FINAL PROJECT REPORT **YEAR**: 3 of 3 years

Project Title: Improving shipping quality of cherry by pre-harvest Ca and NaCl sprays

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Total Project Funding: **Year 1:** $38,620 **Year 2:** $39,551 **Year 3:** $40,505

Budget 1: Yan Wang
Organization Name: OSU-MCAREC **Contract Administrator:** Russ Karow
Telephone: 541-737-4066 **Email address:** Russell.Karow@oregonstate.edu

Item	2014	2015	2016
Salaries	15,104[1]	15,557[7]	16,024[7]
Benefits	2,688[2]	2,769[7]	2,852[7]
Wages	6,810[3]	7,014[7]	7,224[7]
Benefits	1,566[4]	1,613[7]	1,661[7]
Equipment			
Supplies	8,000[5]	8,000	8,000
Travel	500[6]	500	500
Miscellaneous			
Total	34,668	35,453	36,261

Footnotes:
[1]Postdoctoral Research Associate: 800hr at $18.88/hr.
[2]OPE: $3.36/hr.
[3]Wages: 500hr for a Biological Science Tech. at $13.62/hr.
[4]OPE: 23% of the wage.
[5]Supplies: fruit, Ca analysis, gases (helium, nitrogen, hydrogen, standard gases), gas tank rental, chemicals, and MCAREC cold room and land use fees.
[6]Travel to grower's fields
[7]3% increase

Budget 2: Todd Einhorn
Organization Name: OSU-MCAREC **Contract Administrator:** Russ Karow
Telephone: 541-737-4066 **Email address:** Russell.Karow@oregonstate.edu

Item	2014	2015	2016
Salaries			
Benefits			
Wages	3,510	3,645	3,780
Benefits	292	303	314
Equipment			
Supplies	150	150	150
Travel			
Miscellaneous			
Total	3,952	4,098	4,244

Footnotes:
[1]Wages: 270 hours $13/hour temporary labor for 2014, $13.50 for 2015, $14 for 2016
[2]OPE: 8.31% of the wage.

OBJECTIVES

1. Study the effect of preharvest calcium (Ca) and salt (NaCl) treatments on shipping quality of PNW cherry cultivars.
2. Determine the response of fruit growth, fruit size, yield, and return bloom to Ca/NaCl sprays.
3. Develop a commercial Ca spray protocol to improve shipping quality of PNW cherry cultivars.

SIGNIFICANT FINDINGS

<u>Fruit tissue Ca/N concentrations and shipping quality</u>

1. Shipping quality of cherries (‘Lapins’, ‘Sweetheart’ and ‘Skeena’) sampled from different orchards was found to be correlated with fruit tissue Ca content (400-900ppm, dw), but not N content (0.9-1.1%).

<u>Ca spray</u>

2. The optimum Ca spray rate for increasing fruit tissue Ca content was determined to be 0.1-0.15% Ca^{2+}. Higher Ca concentrations (i.e., 0.2%) might cause leaf burning or reduce fruit size. Lower Ca^{2+} concentrations (i.e., 0.05% for 6 or 9 times) didn’t increase fruit tissue Ca content at harvest.
3. The optimum Ca spray timing and frequency were 6 times at weekly interval from pit-hardening to harvest. Ca spray prior to pit-hardening was not found to increase fruit tissue Ca content at harvest.
4. Sprayed at 0.1-0.15% Ca^{2+} for 6 times, all the Ca sources [$CaCl_2$, $Ca(NO_3)_2$, Ca citrate, $Ca(OH)_2$+organic acid (OA), amino acid (AA) chelated Ca, Ca carbonate, and Ca carbonate silicon] increased fruit tissue Ca content with little difference among the Ca sources.
5. Ca spray at 0.1-0.15% Ca^{2+} for 6 times on leaves only didn’t alter fruit tissue Ca content.
6. Sprayed at 0.1-0.15% Ca^{2+} for 6 times, $CaCl_2$ and Ca citrate but not other Ca sources might reduce fruit growth rate and fruit size.
7. Ca spray at 0.1-0.15% Ca^{2+} for 6 times tended to increase fruit SSC and TA slightly without affecting maturation (coloration) at harvest.
8. Ca spray at 0.1-0.15% Ca^{2+} for 6 times increased fruit firmness at harvest, reduced pitting, splitting, stem browning, fruit internal browning and decay after storage/shipping.
9. For improving cherry shipping quality (not for fruit tissue Ca content), OA or AA chelated Ca formulations tended to perform better than other Ca sources; $Ca(NO_3)_2$ is better than $CaCl_2$.
10. None of the Ca treatments affected return bloom (buds per spur or flowers per bud) or fruit set of 2 and 3-year-old spur populations.

<u>NaCl spray</u>

11. NaCl spray at 30, 60, and 120 ppm for 6 times at weekly interval from pit-hardening to harvest increased fruit tissue Na^+ content with a dose response, but didn’t affect Cl^-.
12. NaCl spray at 60 and 120 ppm increased FF, SSC, and TA in ‘Lapins’ but not in ‘Regina’ at harvest and during storage.
13. NaCl spray at 120ppm but not 60ppm reduced fruit size in both ‘Lapins’ and ‘Regina’. NaCl spray enhanced fruit color by increasing anthocyanin accumulation in both cultivars.
14. NaCl spray at 30, 60, and 120 ppm improved stem quality by enhancing cuticle and wax development on stem.
15. There was no synergistic effect between Ca and NaCl pre-harvest treatments on cherry quality and shipping quality.
16. NaCl spray may not be justified as a commercial application practice in cherry production.

METHODS

1. The relationship of fruit tissue Ca and N contents with shipping quality. Fruit of different cultivars was randomly sampled from different orchards. Ca and N contents were determined and fruit quality were evaluated at harvest and after 3 and 5 weeks of storage.

2. Ca and salt treatments.

In 2014, treatments were designed to focus on optimizing the application rate, timing, and frequency. In 2015, treatments were designed to focus on optimizing application timing and Ca sources. In 2016, treatments were designed to optimize Ca sources and confirm the previous findings.

Ca Treatments (2014)	***% Ca***	***Application timing***
$CaCl_2$	0.07	9x, beginning 1wafb
$CaCl_2$	0.07	2x, pit hardening + 1wbh
$CaCl_2$	0.15	2x, pit hardening + 1wbh
$CaCl_2$	0.07	2x, 1 and 2 wbh
$CaCl_2$	0.15	2x, 1 and 2 wbh
$CaCl_2$	0.05	6x, beginning pit hardening
$CaCl_2$	0.10	6x, beginning pit hardening
$CaCl_2$	0.15	6x, beginning pit hardening
$CaCl_2$	0.20	6x, beginning pit hardening
$Ca(NO_3)_2$	0.10	6x, beginning pit hardening
$Ca(NO_3)_2$	0.15	6x, beginning pit hardening
Ca citrate (“6% Calcium”)	0.07 (upper label rate)	6x, beginning pit hardening
Ca(OH)2 + OA (“Cal-8”)	0.20 (within label rate)	6x, beginning pit hardening
AA chelated Ca (Metalosate®)	0.05 (upper label rate)	6x, beginning pit hardening
Ca Treatments (2015)	***% Ca***	***Application timing***
$Ca(NO_3)_2$	0.10	9x, beginning 1wafb
$Ca(NO_3)_2$	0.15	9x, beginning 1wafb
$CaCl_2$	0.10	6x, beginning pit hardening
$CaCl_2$	0.15	6x, beginning pit hardening
$Ca(NO_3)_2$	0.10	6x, beginning pit hardening
$Ca(NO_3)_2$	0.15	6x, beginning pit hardening
Ca citrate (“6% Calcium”)	0.10	6x, beginning pit hardening
Ca citrate (“6% Calcium”)	0.15	6x, beginning pit hardening
Ca(OH)2 + OA (“Cal-8”)	0.10	6x, beginning pit hardening
Ca(OH)2 + OA (“Cal-8”)	0.15	6x, beginning pit hardening
AA chelated Ca (Metalosate®)	0.10	6x, beginning pit hardening
AA chelated Ca (Metalosate®)	0.15	6x, beginning pit hardening
Ca Treatments (2016)	***% Ca***	***Application timing***
$CaCl_2$	0.15	6x, beginning pit hardening
$Ca(NO_3)_2$	0.15	6x, beginning pit hardening
Ca citrate (“6% Calcium”)	0.15	6x, beginning pit hardening
Microcal	0.15	6x, beginning pit hardening
Mainstay	0.15	6x, beginning pit hardening
$Ca(NO_3)_2$ on leaves only	0.15	6x, beginning pit hardening
NaCl treatments 0		6x, beginning pit hardening
30ppm		6x, beginning pit hardening
60ppm		6x, beginning pit hardening
120ppm		6x, beginning pit hardening

Given the large number of treatments evaluated, for clarity of presentation data will only be shown from selected treatments.

Ca solutions with a non-ionic surfactant at 0.1% were sprayed to whole tree canopies using a CO_2 pressurized hand gun sprayer to achieve uniform, complete coverage (i.e., sprayed to drip). Experimental units (trees) were arranged in a completely randomized design with 4 single-tree replications per treatment. The Ca sources, application rate, application frequency, application timing were tested and optimized on different cultivars. NaCl at 0, 30, 60, and 120ppm was applied every week after pit-hardening until commercial harvest (total of 6 applications).

3. Nutrition and quality evaluations. Fruit tissue Ca, Na, Cl, N contents were measured by ICP-AES (Ca, Na), Lachat Quikchem autoanalyzer (Cl), and Kjeldahl (N) methods, respectively. Fruit quality at harvest and shipping quality after 2, 4, and 6 weeks of cold storage were evaluated.

4. Horticultural evaluations. Fruit growth rate of 15 fruit per rep were tagged prior to treatment application and measured weekly using a digital caliper. Return bloom and fruit set were evaluated for two spur populations: Two-year-old spurs (representing spurs that were non-fruiting in 2014, 2015); and, three-year-old spurs (representing spurs that yielded fruit in 2014, 2015).

RESULTS

1. Fruit tissue Ca & N concentrations with shipping quality

Fruit with varied tissue Ca content (300-800ppm dw) from different orchards had different pitting susceptibility and fruit quality after storage/shipping for Lapins, Sweetheart, and Skeena. A trend exits that the higher Ca content, the higher fruit firmness (FF) and better flavor and less pitting after 3-5 weeks storage/shipping. Fruit tissue N content was between 0.9 – 1.1% and was not correlated with fruit quality at harvest and after 3-5 weeks storage/shipping.

2. Ca spray

<u>a. The optimum application rate</u>

Applied 6 times at weekly interval from pit-hardening to harvest, $CaCl_2$ or $Ca(NO_3)_2$ at 0.1-0.15% Ca^{2+} increased fruit tissue Ca content significantly ($p < 0.05$) from 436ppm (control) to 615-655ppm at the time of harvest (Fig. 1). Ca at 0.05% didn't increase fruit tissue Ca content. Ca at 0.2% had no additional benefit on increasing fruit tissue Ca content, but reduced fruit size and caused leaf burning. The trend was similar between $CaCl_2$ and $Ca(NO_3)_2$.

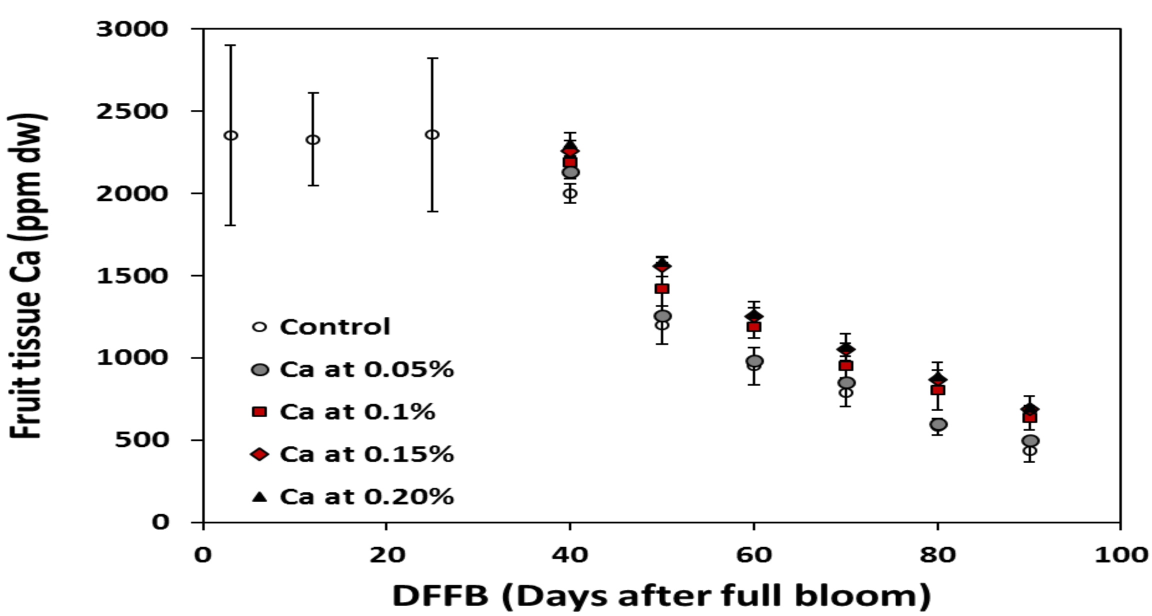


Fig. 1. Effect of Ca application rate on fruit tissue Ca content of 'Lapins' sweet cherry.

b. The optimum application timing and frequency

Compared to 6 times, spray frequency of Ca at 0.1% for 9 times at weekly interval did not improve cherry fruit Ca uptake significantly ($p < 0.05$) (Fig. 2A&B). Ca at 0.1% sprayed twice (pit-hardening + 1-week before harvest or 2-week + 1-week before harvest) did not increase fruit tissue Ca content at harvest compared to control (Fig. 2C&D).

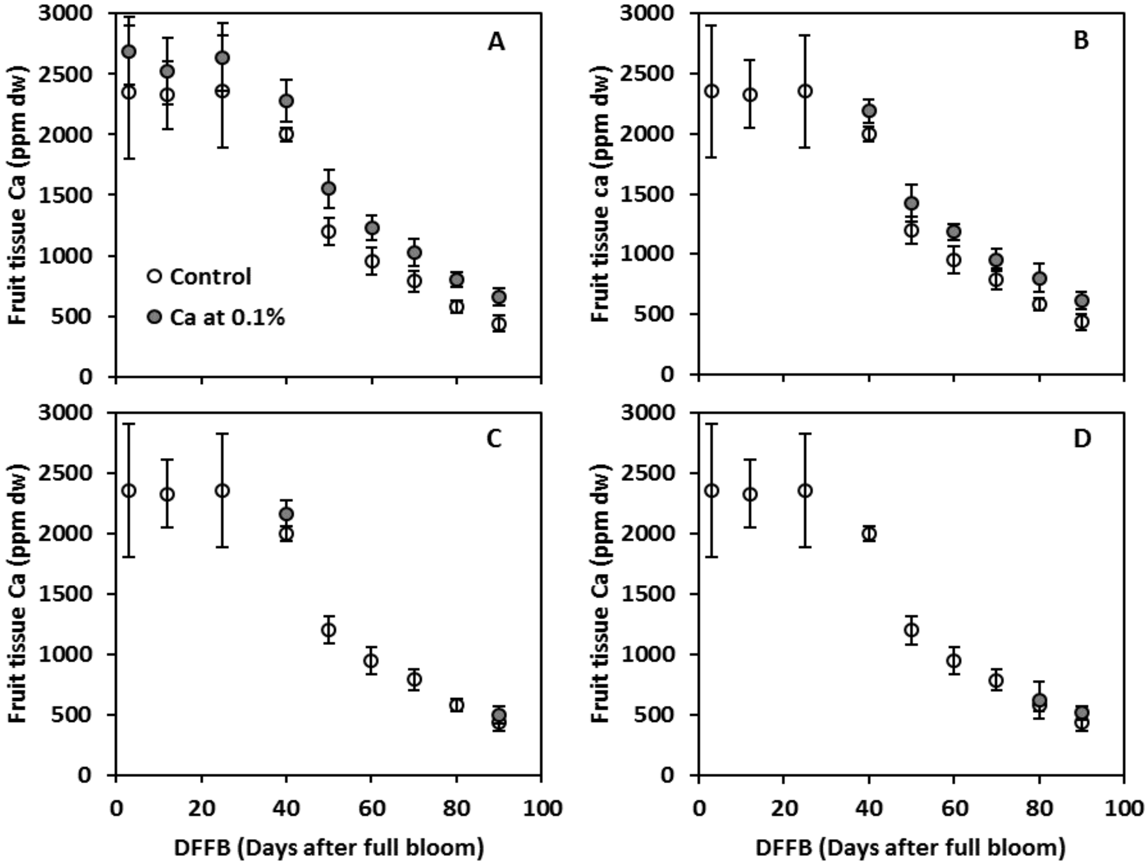
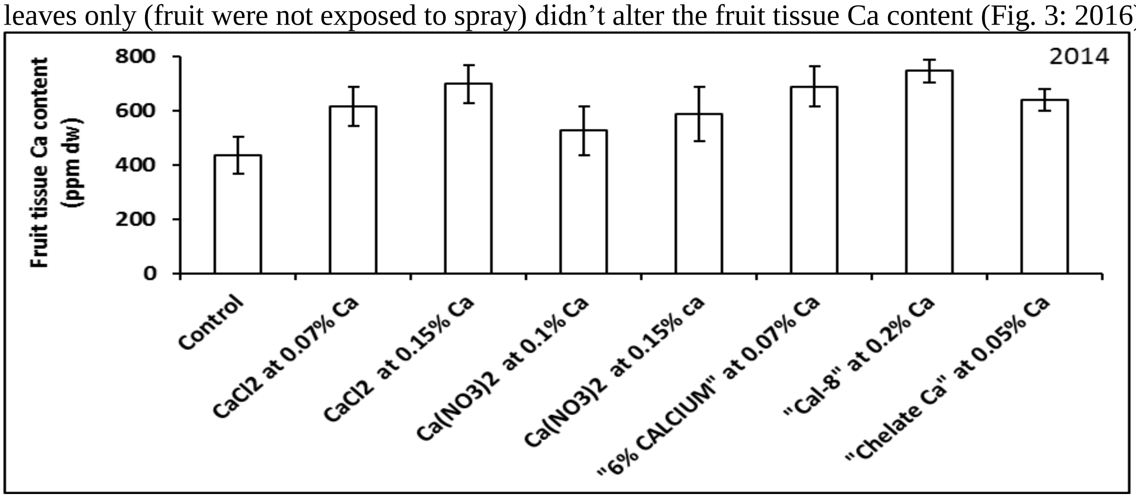


Fig. 2. Effect of frequency and timing of Ca spray on fruit tissue Ca content in 'Lapins' cherry.

c. Ca sources on fruit tissue Ca content

All the Ca sources tested at rates of 0.1-0.15% Ca^{2+} for 6 times at weekly interval from pit-hardening to harvest increased fruit tissue Ca content at similar efficacy (Fig. 3). The Ca spray on leaves only (fruit were not exposed to spray) didn't alter the fruit tissue Ca content (Fig. 3: 2016).



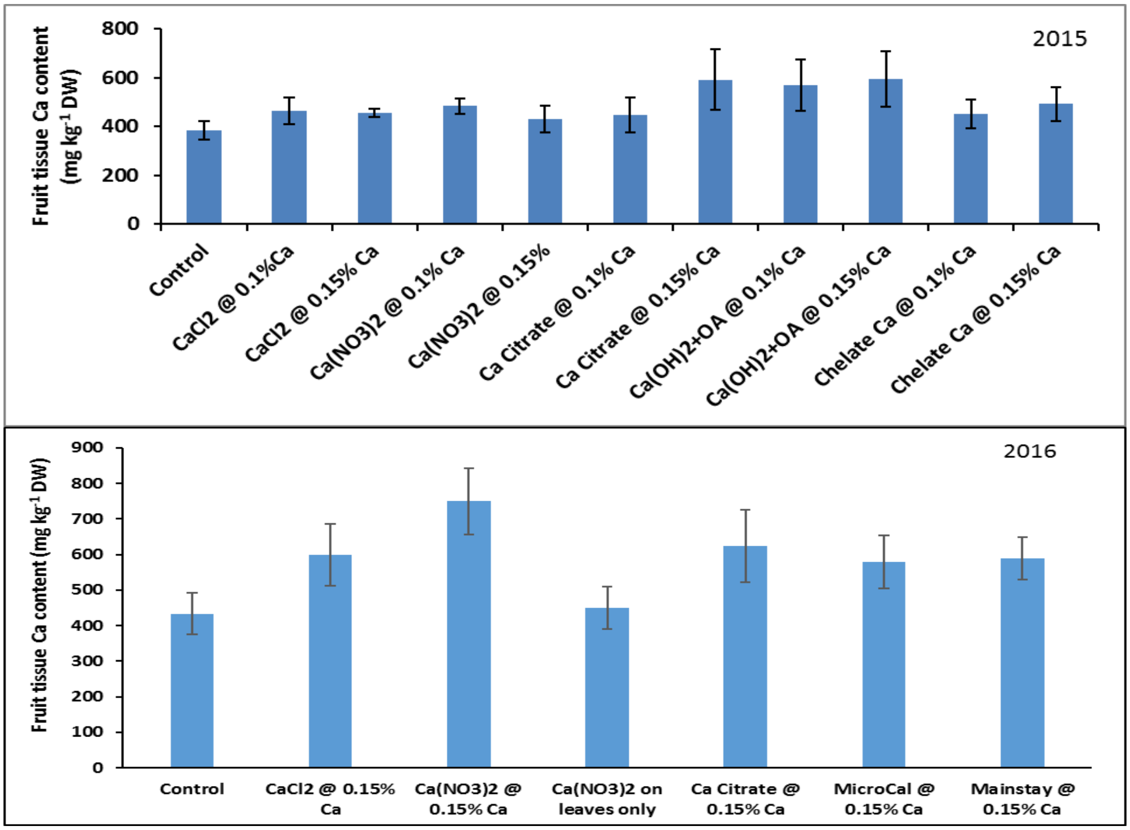


Fig. 3. Effect of Ca sources on fruit tissue Ca content in 'Lapins' at the time of harvest.

d. Effect of Ca spray on fruit quality at harvest

All the Ca sources at 0.1-0.15% Ca for 6x applications did not affect fruit maturity based on fruit color (data not shown). All Ca sprays increased FF ($p < 0.05$) compared to control (Fig. 4). Fruit growth rate and fruit size were unaffected by the Ca treatments at $p < 0.05$. The fact that fruit growth was adversely impacted by a few Ca treatments ($CaCl_2$ and Ca citrate) in 2014 but not in 2015 and 2016 might be attributed to the relatively light crop load in 2015 and 2016. Ca spray tended to increase SSC (Fig. 4) and TA slightly.

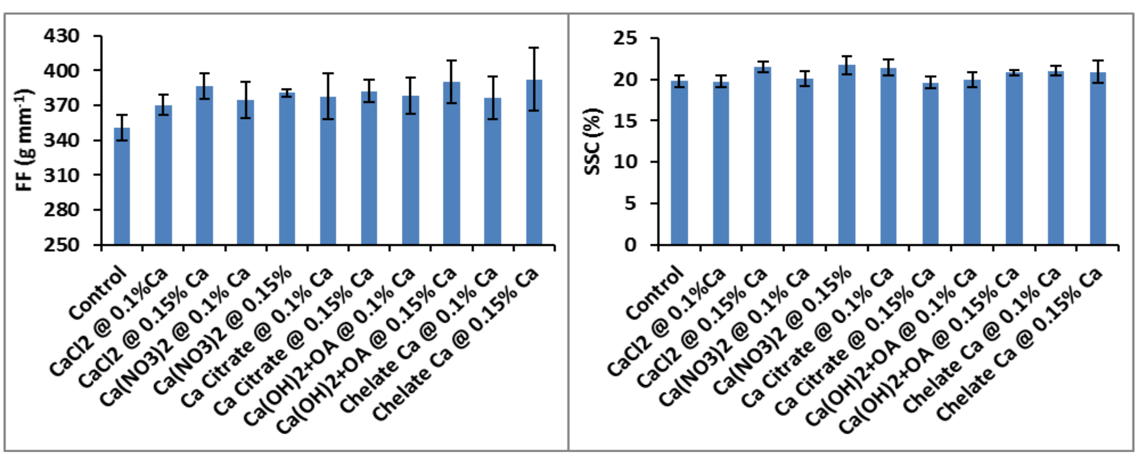


Fig. 4. Effect of Ca spray on fruit firmness (FF) and soluble solid content (SSC) of 'Lapins' at the time of harvest.

e. Effect of Ca spray on shipping quality of sweet cherries after 3 weeks cold storage

For 'Lapins', all the Ca sources at 0.1% Ca^{2+} for 6x applications reduced pitting, decay, and stem browning incidences and retarded fruit skin darkening during 3 weeks storage (Table 1). 'Lapins' fruit treated with the Ca spays tended to have higher FF, SSC, and TA after storage. The Ca sprays reduced splitting, decay, and stem browning in 'Skeena' after storage (Table 1).

Table 1. Effect of Ca sprays at 0.1% Ca^{2+} for 6x applications on shipping quality of 'Lapins' and 'Skeena' after 3 weeks storage at 32°F. Different letters indicate significant differences between treatments according to Fisher's protected LSD test at $p < 0.05$.

	Natural pitting (%)	Splitting (%)	Decay (%)	Pedicel browning (%)	Fruit skin darkening (L*)	Fruit firmness (g mm^{-1})	SSC (%)	TA (%)
				Lapins				
Control	15.8a	0	5.2a	33.3a	30.5b	388b	20.3b	0.68b
$CaCl_2$	8.5b	0	1.3b	23.1b	31.5a	406a	21.5ab	0.71b
$Ca(NO_3)_2$	9.1b	0	2.1b	19.8b	30.9a	411a	21.3ab	0.73b
Ca citrate	8.3b	0	1.8b	21.5b	31.6a	409a	21.8ab	0.76ab
$Ca(OH)_2$+OA	6.6b	0	1.6b	18.6b	31.2a	416a	22.3a	0.78a
AA chelate Ca	7.5b	0	2.2b	18.9b	30.9a	413a	21.5ab	0.79a
				Skeena				
Control	5.8a	6.3a	4.8a	10.0a	30.2a	422a	22.3a	0.78a
$Ca(NO_3)_2$	5.5a	3.2b	1.3b	6.6b	31.0a	436a	22.7a	0.80a

In 2016, fruit internal browning and sensory flavor were evaluated after 6 weeks at 32°F. Result indicated that a higher fruit tissue Ca content helped to reduce internal browning and maintain flavor after a simulated ocean shipping (Fig. 5).

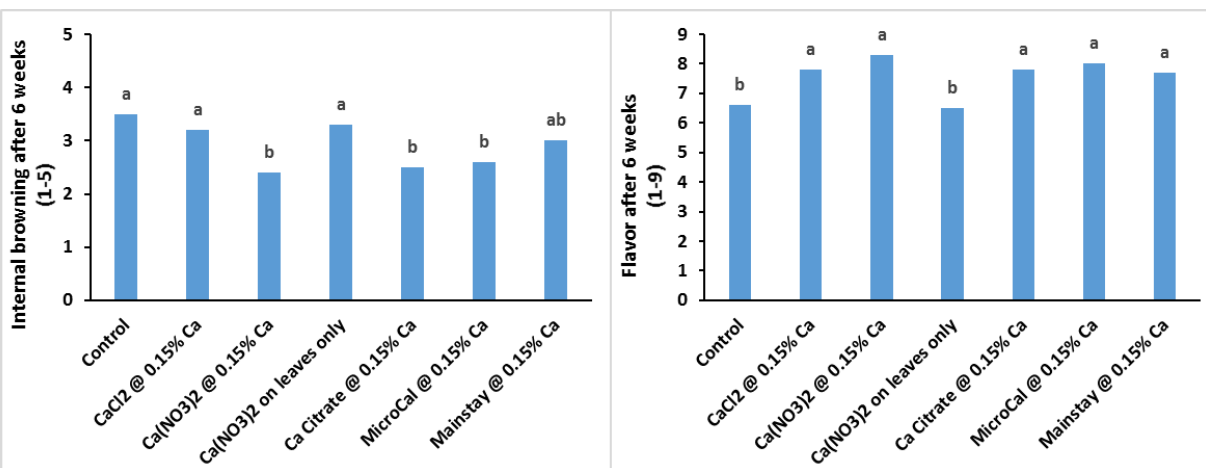


Fig. 5. Effect of Ca spray on internal browning and flavor of 'Lapins' after 6 weeks at 32°F.

f. Effect of Ca spray on horticultural performance of Lapins trees

In 2014, Lapins fruit growth was only affected by $CaCl_2$ and Ca citrate sources when applied 6 to 9 times (Fig. 6). Interestingly, $Ca(NO_3)_2$ applied at equivalent concentrations and frequency to $CaCl_2$ did not reduce fruit growth, likely due to the negative effects of Cl on cell processes. In 2015 and 2016, fruit growth was not affected ($p < 0.05$) by the Ca sprays (data not shown).

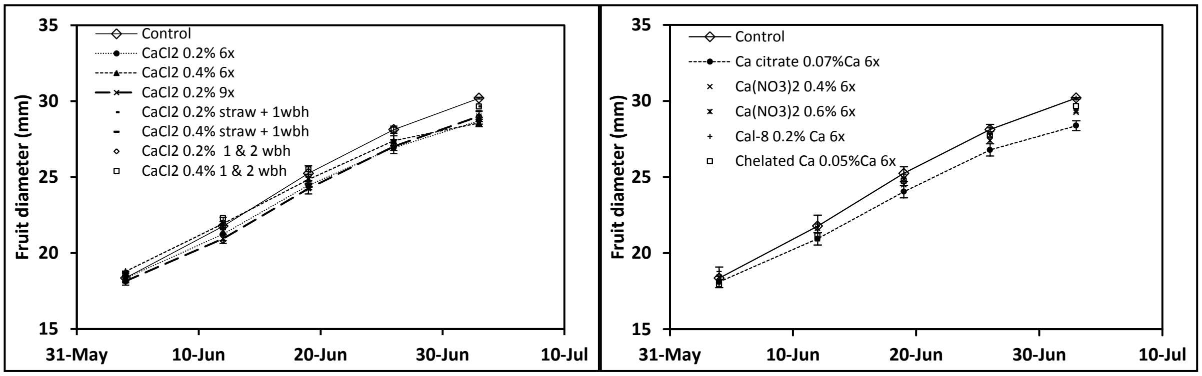


Figure 6. Fruit growth of 'Lapins' sweet cherry as affected by Ca source, concentration and application frequency. All data are means of 3 replicates (n=15). Given the large number of treatments, the data were split between 2 graphs for clarity of presentation; control fruit are shown in each graph for comparative purposes. SE bars and lines are only provided for controls and those treatments that significantly differed from controls.

Return bloom was not affected by 2014 Ca sprays when 2 and 3-year-old spurs were evaluated (Table 2). Average number of flowers per bud and buds per spur was 3, reflecting the non-productive characteristics of Mazzard rootstock. Fruit set was generally low for Lapins; however, the site sustained fairly high flower mortality following the 2014 November freeze event (3°F).

Table 2. Return bloom of 'Lapins' sweet cherry affected by Ca sprays. Different letters indicate significant differences between treatments according to Fisher's protected LSD test at $p < 0.05$.

Treatment	Return Bloom			
	Average no. buds/spur		Average no. flowers/bud	
	2-yr-old spurs	3-yr-old spurs	2-yr-old spurs	3-yr-old spurs
control	3.1	3.6	3.1	2.8 de
CaCl2 0.1% 6 times	3.0	2.8	3.1	2.9 de
CaCl2 0.15% 6 times	3.3	3.4	3.1	3.1 abcd
Ca(NO3)2 0.1% 6 times	2.9	2.9	2.9	2.8 e
Ca(NO3)2 0.15% 6 times	3.2	3.0	3.0	2.8 e
Ca citrate 0.1% Ca 6 times	3.2	3.1	3.2	2.9 bcde
Ca citrate at 0.15% Ca 6 times	3.1	3.4	3.2	3.2 ab
Cal-8 at 0.15% Ca 6 times	3.0	3.1	3.1	3.2 a
Cal-8 at 0.1% Ca 6 times	3.0	3.3	3.1	2.9 de
Chelate Ca at 0.1% Ca 6 times	2.9	2.9	3.0	2.8 e
Chelate Ca at 0.15% Ca 6 times	3.0	3.2	3.0	2.9 de
Ca(NO3)2 at 0.1% 9 times	3.1	2.8	3.0	2.9 cde
Ca(NO3)2 at 0.15% 9 times	3.2	3.6	3.3	3.2 abc
significance	*n.s.*	*n.s.*	*n.s.*	*0.003*

3. NaCl spray (6 times at weekly interval from pit hardening to harvest)

a. Effect of NaCl spray on fruit tissue Na^+ and Cl^- contents

NaCl spray increased fruit tissue Na^+ content with a dose response, but did not affect fruit tissue Cl^- content in 'Lapins' and 'Regina' (Fig. 7).

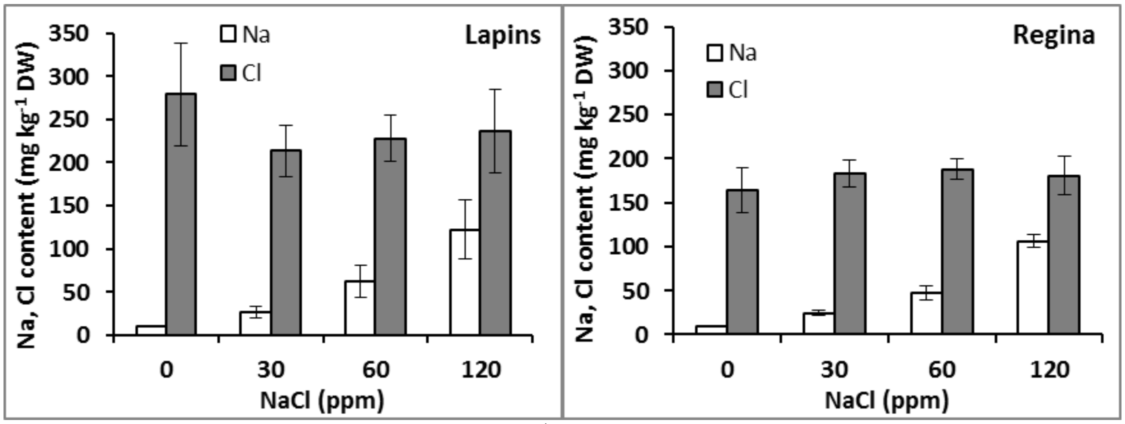


Fig. 7. Effect of NaCl spray on fruit tissue Na^+ and Cl^- contents in 'Lapins' and 'Regina'.

b. Effect of NaCl spray on fruit quality at harvest and after storage/shipping

NaCl sprays at 30 and 60 ppm did not affect fruit size, but a higher rate at 120ppm reduced fruit size in 'Lapins' and 'Regina' (Fig. 8). NaCl sprays at all the application rates enhanced fruit color by increasing anthocyanin accumulation in fruit of both cultivars. The NaCl sprays did not affect fruit total antioxidant capacity (TAC).

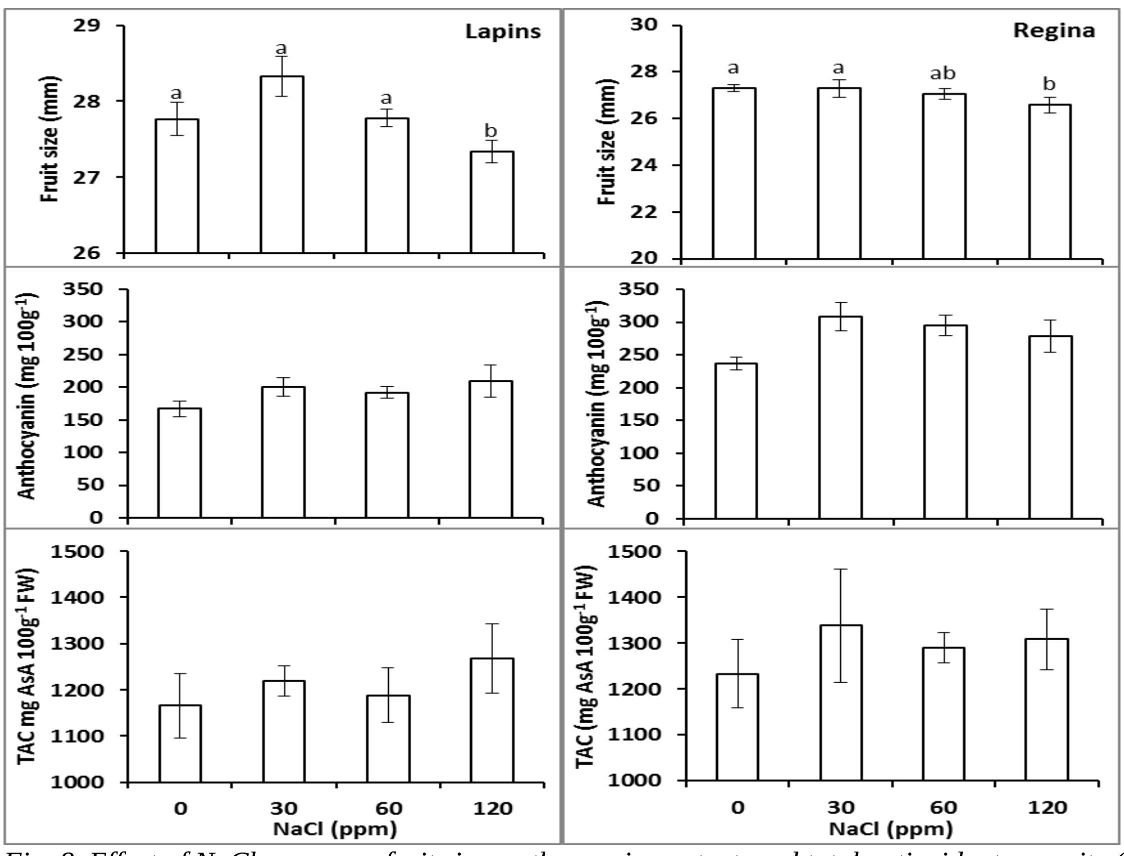


Fig. 8. Effect of NaCl sprays on fruit size, anthocyanin content, and total antioxidant capacity (TAC) of 'Lapins' and 'Regina'.

NaCl sprays at 60 and 120 ppm increased FF, SSC, and TA at harvest and during 3 weeks storage in 'Lapins', but not in 'Regina' (Fig. 9)

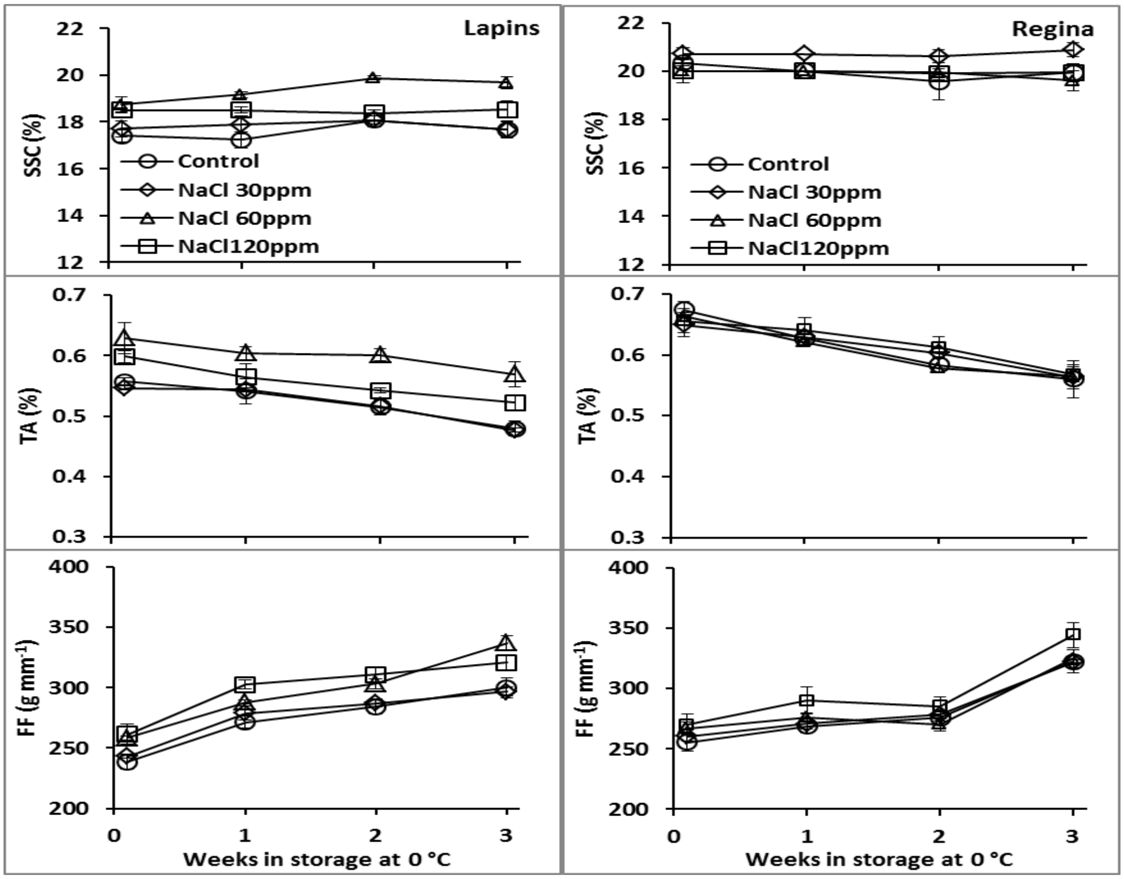


Fig. 9. Effect of NaCl spray on soluble solid content (SSC), titratable acidity (TA), and fruit firmness (FF) of 'Lapins' and 'Regina' at harvest and during 3 weeks storage at 32°F.

c. Effect of NaCl spray on stem quality

NaCl sprays at 30, 60, and 120 ppm improved stem quality by increasing green stem incidence in both 'Lapins' and 'Regina' after 3 weeks storage (Fig. 10). The NaCl sprays maintained higher moisture content in stems of both cultivars after storage. The natural cuticle wax content in NaCl treated stems was higher with a dose response than the control fruit (data not shown).

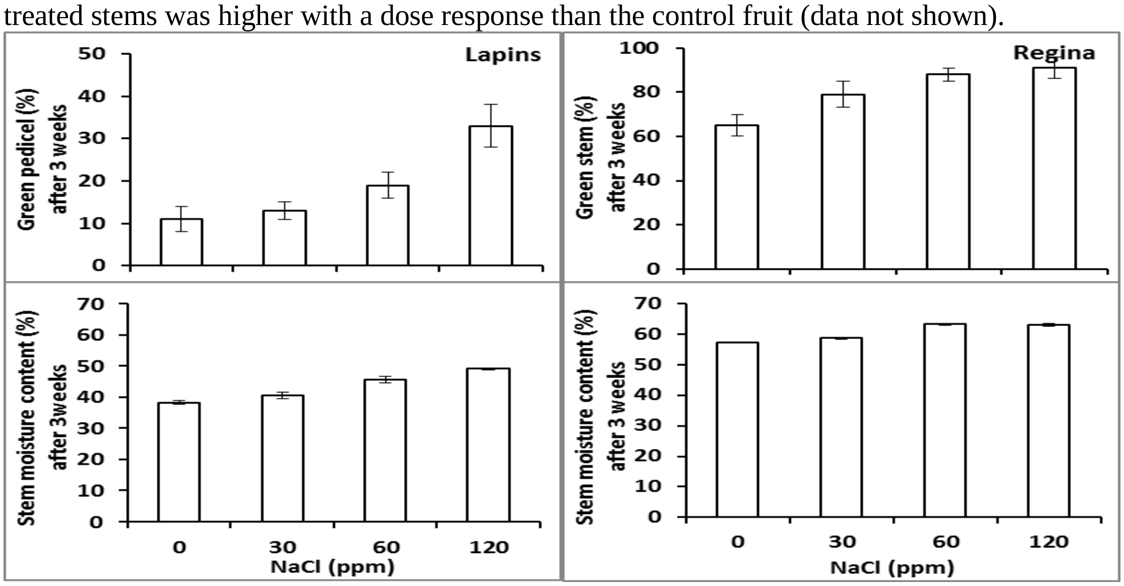


Fig. 10. Effect of NaCl spray on stem quality of 'Lapins' and 'Regina' after 3 weeks storage at 32°F.

EXCUTIVE SUMMARY

Project title: Improving shipping quality of cherry by pre-harvest Ca and NaCl sprays

In this study, fruit tissue Ca content is found to be positively correlated with shipping quality of three PNW cultivars surveyed from 5-9 orchards depending on cultivars. This study indicated that preharvest Ca spray at appropriate rate, timing and frequency is an efficient way to increase cherry fruit tissue Ca content and therefore improves shipping quality of the PNW cultivars. The optimum Ca spray rate is determined to be 0.1-0.15% Ca^{2+}. Higher Ca rates may cause leaf burning or reduce fruit size. Spray with lower Ca^{2+} concentrations doesn't increase fruit tissue Ca content efficiently. The optimum Ca spray timing and frequency for increasing fruit tissue Ca content are 6 times at weekly interval from pit-hardening to harvest. Ca sprayings before the stage of pit-hardening were not found to increase fruit tissue Ca content. Ca spray at 0.1-0.15% Ca^{2+} for 6 times increases fruit firmness at harvest, reduces pitting, splitting, stem browning, fruit internal browning and decay after storage/shipping. At these recommended application rates and frequency, $CaCl_2$ and Ca citrate, but not other formulations, may affect fruit growth rate and fruit size. These Ca treatments don't affect return bloom. When Ca spray at 0.1-0.15% Ca^{2+} for 6 times, organic acid chelated or amino acid chelated Ca formulations are better than the other Ca sources; $Ca(NO_3)_2$ is better than $CaCl_2$ for improving cherry shipping quality. Ca sprayed on leaves doesn't remove to fruit.

NaCl spray at 60 ppm for 6 times at weekly interval from pit-hardening to harvest improves pedicel quality after storage/shipping. A synergistic effect between Ca and NaCl was not found on improving fruit quality at harvest and shipping quality of the PNW cultivars. Therefore, NaCl spray may not be justified as a commercial practice in cherry production.