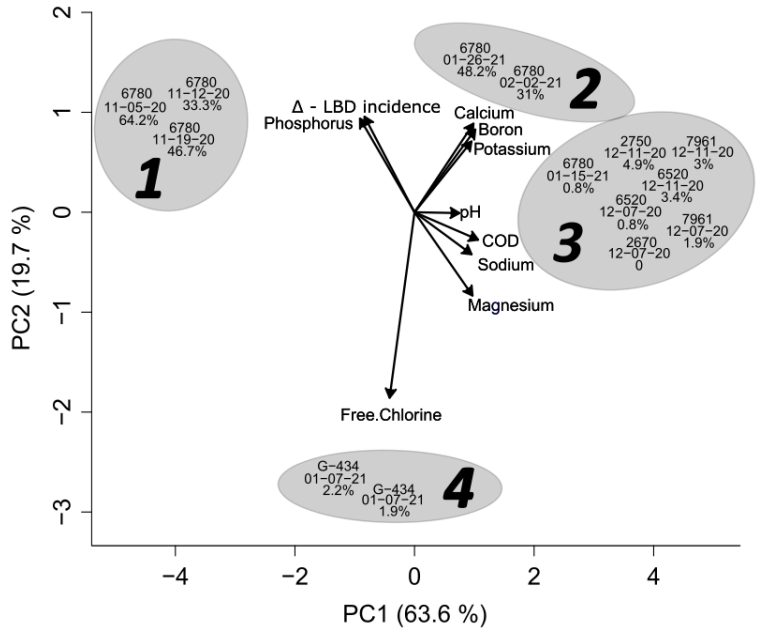

Figure 2. Principal Component Analysis (PCA) combining Δ LBD incidence (from different growers and pull-outs) and water chemistry in flume and pre-sizer. Each cluster component contains Lot number/ sample date/ LBD incidence difference (Δ LBD).

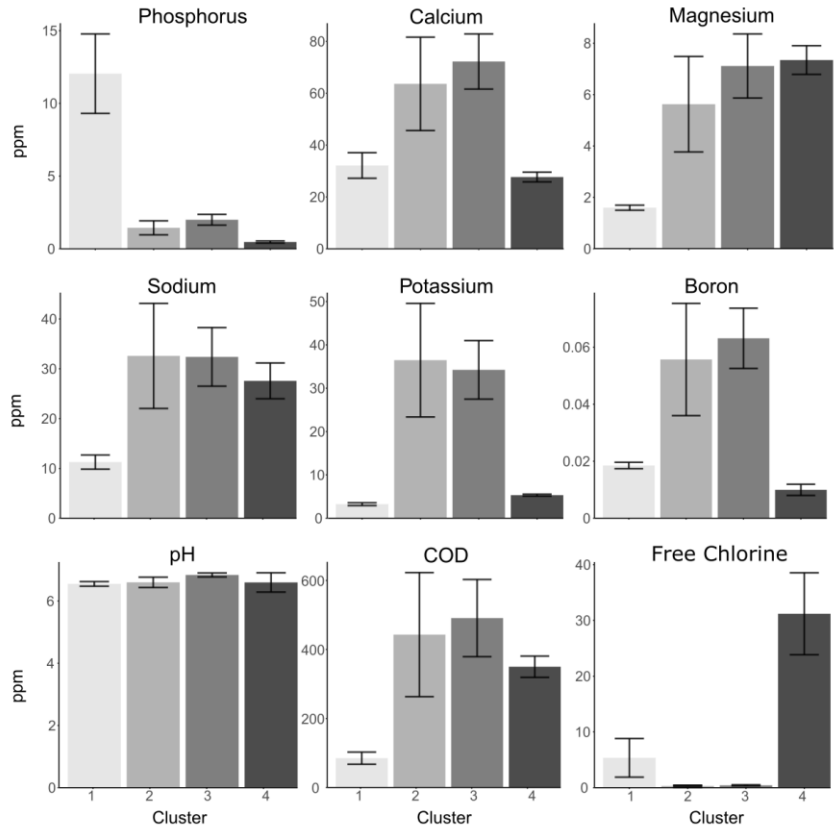

Figure 3. Mean water parameter for each cluster in PCA (Fig. 2). Inside bars indicate standard error within each cluster (n=3).

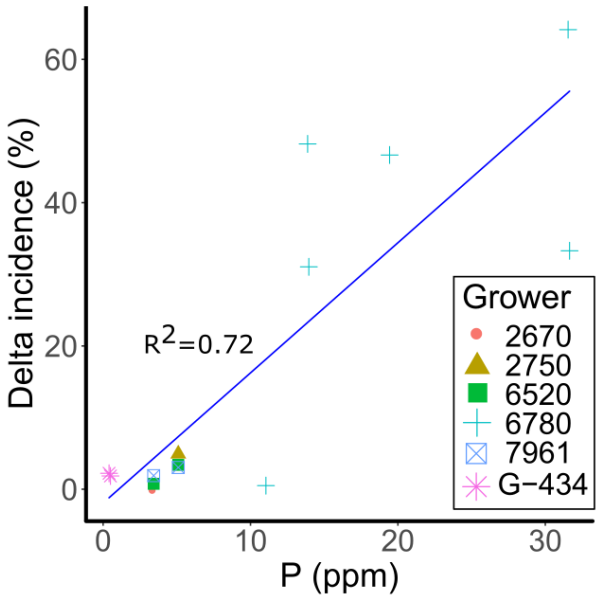

Figure 4. Mean water parameter for each cluster in PCA (Fig. 2). Inside bars indicate standard error (n=3).

Objective 3. Evaluate the effect of chlorine, peroxyacetic acid, chlorine dioxide, and ozone concentrations on LBD development on apples under controlled environment.

Activities

Different sanitizer treatments using simulated water make-up on apple packing lines (Table 4) were used on Gala apples from 3 'susceptible' commercial lots (#7610, #6560, #325). Temperature and pH of each treatment is shown in Table 5. Lenticel breakdown (LBD) incidence (# fruit affected/# total fruit) and severity (mild, moderate and severe, see Obj. 1) were evaluated as follows:

Storage condition→	7 days at 4°C			7 days at 22°C	
Evaluation time→	0h	24h (1d)	96h (4d)	168h (7d)	336h (14d)

Table 4. Treatments and composition of simulated experimental washing conditions (COD).

Treatments	**COD formula**
1) Untreated control	**COD level** = 500 ppm
2) 500 ppm COD water only	**Silt loam soil =** 1.82±0.77 % (w/v)[a]
3) 500 ppm COD + free chlorine 50ppm plus 5% (v/v) phosphoric acid to adjust pH to 6.5	**Unsweetened apple sauce:** 2.42±1.04 % (w/v)
4) 500 ppm COD + PAA 50ppm	

[a] Mean % (w/v) ± standard deviation

Table 5. Temperature and pH of water and pH for each treatment.

Treatment	Temperature (°C)	pH
Control	-	-
Water only	14	6.7
Cl 50 ppm	11	6.5
PAA 50 ppm	16	4.4

A Fisher's exact test was used to analyze the categorical data of the incidence of lenticel breakdown damage based upon the following categorical variables: treatments [Chlorine (Cl) 50 ppm; Peracetic acid (PAA) 50 ppm; Water only, control], storage time (0, 1, 4, 7, 14 days), and lots (6560,7610,0325) A post hoc pairwise comparison was used to compare the levels of each categorical variable when a significant difference was observed. The significance level for all tests was $\alpha = 0.05$. Statistical analysis was performed in R (version 4.0.2) using RStudio (version 1.3.1056) (RStudio, Inc., Boston, MA, USA).

RESULTS

Overall, there were no significant differences ($p>0.05$) in LBD incidence or severity across lots and treatments (Table 6), but there were over storage time within each treatment (Fig. 5).

Table 6. Incidence and severity (Mild, Moderate, Severe) of LBD (%) over 14 days of storage time by lot (#7610, #6560, #325) and treatment (Control, Water only, PAA 500 ppm, Chlorine 50 ppm).

Storage days		0	0	0	1	1	1	4	4	4	7	7	7	14	14	14
Scale		Mild	Mod	Sev	Mild	Mod	Sev	Mild	Mod	Sev	Mild	Mod	Sev	Mild	Mod	Sev
Treatment / Lot																
Control	7610	6.0%	0.0%	0.0%	8.0%	0.0%	0.0%	15.0%	0.0%	0.0%	20.0%	0.0%	0.0%	20.0%	0.0%	0.0%
	6560	2.0%	0.0%	0.0%	4.0%	0.0%	0.0%	5.0%	0.0%	0.0%	5.0%	0.0%	0.0%	8.0%	0.0%	0.0%
	325	3.0%	0.0%	0.0%	3.0%	0.0%	0.0%	12.0%	0.0%	0.0%	15.0%	0.0%	0.0%	15.0%	0.0%	0.0%
	Total	3.7%	0.0%	0.0%	5.0%	0.0%	0.0%	10.7%	0.0%	0.0%	13.3%	0.0%	0.0%	14.3%	0.0%	0.0%
Water only	7610	10.0%	0.0%	0.0%	10.0%	0.0%	0.0%	11.0%	0.0%	0.0%	12.0%	0.0%	0.0%	14.0%	0.0%	0.0%
	6560	5.0%	0.0%	0.0%	7.0%	0.0%	0.0%	9.0%	0.0%	0.0%	14.0%	0.0%	0.0%	16.0%	1.0%	0.0%
	325	4.0%	0.0%	0.0%	6.0%	0.0%	0.0%	11.0%	0.0%	0.0%	20.0%	0.0%	0.0%	24.0%	0.0%	0.0%
	Total	6.3%	0.0%	0.0%	7.7%	0.0%	0.0%	10.3%	0.0%	0.0%	15.3%	0.0%	0.0%	18.0%	0.3%	0.0%
PAA 50 ppm	7610	8.0%	0.0%	0.0%	9.0%	0.0%	0.0%	11.0%	0.0%	0.0%	17.0%	0.0%	0.0%	20.0%	0.0%	0.0%
	6560	4.0%	0.0%	0.0%	7.0%	0.0%	0.0%	10.0%	0.0%	0.0%	9.0%	1.0%	0.0%	15.0%	1.0%	0.0%
	325	5.0%	1.0%	0.0%	5.0%	2.0%	0.0%	11.0%	2.0%	0.0%	13.0%	2.0%	0.0%	15.0%	2.0%	1.0%
	Total	5.7%	0.3%	0.0%	7.0%	0.7%	0.0%	10.7%	0.7%	0.0%	13.0%	1.0%	0.0%	16.7%	1.0%	0.3%
Chlorine 50 ppm	7610	5.0%	0.0%	0.0%	6.0%	0.0%	0.0%	10.0%	0.0%	0.0%	14.0%	0.0%	0.0%	15.0%	0.0%	0.0%
	6560	3.0%	0.0%	0.0%	4.0%	0.0%	0.0%	13.0%	0.0%	0.0%	15.0%	0.0%	0.0%	20.0%	0.0%	0.0%
	325	2.0%	0.0%	0.0%	4.0%	0.0%	0.0%	8.0%	0.0%	0.0%	9.0%	0.0%	0.0%	17.0%	1.0%	0.0%
	Total	3.3%	0.0%	0.0%	4.7%	0.0%	0.0%	10.3%	0.0%	0.0%	12.7%	0.0%	0.0%	17.3%	0.3%	0.0%

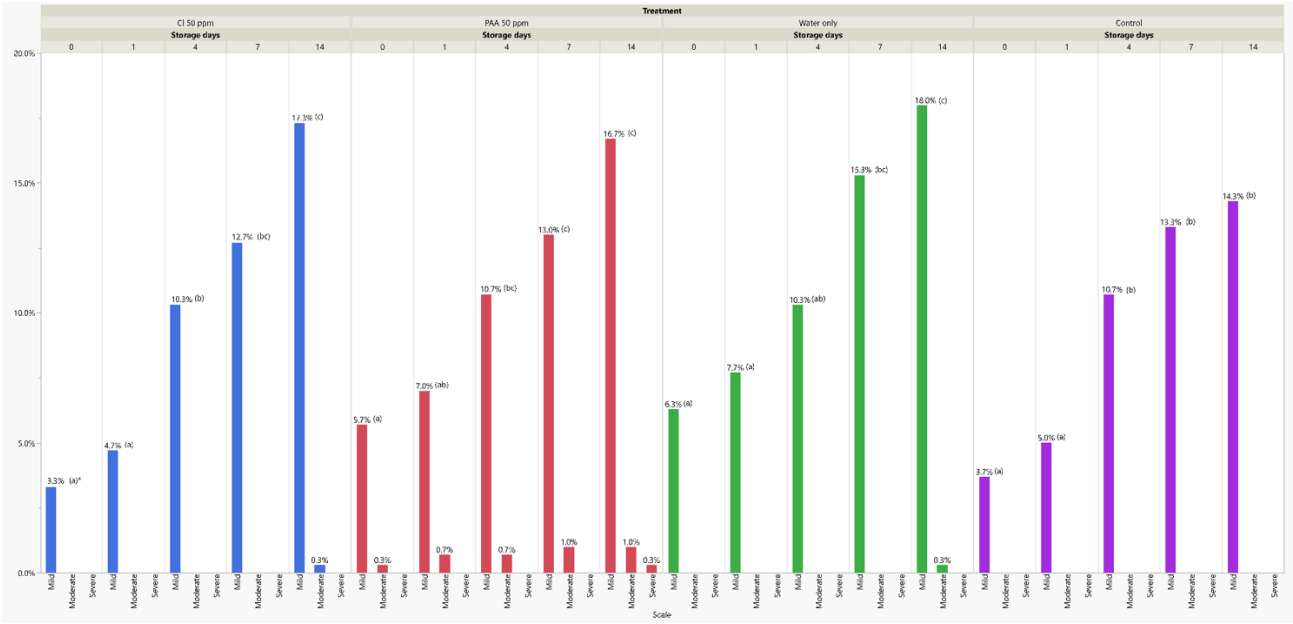

Figure 5. Incidence of LBD (%) over 14 days of storage time by treatment applied [Chlorine (Cl) 50 ppm; Peracetic acid (PAA) 50 ppm; water only, control]
*Value bars within treatments followed by the same lowercase letters in parenthesis are significantly different during storage time.

Executive Summary

Project Title: Effect of dump tank composition on lenticel breakdown disorder

Keywords: LBD, apple quality, Gala, heat stress, postharvest, packing

Abstract:
Lenticel breakdown (LBD) is an important physiological disorder on apples when growing in dry and hot environments. It appears mostly after fruit has been processed (packed and/or presized). Although it is of multi-factorial origin, processing conditions have a major influence on its development. The objective of this work was to assess the effect of water chemistry (carbohydrate, metals and minerals content, pH, ORP, conductivity, temperature, turbidity, COD, free chlorine) during processing on LBD development in commercial fruit lots throughout the storage period. Five different lots of Gala apple were sampled pre and post packaging/processing, along with water samples taken from different sections of the line (presizer, confection line: dump tanks, flumes) at the same time. Fruit from all lots developed LBD symptoms after processing, but only the most susceptible one's pre-processing. Symptoms started to appear 24 h after it and they continued to increase in number of fruit affected and severity until 1 week in air storage plus 7 days at 68°F. Phosphorus accumulation in the water was positively correlated with high incidences of LBD. Calcium, Boron and Potassium may also be playing a role in disorder's expression. High free chlorine was not correlated with LBD development. Neither chlorine (50ppm) or peracetic acid (PAA, 50ppm) solutions applied to susceptible fruit lots increased LBD incidence or severity.