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Lenticel Breakdown Disorder Development on Apples (*Malus domestica* Borkh.): A Survey of Water Chemistry during Packaging and the Effect of Sanitizers in the Processing Water

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Abstract. **Lenticel breakdown (LBD) is a major physiological disorder in apples, particularly those grown in hot and dry environments. It develops primarily after processing (packing and presizing), with processing conditions playing a key role. This study examined the impact of water chemistry (pH, minerals, metals, carbohydrates, oxidation–reduction potential, conductivity, temperature, turbidity, chemical oxygen demand, free chlorine) and sanitizers (chlorine, peracetic acid) on LBD in commercial 'Gala' apple batches during storage. Six batches were sampled pre- and postprocessing, alongside water samples from different processing sections. All batches showed LBD postprocessing, but only highly susceptible ones developed symptoms preprocessing. Symptoms appeared 24 hours after processing and worsened over 1 week during a poststorage holding period at 1 °C plus 7 days at 20 °C, mimicking transit and shelf-life conditions. Phosphorus accumulation in the packing water correlated with a greater LBD incidence, whereas calcium, boron, and potassium may also contribute. Chlorine (50 mg·L^{-1}) and peracetic acid (50 mg·L^{-1}) did not increase LBD severity. Findings confirmed batch susceptibility, likely a result of preharvest factors, highlighting the role of the packaging process in disorder development. Proper water management (replacement, filtration) is critical to minimize LBD when handling susceptible apples. Sanitizers at recommended doses were not linked to LBD formation.**

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Lenticel breakdown (LBD) is a recurrent physiological disorder in apples that appears as sunken (and later brown) pits centered in a lenticel of the fruit's surface (with little or no corking of the underneath cortex tissue), usually 48 to 72 h after being processed and packed (Curry 2003; Curry et al. 2008; Kupferman 2009a). The latter is important for identifying the disorder correctly, apart from others with similar symptoms, such as lenticel blotch pit, lenticel marking, bitter pit, and blister spot, all of which have different underlying causes (Meheriuk et al. 1994). In the late 1990s, LBD became an important quality issue in Washington, USA, and became a research priority in 2000 because of to its economic importance (Curry et al. 2008; Kupferman 2009a), leading to a substantial wealth of scientific information on its origin and how to mitigate it (Hanrahan 2006; Kupferman 2009a, 2009b). Since then, LBD has been reported in other apple-growing areas in the world (Acevedo 2004; Antoniolli 2006; Lotze and Theron 2009). Lately, it has regained importance as a result of increasingly stressful environmental conditions, including extreme temperatures during the growing season in Washington, USA (Thompson et al. 2022), and other apple-producing states in the United States, such as New York and Michigan (Torres CA, personal communication).

'Gala' apples are highly susceptible to LBD, regardless of the sport, but with some differences among them. It can also appear in 'Fuji', 'Braeburn', and other less susceptible cultivars such as 'Granny Smith', 'Red Delicious', and 'Golden Delicious' (Curry et al. 2008). Although it is a multifactorial disorder, where environmental conditions in the orchard, mineral imbalances, and harvest maturity play important roles—translated into susceptibility variation among sites and seasons—processing practices after storage have a major effect on the disorder's development (Curry 2003; Kupferman 2007).

Hot and dry environments (high desiccation potential), especially during the last weeks of fruit growth, increase fruit susceptibility to developing LBD (Curry 2003) because the cuticle is not able to cover (microcracks) hypodermal cells fast enough in the enlarging fruit (Curry et al. 2008), ultimately causing cell desiccation and necrosis (Maguire et al. 1999), and LBD development postharvest (Singh et al. 2016). Preharvest applications of lipophilic coatings to reduce water vapor permeability through the cuticle have been shown to reduce LBD incidence and severity by filling cuticle microcracks and, therefore, protecting the inner cells from desiccation and contamination after harvest (Curry et al. 2008). Given that dry and hot growing environments affect lenticel morphology on the fruit, and thus LBD potential postharvest, climate change events may increase fruit susceptibility in the future.

Advanced maturity at harvest has also been shown to increase fruit susceptibility to LBD postharvest (Curry 2003; Kupferman 2009a). Similarly, the incidence and severity of LBD increase with time in storage, as the fruit ripens (Morales 1995).

In susceptible fruit, dump tank temperature, brushing, and soap/detergent type during packaging have been shown to exacerbate the disorder (Curry 2003). Therefore, the general recommendations to minimize LBD development are to reduce temperature differences between the fruit and packaging waters (especially that of the dump tank), use neutral detergents to clean the fruit, and use soft brushes to avoid abrasiveness, among others (Curry 2001; Kupferman 2007).

Although it has been observed that chemicals and mineral residues in the water used in dump tanks and flumes can trigger LBD

Table 1. Harvest maturity (flesh firmness, starch index) and postharvest treatments of fruit from different 'Gala' apples (information provided by each warehouse).

Warehouse	Batch	Harvest in 2020	Treatments in 2020[i]	Firmness (N; mean ± *SD*)	Starch index (1–8)
1	A	1 Sep	1-MCP + Sch; 3 Sep	86.7 ± 10.2	2.3
1	B	6 Sep	1-MCP + Sch; 2, 3, and 14 Sep	83.6 ± 5.3	3.0
1	C	4 Sep	1-MCP + Sch; 2 and 13 Sep	86.7 ± 7.6	2.3
2	D	2 Sep	1-MCP + Sch; 3 and 14 Sep	84.5 ± 8.9	2.8
2	E	1 Sep	1-MCP + Sch; 3 and 14 Sep	82.3 ± 10.7	2.9
2	F	3 Sep	1-MCP + Sch; 4 and 14 Sep	83.2 ± 6.7	2.8

[i] 1-Methylcyclopropene (MCP; 1 $\mu L \cdot L^{-1}$, SmartFresh™) and Scholar (Sch) Max fogging (1 g/bin; 408.2 kg fruit/bin) were commercially applied.

appearance (Curry 2003; Kupferman 2005), the extent to which these residues in the water cause/exacerbate LBD after processing is still poorly understood, mainly because of the multifactorial nature of this disorder and the different practices carried out by different warehouses. Typical apple-packing processing includes a washing step using recirculated water containing sanitizers such as Cl or peracetic acid (PAA). However, there is little or no information on the effect of commercially available antimicrobial compounds on LBD development. Therefore, our objectives were to correlate the mineral and organic composition of processing water during packaging, and to determine the effect of water sanitizers on LBD development in susceptible fruit.

Materials and Methods

Experiment 1: Effect of water composition during processing over LBD development

Fruit material and LBD evaluation. Different commercial batches (fruit lots from different growers or orchard blocks) of 'Gala' apples grown in central Washington, USA, orchards (Table 1) were sampled from two packing facilities at three different times during the storage season, between 1 and 6 months in controlled atmosphere (CA) (2% O_2, 0.5% CO_2, 0.5 °C) at each facility, and processed either through a presizer (within the first 2–3 weeks of harvest) and later packed (prior shipment) or commit-to-pack (not presized, and packed directly from orchard bins). For each batch, fruit were collected before and after being processed in the commercial line. LBD incidence [(No. of fruit affected/No. of total fruit) × 100], measured as a percentage, and severity [rated from 0–3 points, where 0 point = none, 1 point = mild (1–3 lesions/fruit), 2 points = moderate (≥4 lesions/fruit), and 3 points = severe (50% area affected by lesions)] were then evaluated visually at 0, 24, and 96 h at room temperature (20 °C) immediately after retrieving the sample; at 1 week in cold storage (1 °C); and at 1 week in cold storage plus 7 d at 20 °C, simulating transit and shelf life of retrieving the sample. Fruit maturity for each sample was evaluated at the time of sampling. Three replicates (n = 100 each) per batch were used for fruit quality evaluations.

Table 2. Observed physicochemical attributes for flume water chemistry (N = 104).

Value	pH	ORP (mV)	Conductivity ($\mu S \cdot cm^{-1}$)	Temp (°C)	Turbidity (FAU)	COD ($mg \cdot L^{-1}$)	PAA ($mg \cdot L^{-1}$)	Free Cl ($mg \cdot L^{-1}$)
Mean	5.21	562.99	386.30	20.33	72.57	592.37	62.42	11.46
Min	2.46	194.30	2.41	11.70	0.00	10.00	2.00	0.50
Max	7.46	969.00	1574.00	34.30	250.00	2510.00	150.00	65.00

COD = chemical oxygen demand; FAU = formazin attenuation units; ORP = oxidation–reduction potential; PAA = peracetic acid.

Table 3. Mean lenticel breakdown incidence and severity observed at different evaluation times[i] in different batches of fruit prepacked (or before being processed in the packing line) and already packed in cardboard boxes (postprocessing in the packing line) at the warehouse, after warehouse sampling.

			LBD incidence (%)					LBD severity[ii]				
Batch	Processing date (storage length)	Sample	0 h	24 h	96 h	1 week (cold)	1 week + 7 d	0 h	24 h	96 h	1 week (cold)	1 week + 7 d
B	7 Dec 2020 (3.1 months)	Prepacked	0.0	0.0	0.0	3.0	4.0	0.0	0.0	0.0	0.03	0.04
		Packed	0.0	0.0	0.0	2.0	2.7	0.0	0.0	0.0	0.05	0.06
		Significance	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	11 Dec 2020 (3.2 months)	Prepacked	0.0 b[iii]	0.0 b	0.0 b	0.0 b	0.0 b	0.0	0.0	0.0	0.0	0.0
		Packed	1.3 a	1.3 a	3.0 a	3.0 a	3.0 a	0.03	0.05	0.05	0.06	0.06
		Significance	*	*	**	**	**	ns	ns	ns	ns	ns
C	7 Dec 2020 (3.1 months)	Prepacked	0.0	0.0	0.3	0.7	0.7	0.0	0.0	0.0	0.02	0.02
		Packed	0.0	0.0	0.3	1.3	1.3	0.0	0.0	0.0	0.01	0.01
		Significance	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	11 Dec 2020 (3.3 months)	Prepacked	0.0	0.0	0.0	0.0 b	0.0 b	0.0	0.0	0.0	0.0	0.0
		Packed	0.0	0.0	0.3	2.3 a	3.0 a	0.0	0.0	0.0	0.03	0.03
		Significance	ns	ns	ns	**	**	ns	ns	ns	ns	ns
D	11 Dec 2020 (3.4 months)	Prepacked	0.0	0.7	1.3	2.3	3.3	0.01	0.02 b	0.02 b	0.03 b	0.05 b
		Packed	2.3	2.3	4.0	5.0	7.7	0.03	0.05 a	0.05 a	0.06 a	0.10 a
		Significance	ns	ns	ns	ns	ns	ns	*	*	*	*
E	7 Dec 2020 (3.3 months)	Prepacked	0.0	0.0	0.3	1.3	3.3	0.0	0.0	0.01	0.02	0.03
		Packed	0.0	0.0	0.6	1.7	3.3	0.0	0.0	0.0	0.02	0.04
		Significance	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
F	7 Jan 2021 (4.2 months)	Prepacked	0.0	0.3	1.3	2.0	3.0	0.0	0.0	0.01	0.01	0.03
		Packed	0.0	0.5	0.5	0.8	1.5	0.0	0.01	0.01	0.01	0.02
		Significance	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

[i] Evaluation times were at 0 (sampling) 24, and 96 h; 1 week in cold storage (1 °C), and 1 week in cold storage plus 7 d at 20 °C).

[ii] Severity is rated as follows: 0 point = none; 1 point = mild (1–3 lesions/fruit); 2 points = moderate (≥4 lesions/fruit), 3 points = severe (50% area of the fruit affected by lesions).

[iii] Different letters indicate significant statistical differences between sample means (prepack/packed) at each processing date according to the Kruskal-Wallis nonparametric test.

ns, *, ** Nonsignificant or significant at $P \leq 0.05$ and 0.01, respectively.

LBD = lenticel breakdown.

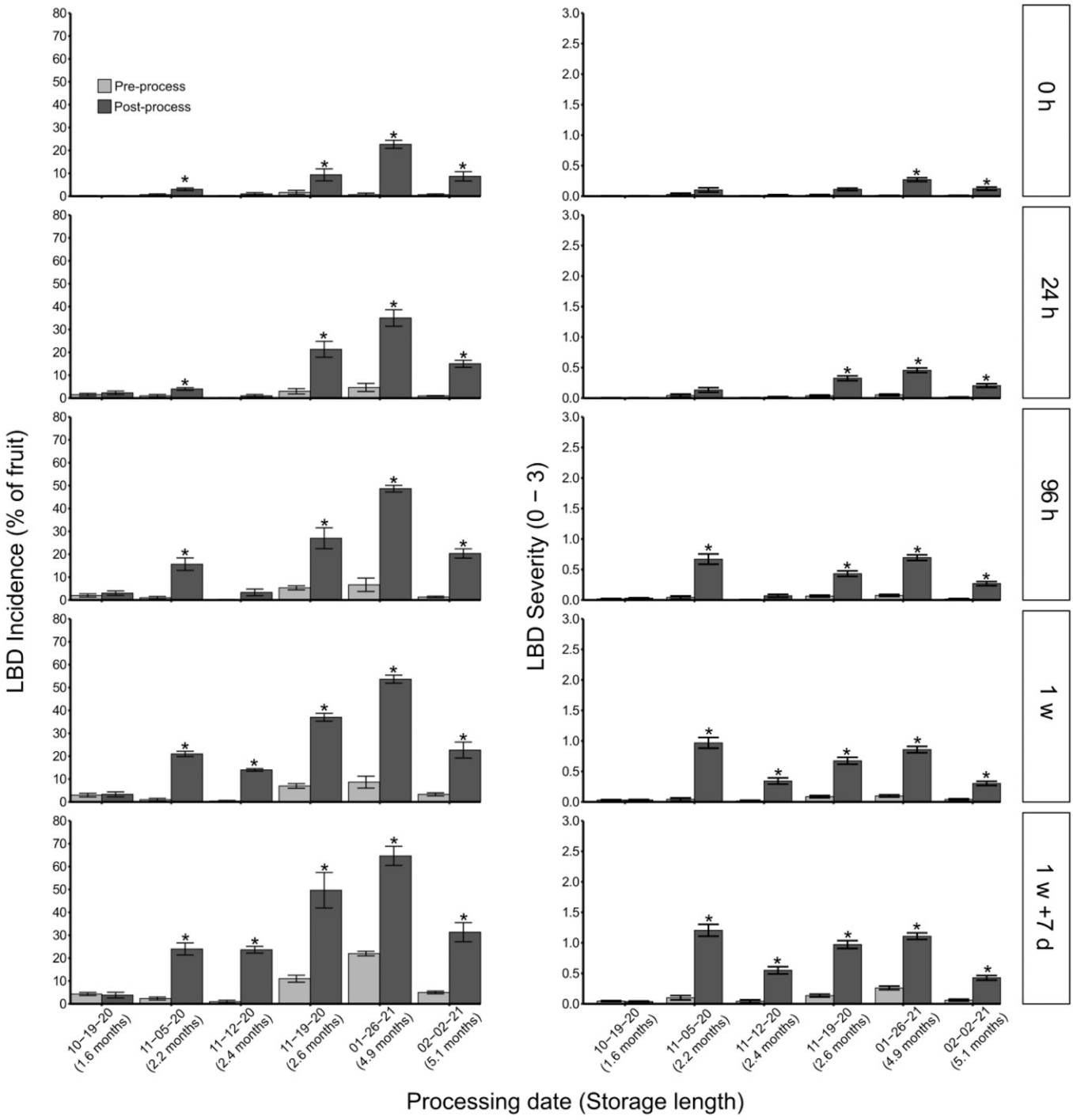

Fig. 1. Lenticel breakdown (LBD) incidence (percentage of fruit affected) (**left**) and severity (0–3 points, where 0 point = none, 1 point = mild (1–3 lesions/fruit), 2 points = moderate (≥ 4 lesions/fruit), 3 points = severe (50% area of the fruit affected by lesions) (**right**) of fruit from batch A pre- (before presizing) and postprocess (after presizing) at each time of evaluation (0, 24, and 96 h; 1 week in cold storage after packaging; and 1 week plus 7 d at 20 °C after packaging to simulate shelf life) during the storage season. Bars represent the mean ± the standard error (n = 3). Asterisks indicate significant statistical differences (Kruskal-Wallis, $P \leq 0.05$) between sample means (preline/postline) at each processing date.

Water composition during processing. The water makeup was determined for all water sources (presizer, flumes) during the processing of each batch of fruit in each of the packing facilities. Water analyses included pH, oxidation–reduction potential (ORP), conductivity, temperature, turbidity, chemical oxygen demand (COD) (Table 2), free Cl, and minerals including Al, Sb, Ba, Be, B, Ca, Li, Mg, P, K, Se, Na, Sr, As, Bi, Cd, Cr, Co, Cu, Fe, Pb, Mn, Hg, Mo, Ni, Ag, Tl, Th, Sn, Ti, U, V, Zn, and Zr content (all measured in milligrams per liter). The ORP, conductivity, pH, and temperature were measured using a portable multiparameter meter (Hach sensION+ Portable Meter MM150, Edition 3; Hach, Loveland, CO, USA). The COD of each sample was measured by taking 2 mL of the sample and dispensing it into either a low- or high-range COD (20–1500 $mg \cdot L^{-1}$ COD) (TNTplus; Hach). The vial was shaken and placed into a dry thermostat digital reactor (Hach DRB200; Hach). After digestion, the COD was determined by placing the vial in a multiparameter portable colorimeter (DR9000; Hach) and calibrated against standards. Turbidity was also recorded using the multiparameter portable colorimeter. Free Cl concentration was quantified using a free Cl titration kit (FAS-DPD; LaMotte Co., Chestertown,

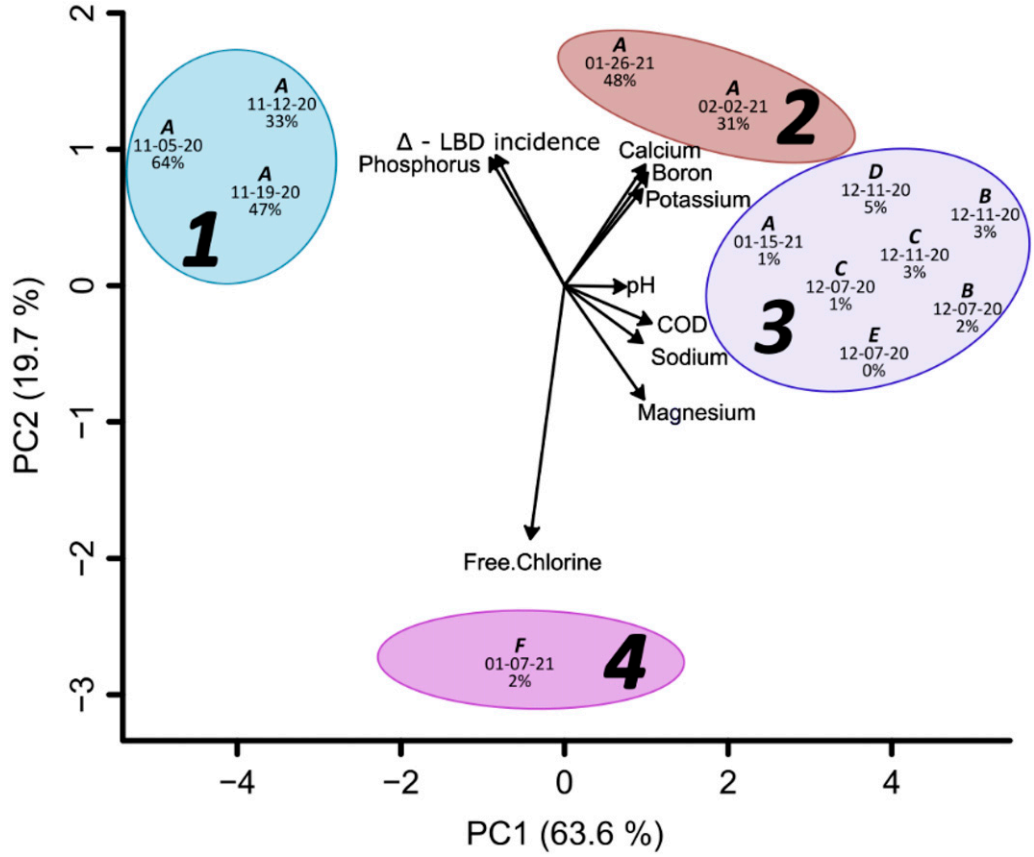

Fig. 2. Principal component (PC) analysis biplot combining Δ lenticel breakdown (LBD) (LBD incidence postprocessing less the incidence preprocessing) during commercial processing in the warehouse, from six batches (*A*–*F*) and sampling points and water chemistry [P, Ca, Mg, B, Na, and K content; chemical oxygen demand (COD), and pH]. The information inside each cluster indicates the batch (*A*–*F*), processing date, and ΔLBD for each sample.

MD, USA). Mineral content was evaluated using inductively coupled plasma mass spectroscopy (ICP-MS), with testing taking place in a third-party testing laboratory following Environmental Protection Agency (EPA) method 3050b for sample preparation and EPA method 6020 for ICP-MS. All ICP-MS samples were frozen and shipped in a frozen state until analysis. All analyses were done in triplicate for each water source. These parameters were later used to obtain a linear regression with LBD incidence after 1 week in cold storage plus 7 d at 20 °C.

Fruit maturity evaluations. Maturity indices included flesh firmness measured with a fruit texture analyzer (GS-20; Guss Manufacturing Ltd. Strand, Cape Town, South Africa), a starch index measured visually using the Cornell Starch Iodine Index chart [1- to 8-point scale (Blanpied and Silsby 1992)], and the soluble solids content measured using a digital refractometer (PR-20; Atago, Bellevue, WA, USA). These were measured in 30 fruit per treatment (n = 10 per replicate).

Experiment 2: Effect of sanitizers on LBD development

LBD induction. To induce LBD development, 'Gala' apples from three susceptible commercial batches were submerged for 1 min in 8 L of simulated water containing either sanitizer or water only. A no-treatment control was included. Fruit were then dried at 20 °C for 1 h and stored for 0, 24, and 96 h; for 1 week in cold storage at 1 °C and 90% relative humidity; or for 1 week in cold storage at 2 °C plus 7 d at 20 °C (14 d total). At each storage time point, 100 apples of each batch were evaluated visually for LBD based on the number of damaged lenticels (mild, 1–5 lenticels; moderate, 5–25 lenticels; and severe, >25 lenticels). Treatments were arranged in a completely randomized experimental design using 100 fruit per batch, treatment, and storage time.

Model washing-water preparation. A simulated washing-water formula, such as those found on apple packing lines (Anderson 2021), was prepared under laboratory conditions. Briefly, washing water at an organic load level of 500 mg·L^{-1} COD was created using distilled water (1 L); sterile, local silt loam soil [1.82% (w/v)]; and unsweetened apple sauce [2.42% (w/v)] (Tree Top, Inc., Selah, WA, USA). After mixing, the solution was filtered through eight layers of grade-90 cheesecloth (Lion Service, Inc., Charlotte, NC, USA) and jumbo-size cotton balls (Target Inc., Minneapolis, MN, USA) to remove any debris and to achieve turbidity readings similar to those recorded from commercial apple-packing flumes. All water was kept at 21 °C and prepared 1 d before experimentation.

Sanitizer treatments. Eight liters of simulated washing water containing either PAA (Shield-Brite PAA 15.0%; Pace International LLC, Wapato, WA, USA) or free Cl (Pac-Chlor 12%; Pace International LLC) at 50 mg·L^{-1} was prepared in the laboratory to mimic the water makeup from the packing facilities. For Cl treatments, the pH of the washing water was adjusted to 6.50 with a 5% (v/v) H_3PO_4 solution (RICCA Chemical Co., Arlington, TX, USA). Sanitizer concentrations were determined using titration test kits for free Cl (LaMotte), and total PAA acid (AquaPhoenix Scientific, Hanover, PA, USA). Temperature and pH levels of simulated water were recorded.

Statistical analysis. Statistical differences among batches were determined using analysis of variance and multiple range tests for mean separation ($P \leq 0.05$). The Kruskal-Wallis test was used for data not normally distributed (e.g., LBD incidence). Multivariate analysis was used to evaluate the effect of different processing conditions, fruit maturity, and postharvest treatments/protocols.

For the sanitizer experiment, the Fisher's exact test was used to analyze the categorical data of the incidence of LBD damage based on the following categorical variables: treatments (50 mg·L^{-1} Cl, 50 mg·L^{-1} PAA, and a water-only control), storage time (0, 1, 4, 7, and 14 d), and batches. 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 v. 4.0.2 (R Foundation for Statistical Computing, Vienna, Austria)

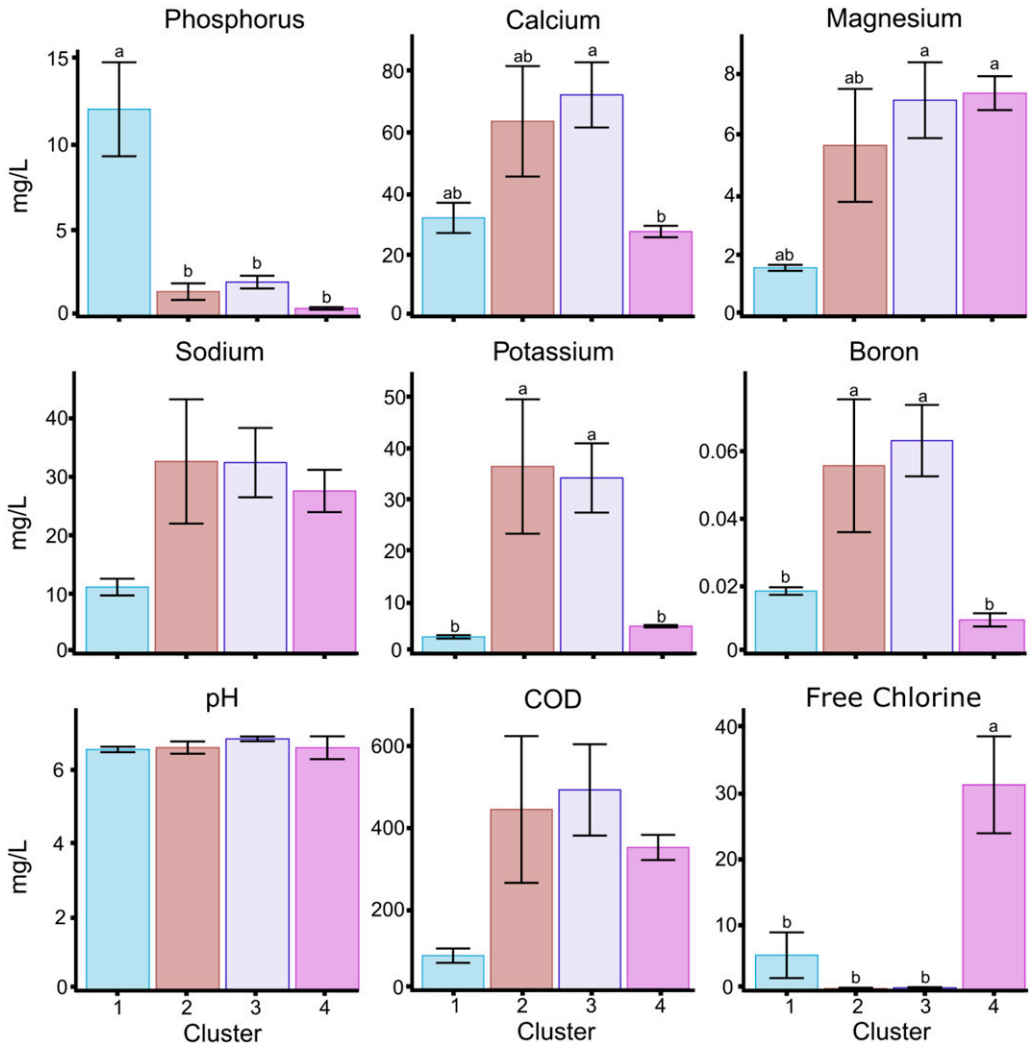

Fig. 3. Packaging water composition [P, Ca, Mg, Na, K, and B content; pH; chemical oxygen demand (COD); and free chlorine level] of samples grouped in each cluster (1–4) identified in the principal component analysis shown in Fig. 2. Bars indicate the mean ± standard error (n = 3). Analysis of variance ($P \leq 0.05$) letters within each water component indicate significant differences between clusters (Tukey's honestly significant difference, $P \leq 0.05$).

using RStudio v. 1.3.1056 (RStudio, Inc., Boston, MA, USA).

Results

Experiment 1: Effect of water composition during processing over LBD development. Fruit from all six batches developed LBD after being processed either through a presizer or the packing line (Table 3). In two of them packed after 3 months of storage, there was only LBD development postprocessing (Table 3), indicating low-susceptibility batches.

In all batches and time points during the storage season, LBD incidence and severity increased ($P \leq 0.05$) until 1 week in cold storage (simulated transit) plus 7 d at 20 °C (simulated shelf life) (Table 3).

In batch A, packed six times during the storage seasons, LBD development increased over time pre- and postprocessing ($P \leq 0.05$) (Fig. 1), without a significant interaction between both factors.

Maturity indices at harvest (Table 1) cannot explain differences in fruit susceptibility to developing LBD (Table 3). Maturity indices (flesh firmness, soluble solids content, starch index) at the time of the line processing did not correlate with the overall incidence of LBD ($P \leq 0.05$).

Preharvest factors, including weather, dehydration pressure, nutritional levels, tree vigor, and other factors affecting LBD development, were not considered in this study.

To study the correlation of water analysis components, LBD incidence differences pre- and postprocessing was used (ΔLBD). This term removes the natural susceptibility of the fruit to develop this disorder without processing. In the case of water chemistry, correlations were made with the highest value of each parameter found during the batch process.

In one of the warehouses, the highest ORP, conductivity, temperature, turbidity, free Cl, and mineral levels were observed at the dump tank or first flume in the processing line. In the second warehouse, this was not the case, and mineral content varied among flumes 1, 2, and 3 (data not shown).

In the principal component analysis combining all batches and sampling dates, ΔLBD, and water chemistry, four clusters were identified and separated by different water components (Fig. 2). Cluster 1 grouped the most susceptible batches (highest ΔLBD at 48%) packed on different dates after 3 months of storage and was associated positively with the P content in the processing water (Fig. 3). Furthermore, the level of P in the processing water related linearly with ΔLBD when all batches were combined (Fig. 4). Cluster 1 also grouped those batches that were processed with waters containing low free Cl, Mg, and Na levels; and low COD and pH (Fig. 3). Cluster 2, which had the same batch as cluster 1 but was processed on different dates, grouped fruit with a ΔLBD of 39% on average, and was associated positively with Ca, B, and K levels in the processing water. This association was also true for cluster 3, although this grouped fruit with a low ΔLBD (~2%) (Fig. 3). Cluster 4 had only one batch with a low ΔLBD as well (~2%), but this batch was also associated with the highest free Cl level (Figs. 2 and 3).

The correlation among variables was obtained from the loading plot (Fig. 2, black arrows). ΔLBD was correlated positively only

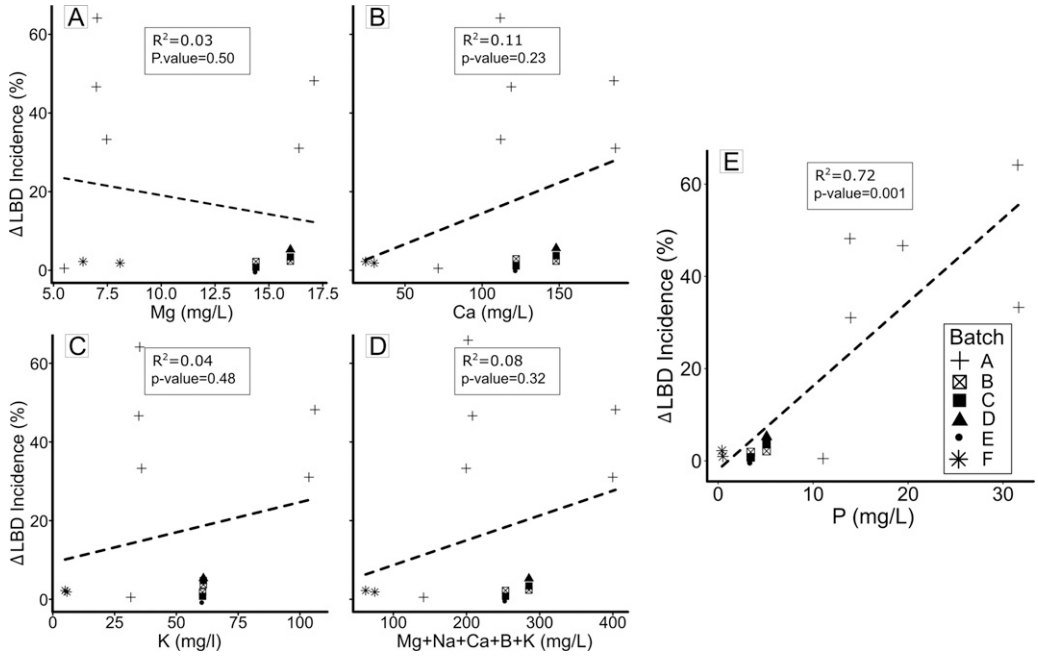

Fig. 4. Linear regressions between Δ lenticel breakdown (LBD) (LBD incidence postprocessing less the incidence preprocessing) from different batches and sampling points and the highest Mg (**A**), Ca (**B**), K (**C**), Mg+Na+Ca+B+K (**D**), and P (**E**) content in processing water of the warehouse. The linear regression coefficient and *P* value are shown as insets in each panel for each water mineral.

with P and correlated negatively with Mg, Na, COD, and pH. There was no correlation between ΔLBD and Ca, B, K, and free Cl.

Experiment 2: Effect of sanitizers on LBD development. The effect of two common commercially available sanitizers (Cl and PAA) was evaluated on three susceptible batches to assess their effect on the incidence and severity of LBD. Figure 5 illustrates the percentage of LBD incidence and severity for each treatment. No significant differences were found across the three batches evaluated ($P \leq 0.05$); consequently, the data were represented by treatment and storage time for clearer interpretation. Overall, no significant differences ($P \leq 0.05$) in LBD incidence or severity were observed among treatments, suggesting that sanitizer application did not exacerbate LBD incidence or severity. Regardless of the treatment, the incidence of LBD increased with a longer storage time ($P \leq 0.05$). The severity of LBD was mostly classified as mild across all batches and treatments. All treatments showed an ∼15% incidence of LBD after 1 week in cold storage plus 7 d at 20 °C (Fig. 5).

Discussion

LBD is a multifactorial disorder in which environmental conditions in the orchard, mineral imbalances, and harvest maturity play important roles, which translates into susceptibility variation among sites and seasons (Curry 2003; Kupferman 2009a; Tessmer et al. 2016; Turketti et al. 2012). In our study, we observed different susceptibilities to developing LBD among commercial batches (Table 3, Fig. 2). These fruit batches came from different growing environments but had similar maturity indices at harvest and were treated with 1-methylcyclopropene within 1 week after harvest (Table 1). Therefore, differences may be attributed to growing conditions in the orchard (temperature, relative humidity, crop protectants), potentially leading to differences in wax morphology and chemical composition of the cuticle, as suggested by Curry (2005) and Veraverbeke et al. (2001), more than harvest maturity, which is measured by flesh firmness or a starch index (Curry 2003). These factors were not addressed in our study.

In agreement with previous work (Curry 2001; Kupferman 2007), processing practices, presizing, and/or packaging had a major effect on LBD disorder development in all batches (Table 3). Furthermore, fruit that had been presized and then packed during the storage season (i.e., processed twice) had higher levels of LBD than when processed only once (Fig. 1).

As reported by Curry (2001), Kupferman (2007), and Tessmer et al. (2016), LBD incidence increased over time in storage (Table 3). Although there were differences in LBD incidence among batches (Table 3), it cannot be explained by differences in firmness or starch degradation at harvest or at the time of the packaging, the latter of which is in agreement with Tessmer et al. (2016).

There is little information regarding crop protectants and LBD development postharvest except for Ca treatments. Singh et al. (2016, 2021) found that $CaCl_2$ applied by submersion postharvest can lead to an increased number of open lenticels postharvest and, therefore, potentially greater LBD development, but this is not always the case (Friedman et al. 2023). Potassium chloride applications did not promote open lenticels (Singh et al. 2016). Preharvest Ca treatments have also been shown to increase LBD incidence postharvest, most prominently in low-humidity growing sites (Friedman et al. 2023). In the study by Friedman et al. (2023), they also found a correlation between LBD and nighttime/daytime temperature before harvest. On the other hand, Kupferman (2007), in preliminary studies, showed that $FeSO_4$ applied in a high concentration solution (500 mg·L^{-1}) postharvest caused LBD in 'Gala' apples. In our study, the mineral content in the water, especially the initial dump tank during processing, correlated positively with LBD development on the fruit, particularly P, which was in extremely high concentrations (Fig. 3). All these minerals came from residues in the fruit from the orchards (or bins), where nutrients, fungicides, and other crop protectants are applied regularly. Therefore, the more mineral residues accumulate in the water, the faster they reach critical levels that damage susceptible fruit, leaving few available control practices, including replacing the water or filtering it.

In Washington, USA, a typical apple-packing process includes a washing step that uses recirculated water immersion systems in dump tanks and flumes. Water generally contains sanitizers such as Cl or PAA to maintain water quality and reduce the potential for cross-contamination of apples (Ruiz-Llacsahuanga et al. 2021). Studies evaluating the impact of these antimicrobials on the development of postharvest disorders in apples, specifically LBD, are scarce. Our investigation suggested that neither Cl nor PAA at 50 mg·L^{-1} was associated with an increased incidence or severity of LBD. Conversely, another study (Lallu 2010) assessed the effect of Cl in water dump tanks on the development of browning symptoms on 'Royal Gala' apple, and the researcher reported that the disorder may be associated

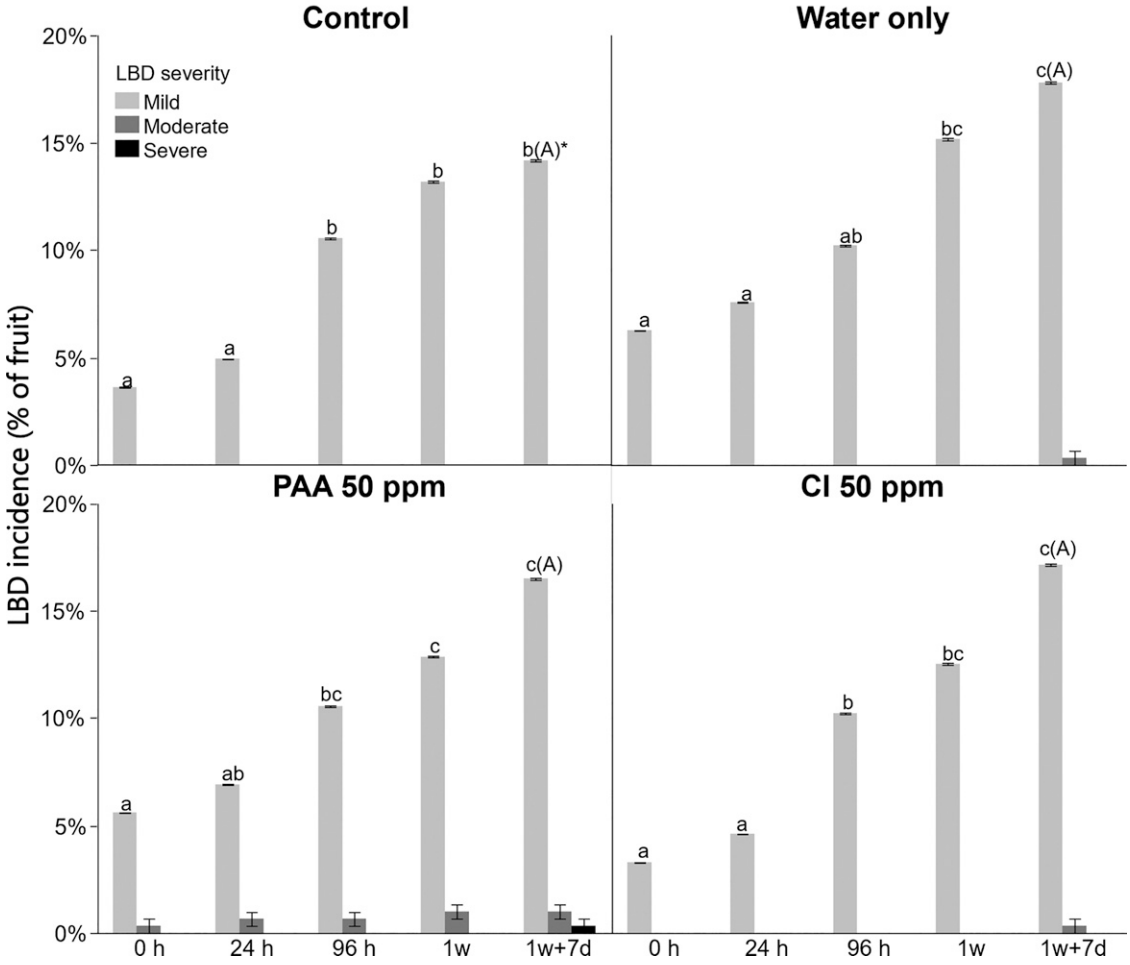

Fig. 5. Incidence of lenticel breakdown (LBD; percentage of fruit affected) over 14 d of storage time [0, 24, and 96 h; 1 week in cold storage (1 °C) after packaging; and 1 week in cold storage (1 °C) after packaging plus 7 d at 20 °C to simulate shelf life] by treatment applied [control, water only, 50 mg·L^{-1} peracetic acid (PAA), and 50 mg·L^{-1} Cl]. *Bars within treatments that are not followed by the same lowercase letters are significantly different during storage time. Bars at 1 w +7 d RA that are not followed by the same uppercase letter are significantly different across treatments ($P \leq 0.05$).

with preharvest factors, although the immersion time in chlorinated water highly influenced the expression of browning over time. Sehirli et al. (2020) evaluated the impact of Cl and PAA at similar concentrations ranging from 50 to 150 mg·L^{-1} in hydrocooling water used for packing fresh cherries and found that none of these sanitizers was related to the development of pitting or stem browning.

Conclusion

LBD in commercial batches of 'Gala' apples showed high variability, most probably resulting from the preharvest growing conditions of each one. In all of them, there was an increase in the LBD disorder over the storage time and after the packaging process, which played a key role in its development. Phosphorus accumulation in the processing water was associated positively with a high LBD incidence, although Ca, B, and K may also be playing roles in this disorder. Therefore, water management (e.g., replacement, filtering of different water sections in the packing line or presizer) during processing is critical when running susceptible batches of fruit. The use of sanitizers such as chlorine or PAA at a 50-mg·L^{-1} commercial dose was not associated with LBD. This is helpful information for the industry, because the use of Cl or PAA is a control measure used during postharvest washing to prevent cross-contamination with foodborne pathogens.

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