Project Title: Nutrient management for high quality sweet cherries

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Budget 1

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Item	**2021**	**2022**	**2023**
Salaries			
Benefits			
Wages[1]	9,600	9,984	10,384
Benefits	928	966	1,004
Equipment			
Supplies[2]	3,888	3,888	3,888
Travel	300	300	300
Miscellaneous			
Plot Fees			
Total	14,716	15,138	15,576

Footnotes: [1] Wages for two temporary support at 15 USD/hour for Sallato's and Torre's lab for 310 hours each (9.4% benefits), plus 600 hours of technician at Sallato's lab at 15 USD/hour and 68.3% benefit. [2] Supplies include laboratory supplies and nutrient samples at 18 USD/sample.

OBJECTIVES

The goal of this project is to improve nutrient management strategies from an understanding of the nutritional composition of good and poor-quality fruit. We proposed to undertake a prospective analysis of orchard growing conditions and fruit nutrient levels and their relationship with key quality parameters: size, firmness, and storability. This research approach permits an in-depth analysis of fruit nutritional content and fruit quality, identifies predictors, determines nutrient extraction, and begins to develop fruit-specific nutritional management strategies for sweet cherry.

1) Identify adequate nutrient conditions for fruit quality in sweet cherry.

2) Determine nutrient demand of different sweet cherry varieties.

3) Identify key conditions leading to better fruit quality and storability in sweet cherry.

4) Develop outreach and educational materials and workshops.

SIGNIFICANT FINDINGS

- Differences in year explained 12% and 15% of fruit firmness and size variability, respectively. In 2022, fruit firmness was 16% higher.
- Variety differences explained only 5% of firmness and size variability, when compared across years, while the interaction of year and cultivar, explained 20% of firmness variability, and 23% of size variability.
- Firmness and size were highly variable within samples. (e.g., ranging between 89 and 480 $g \cdot mm^{-1}$ in Skeena). This level of variability was also observed with fruit size. Addressing fruit quality variability within orchards should be a key goal for Washington growers.
- Very soft fruit (firmness < 200 $g \cdot mm^{-1}$) had consistently lower N and S concentration. However, above this level there was no strong relationship between fruit quality and nutrients ($r < 0.60$) despite the large number of samples and wide range of quality conditions.
- Macronutrients were always higher in the small fruit, suggesting a dilution factor due to other components associated with bigger fruit (sugars, acids, water).
- There is a lack of relationship between fruit quality parameters and nutrient concentrations that we attribute to the high levels of nutrients found in all samples, being within or above the critical values reported for sweet cherry in the literature.
- Nutrient extraction (lbs. per ton of fruit) was determined for Skeena, Coral Champagne, and Chelan. Given the consistency of the results across sites, years and cultivars, these values are likely representative of most sweet cherry cultivars grown in Washington.
- Postharvest differences were found associated to the cultivar, year and site. For example, stem retention was twice as high in Chelan compared to Coral Champagne and Skeena, but also there was a strong influence of the year.
- Some postharvest defects correlated strongly with nutrient levels; however, these correlations varied among cultivars, with Chelan and Coral Champagne having more correlations compared to Skeena, which had none.

METHODS

This project takes an observational approach to better understanding the relationships between cherry fruit quality/storability, and fruit nutrient content. There are no treatments imposed, instead, we collected fruit from four commercial warehouses around the state and worked with the natural variability in quality that exists.

The relationship between fruit quality and storability was analyzed for Chelan, Coral Champagne from three commercial orchards and five commercial orchards of Skeena. For each cultivar and orchard, we obtained four replicate bulk fruit samples of at least 5 lbs of the largest and smallest fruit size from the packing house (typically 12-row and 9-row+), in order to have sufficient fruit for storage and nutrient testing from each size category. Each replicated sample from each size category was divided in half (ca. 2.5 lbs). One set of samples were sent to Torre's laboratory at TFREC for storage evaluation test, and the other half were taken to Whiting's laboratory for harvest analysis at IAREC. In Whiting's laboratory, fruit were analyzed individually for weight, size (mm) and firmness (Firmtech II). Further, for each sample unit (ca. 100 fruit each), the 10^{th} and 90^{th} percentile ranking of firmness testing were selected for nutritional analysis (minimum 15 fruit per category) (Figure 1). To determine fruit nutrient content, each fruit sample were separated into pulp, stems and pits to determine fresh and dry weight ratios. Dried tissue samples were homogenized and sent for chemical analysis of nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), cupper (Cu), zinc (Zn) and boron (B). To ensure representative and consistent nutrient analyses, samples were sent to Soil Test laboratory (Moses Lake) for total nutrient. Soil Test laboratory is a certified laboratory by the Soil Science Society of America and the North American Proficiency Test Program (NAPT) for plant program assessment (visit https://www.naptprogram.org/about/participants?ssoContinue=1). The laboratory incorporates blind certified sample to monitor nutrient accuracy by utilizing certified material from NAPT program.

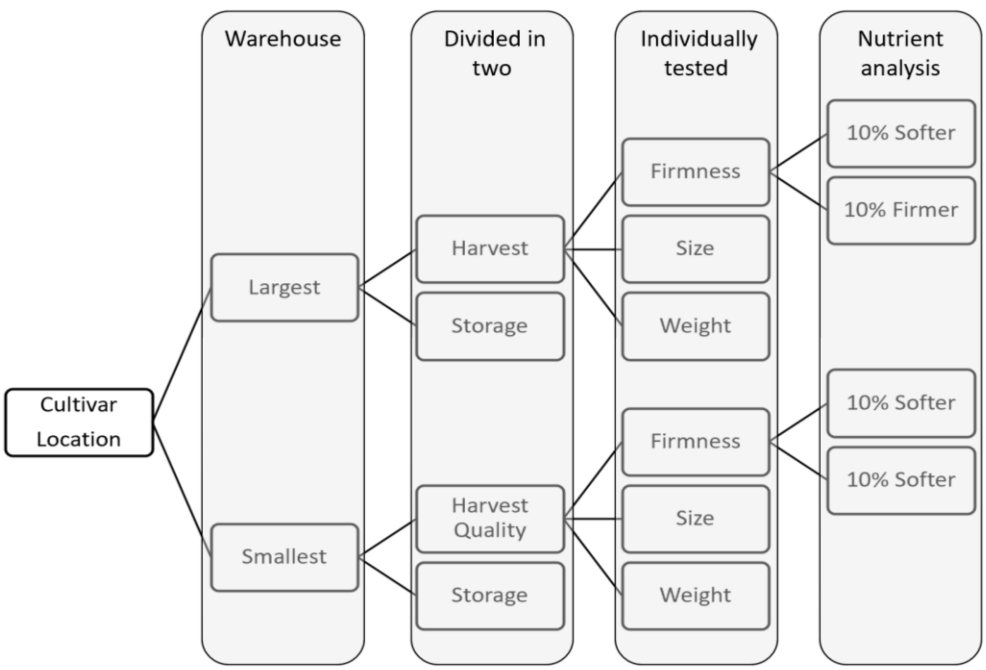

Figure 1.
Fruit sampling scheme for nutrient and storability analyses.

In Co-PI Torres's laboratory in Wenatchee, fruit was stored for four weeks in cold storage, and analyzed fruit weight, color, size and firmness, plus storage disorders including decay, stem browning, or pitting.

RESULTS AND DISCUSSION

Fruit quality summary by year, cultivar, and site

Fruit quality varied widely across years, cultivars, and sites (Table 1). When evaluating all the fruit received from the packing houses, differences from years explained 12% and 15% of fruit firmness and size variability, respectively ($p<0.001$). Fruit firmness was 16% higher in 2022, ranging between 269 and 388 $g \cdot mm^{-1}$ across cultivar and sites. Fruit size was also 3% and 14% higher in 2022, compared to 2021 and 2023, respectively (Table 1). The variety, on the other hand, explained only 5% of firmness and size variability, when comparing across year ($p<0.001$), while the interaction of year and cultivar, explained 20% of firmness variability and 23% of size variability.

Skeena fruit were consistently larger than Coral Champagne and Chelan (4 to14% larger), and Chelan was larger than Coral Champagne in 2021 and 2023, but smaller in 2023. In relation to fruit firmness, Coral Champagne was always softer (238 – 292 $g \cdot mm^{-1}$) than the other two varieties, while Chelan was firmer than Skeena in 2021 and 2023, but not in 2022 (Table 1). The impact of site on fruit firmness and size was also significant ($p<0.05$), however among the explanatory variables, year and cultivars were the most influential. Across all years, the variability in firmness among sites, cultivars and years is very high. Figure 1 represents firmness and size variability among orchards for Skeena in 2022, underscoring the importance of managing variability in orchards to maximize the proportion of higher quality fruit.

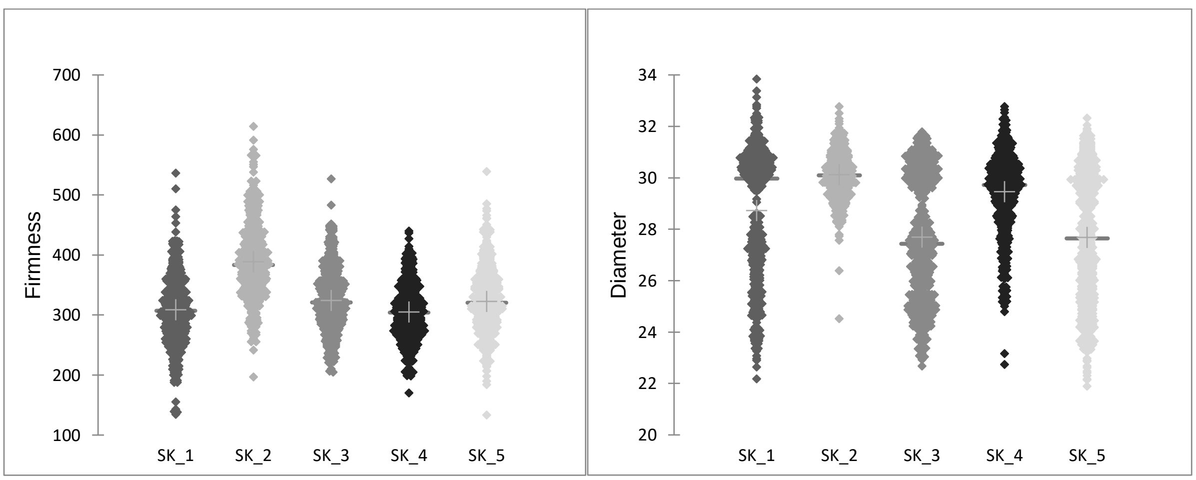

Figure 1. Firmness (left) and fruit size (right) variability across Skeena orchards in 2022. Middle cross indicates mean value.

Table 1. Fruit firmness and diameter differences by year, cultivar, and site. Different letters indicate statistical differences between years (bold capital), cultivars within years (bold) and among sites within year and cultivar (small letters) (Tukey test and $p< 0.05$)

			Firmness ($g \cdot mm^{-1}$)				Diameter (mm)			
Year	Variety	Site	Mean	Min	Max	StdDev	Mean	Min	Max	StdDev
2021	Chelan	1	295b	139	427	51.5	25b	20	33	3.4
		2	301a	159	444	49.4	26b	20	30	3.3
		3	255c	140	367	43.8	29a	25	35	2.9
	Chelan		**285.1a**	**139**	**444**	**52.4**	**26.6b**	**20**	**35**	**3.7**
	Coral	1	233b	123	377	44.8	25b	19	32	4.3
		2	236b	131	382	43.6	27a	22	32	2.8
		3	247a	140	360	36.2	25b	20	32	4.1
	Coral		**238.6c**	**123**	**382**	**42.1**	**25.6c**	**19**	**32**	**3.9**
	Skeena	1	304a	176	422	43.6	27b	24	32	2.1
		2	278c	161	394	36.7	28a	22	32	1.9
		3	289b	172	419	42.9	26c	22	30	2.0
		4	260d	146	394	40.4	26c	22	31	2.3
		5	260d	164	378	33.4	28a	25	31	1.2
	Skeena		**277.3b**	**146**	**422**	**42.5**	**26.8a**	**22**	**32**	**2.1**
2021			**269.3B**	**123**	**444**	**49.5**	**26.4B**	**19**	**35**	**3.2**
2022	Chelan	1	269c	134	434	48.3	25c	20	32	3.5
		2	350a	150	613	60.8	27b	21	34	3.6
		3	313b	154	544	58.7	29a	22	35	3.3
	Chelan		**310.9b**	**134**	**613**	**65.6**	**26.9b**	**20**	**35**	**3.8**
	Coral	1	275b	130	457	62.3	26b	21	31	3.4
		2	302a	199	636	45.2	27a	22	34	4.0
		3	298a	140	448	47.3	26b	20	34	4.5
	Coral		**292.0c**	**130**	**636**	**53.3**	**26.0c**	**20**	**34**	**4.0**
	Skeena	1	309c	134	537	54.9	29c	22	34	2.5
		2	388a	197	614	62.9	30a	25	33	1.0
		3	324b	205	527	49.1	28d	23	32	2.4
		4	305c	170	440	43.4	29b	23	33	1.5
		5	322b	133	539	49.9	28d	22	32	2.5
	Skeena		**326.5a**	**133**	**614**	**58.2**	**28.6a**	**22**	**34**	**2.3**
2022			**311.4A**	**130**	**636**	**60.9**	**27.3A**	**20**	**35**	**3.6**
2023	Chelan	2	267b	139	478	47.0	22a	18	30	2.4
		3	303a	169	628	57.0	22a	18	26	2.1
	Chelan		**285.0a**	**139**	**628**	**55.1**	**22.2c**	**18**	**30**	**2.3**
	Coral	1	245b	156	401	37.2	23a	17	31	4.1
		3	265a	137	408	37.1	24a	17	30	2.3
	Coral		**255.1c**	**137**	**408**	**38.6**	**23.5b**	**17**	**31**	**3.3**
	Skeena	1	268a	101	455	55.4	25b	21	32	2.3
		3	265ab	97	480	54.7	26a	20	31	2.1
		4	261b	89	468	47.0	25b	21	31	2.2
	Skeena		**264.8b**	**89**	**480**	**52.6**	**25.4a**	**20**	**32**	**2.2**
2023 Total			**268.2B**	**89**	**628**	**51.2**	**23.9C**	**17**	**32**	**2.9**

Nutrient distribution by cultivar

The distribution of nutrient concentration by cultivars also was highly variable (Figure 2). Fruit nutrient concentration distribution in these Washington orchards were either within or above the critical levels reported in the literature (Figure 2).

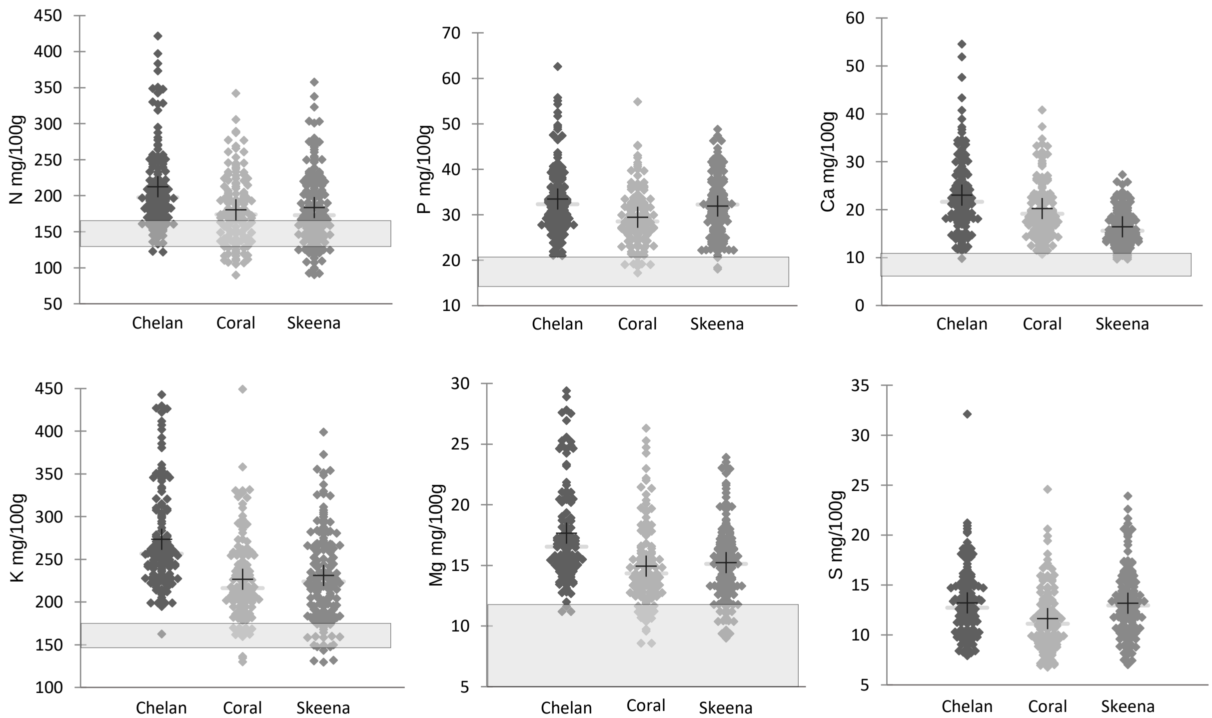

Figure 2. Fruit macronutrient distribution by cultivar. The gray boxes corresponds to the critical range reported in the literature for sweet cherries.

Nutrient differences of segregated fruit by year, cultivar and site

Within each size category, fruit from the 10^{th} and 90^{th} percentile ranking of firmness were selected for individual fruit quality analyses and nutrient analyses. When combining all categories and sites, fruit concentration of N, K, Mg and S was different among years, and all macronutrients were different among cultivars (Table 2).

Nitrogen was 6 and 15% higher in 2022 when compared with 2021 and 2023 respectively. However, K and Mg were higher in 2021, and S lowest in 2023, with no relation to fruit firmness or size. Among cultivars, Chelan had more than 15% higher N concentration, with no differences between Coral Champagne and Skeena, and no relationship with fruit quality (i.e., Chelan and Skeena were the firmest and Skeena were the largest). Coral Champagne had the lowest P and S, while highest K, Ca, Mg, again, with no relation with fruit firmness and size (Table 2). Overall, the cultivar and cultivar*year interaction had a greater influence in fruit nutrient variability.

Nutrients also varied by site and year (Table 3), however with no clear relation with fruit firmness and size differences. For example, Chelan site 2 had softer fruit in 2021, when compared with the other two sites, while there were no associated differences in nutrient levels. In 2022 and 2023, the same site 2 had firmer fruit, and again with no differences in nutrient levels, except higher B in 2023. For Coral

Champagne, site 1 had firmer and larger fruit, and higher N and P levels. However, in 2022, even though site 1 also had the largest fruit, nutrient concentration was not different from site 2 that had the smallest fruit. Similarly, for Skeena, site 1 having the firmest fruit in 2021 and 2022, only in 2021 had the highest N and B levels, while there were no differences in 2022. Regardless of the firmness and size differences between sites, note that Ca concentration only showed differences among sites in 2021 for Chelan and Skeena, and those differences did not align with firmer fruit, as it is sometimes perceived.

Table 2. Fruit firmness, size, weight, dry matter (DM) and macronutrient differences among years and variety. Different letters in the same column indicate significant differences within year and variety based on Tukey test ($p<0.05$). R^2 indicates the percentage of the variability in nutrient concentration (%) explained by the interaction of year and variety, shown only for factors with significant p value.

Factor		Firmness ($g.mm^{-1}$)	Size (mm)	Weight (g)	DM	N	P	K	Ca	Mg	S
						mg $\cdot 100g^{-1}$ (fresh)					
Year	2021	273.0 b	26.7 b	9.0 b	19 a	189.0 b	32.1	261.0 a	19.5	16.8 a	12.9 a
	2022	316.0 a	29.9 a	10.8 a	19 a	201.4 a	30.8	234.3 b	19.6	15.3 b	13.2 a
	2023	275.0 b	22.8 c	8.2 b	18 b	174.6 b	32.1	216.7 c	20.3	15.0 b	11.0 b
p value		<0.001	<0.001	<0.001	0.01	0.003	0.18	<0.001	0.702	<0.001	0.001
Variety	Ch*	295.5 a	26.5 b	8.3 c	19	212.6 a	33.5 a	273.4 a	23.0 a	17.7 a	13.2 a
	CC	268.2 b	26.7 b	9.1 b	19	180.5 b	29.4 b	226.8 b	20.2 b	14.9 b	11.6 b
	Sk	306.5 a	28.7 a	11.1 a	19	184.0 b	31.9 a	231.1 b	16.4 c	15.2 b	13.2 a
p value		0.000	<0.001	<0.001	0.51	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Year*Variety		0.89	0.22	0.007	0.99	0.000	0.270	0.001	0.642	0.188	0.000
	R^2	-	-	0.24	-	0.15	-	0.27	-	-	0.12

*Ch; Chelan, CC; Coral Champagne, Sk; Skeena.

Nutrient relationships with fruit quality

Correlation analysis is a useful tool to identify relationship between variables, especially when there is a large and wide range of values within each variable. When combining all cultivars, sites and years, firmness correlated significantly ($p<0.001$) with N and S concentrations in dry and fresh weight, however the relations were weak (R2 below 0.23) (Table 4). Fruit diameter and weight were negatively related with P, K, Ca, Mg concentrations, but again the correlations were weak (R2 below 0.5) (Table 4).

Given the influence of years and cultivar in fruit quality (described above), we evaluated the correlation after grouping by year or cultivar. For firmness, the correlations with nutrients were either not significant ($p>0.05$) or weak (R2 < 0.37) across all years and cultivars (data not shown). When grouping by year, fruit size (diameter or weight) was strongly and negatively correlated Ca concentration (R2 > -0.70) and Ca content (R2 > -0.69), but only in 2021 (data not shown). While there were no strong correlations between fruit quality and nutrients when grouping by cultivar. The negative relation between nutrient concentration and fruit size appears to be a consequence of dilution, rather than a cause effect relationship. For example, when mean fruit nutrient levels were compared by size category, nutrients were always higher in the small fruit, while no differences were found between firm and soft fruit (Table 5). The interaction of fruit quality categories firmness x size, was a secondary factor for nutrient levels, being significant ($p<0.05$) for P, K, Ca, Mg and S (Table 5), however the percentage explained by the interaction was generally low.

Table 3. Firmness, size and nutrient concentration by cultivar, site and year. Different letters in the same column indicate significant differences based on Tukey test (p<0.05). Lines in grey highlight sites described in the paragraph.

Cultivar	Year /Site		Firmness (g.mm-1)	Diameter (mm)	Nutrient concentration fresh (mg.100g-1)					
					N	P	K	Ca	Mg	S
Chelan	2021	1	333 a	28.1 b	188 a	30.5	249	12.4 b	14.6	12.0 a
		2	283 b	32.2 a	178 a	27.3	246	14.4 ab	16.3	13.9 a
		3	339 a	28.5 b	145 b	27.9	251	16.3 a	14.3	9.2 b
	p value		<0.0001	<0.0001	0.005	0.340	0.946	0.008	0.082	0.001
	2022	1	471 a	33.3 a	254 a	41.1 a	354 a	33.6	20.0 a	15.4 a
		2	400 b	32.5 b	203 b	27.6 b	249 b	20.7	16.2 b	16.2 a
		3	329 c	31.6 c	178 b	31.4 b	250 b	20.3	14.7 b	10.1 b
	p value		<0.0001	<0.0001	0.005	0.001	0.002	0.058	0.000	<0.0001
	2023	2	402 a	24.4	231	36.1	254	19.3	16.2	14.6 a
		3	345 b	24.0	221	42.8	250	31.8	18.0	12.1 b
	p value		0.000	0.111	0.632	0.397	0.827	0.172	0.164	0.002
Coral Champagne	2021	1	315 a	30.0 a	167 a	29.2 a	208	14.4	13.2	11.5
		2	270 c	29.6 b	155 ab	22.8 b	183	14.2	11.6	9.7
		3	291 b	29.7 b	133 b	20.6 b	164	12.9	10.9	9.4
	p value		<0.0001	0.015	0.021	0.010	0.107	0.341	0.158	0.188
	2022	1	357	34.5 a	247 a	36.6 a	282 a	16.3	14.8	19.4 a
		2	396	32.3 c	263 a	32.2 ab	262 ab	22.0	16.4	15.8 ab
		3	375	33.2 b	187 b	28.9 b	236 b	21.8	15.8	12.6 b
	p value		0.078	<0.0001	0.008	0.046	0.052	0.124	0.423	0.026
	2023	1	314	25.8 b	160 a	29.1	191	19.1	14.3	8.7
		3	304	27.7 a	123 b	33.1	221	18.3	12.7	10.2
	p value		0.177	<0.0001	0.023	0.221	0.129	0.704	0.133	0.153
Skeena	2021	1	377 a	29.8 a	246 a	29.3	247 ab	13.7 ab	15.6	17.4 a
		2	365 a	28.1 b	165 bc	36.9	298 a	20.1 a	17.8	12.3 b
		3	343 b	29.1 a	203 ab	32.6	211 b	18.3 ab	14.7	11.6 b
		4	304 c	28.1 b	169 bc	28.1	221 ab	12.9 b	13.8	12.2 b
		5	313 c	28.1 b	109 c	26.9	219 b	14.9 ab	13.1	9.1 b
	p value		<0.0001	<0.0001	0.000	0.083	0.022	0.023	0.101	0.002
	2022	1	510 a	32.1 bc	281	41.8 a	234	19.4	20.0 a	18.7
		2	411 b	30.2 d	214	31.2 b	206	12.7	14.9 ab	15.4
		3	395 b	33.1 a	212	34.2 ab	235	18.0	14.6 b	13.3
		4	385 bc	32.7 ab	199	34.0 ab	189	17.2	16.1 ab	14.0
		5	361 c	31.6 c	168	30.0 b	190	13.7	13.8 b	13.1
	p value		<0.0001	<0.0001	0.083	0.018	0.269	0.048	0.023	0.059
	2023	1	353	27.6 a	197 a	47.8	335	18.3	19.5	13.2 a
		3	353	22.7 b	147 b	42.0	280	20.6	15.5	10.2 ab
		4	349	22.3 b	114 b	39.6	266	15.9	15.2	7.9 b
	p value		0.754	<0.0001	0.001	0.392	0.212	0.649	0.153	0.023

Table 4. Pearson correlation between fruit quality indicators and dry nutrient concentration (%) and fresh nutrient concentration (mg/100g). Bold values indicate significance level of p< 0.05.

Variables	Firmness (g·mm^{-1})	Diameter (mm)	Weight (g)
N %	**0.197**	0.091	**-0.132**
P %	0.012	**-0.329**	**-0.225**
K %	-0.049	**-0.254**	**-0.382**
Ca %	-0.052	**-0.363**	**-0.501**
Mg %	-0.038	**-0.276**	**-0.423**
S %	**0.198**	**0.209**	-0.021
Dry Matter %	**0.108**	-0.006	**0.105**
N mg/100g	**0.247**	**0.107**	-0.071
P mg/100g	0.078	**-0.252**	**-0.093**
K mg/100g	0.024	**-0.201**	**-0.220**
Ca mg/100g	0.005	**-0.326**	**-0.407**
Mg mg/100g	0.035	**-0.224**	**-0.277**
S mg/100g	**0.250**	**0.211**	0.024

Table 5. Fruit nutrient concentration differences between size, firmness, and the interaction of size x firmness categories across all three years and cultivars. Different letters in the same column indicate significant differences within size and firmness category based on ANOVA test (p<0.05). R^2 indicates the percentage of the variability in nutrient concentration (%) explained by the interaction of fruit size and firmness.

Fruit Quality Category			Nutrient concentration dry (%)[1]						
		Unit[2]	Dry Matter	N	P	K	Ca	Mg	S
SIZE	Small	24.6 b	18%b	1.05 a	0.17 a	1.36 a	0.12 a	0.09 a	0.07 a
	Big	30.0 a	19%a	0.98 b	0.16 b	1.22 b	0.09 b	0.08 b	0.07 b
	p value	<0.0001	0.004	0.002	<0.0001	<0.0001	<0.0001	<0.0001	0.006
FIRMNESS	Firm	361 a	0.19	1.02	0.17	1.28	0.10	0.08	0.07
	Soft	221 a	0.19	1.00	0.17	1.29	0.10	0.08	0.07
	p value	<0.0001	0.683	0.482	0.474	0.462	0.373	0.361	0.299
SIZE x FIRMNESS	p value		0.595	0.098	0.002	0.040	0.067	0.034	0.013
	R^2		0.02	0.03	0.08	0.11	0.24	0.15	0.04

[1]Means of 208 fruits/category. [2]Unit of category, being diameter (mm) for size, and force (g.mm^{-1}) for firmness.

Nutrient extraction to determine demand

Fruit nutrient extraction varied slightly among years, cultivar and site (p <0.001). However, these differences are of agronomic irrelevance (data not shown). For example, Ca extraction was lowest in 2022 with mean value of 0.34 lbs per ton of fruit, and highest in 2023 with 0.38 lbs per ton of fruit. When translating this to a per acre rate for an orchard producing 10 tons of fruit, the difference between 2022 and 2023 is only 0.4 lbs. Thus, we opted to provide a range of nutrient extraction values to account for the variability across years and sites. Note that regardless of the differences in fruit quality and yields between years, the extraction remained stable and within a small range. Thus, nutrient extraction values determined in our study provide a confident estimation of nutrient demand in mature orchards, and should guide nutrient management rates to prevent excessive use of fertilizers.

Table X. Nutrient extraction ranges for Washington Sweet cherry cultivars.

	N	P	K	Ca	Mg	S	Zn	Mn	Cu	B
Nutrient / Cultivar	Lb/USTon						g/USTon			
Chelan	3.2 - 4.6	0.5 - 0.7	3.9 - 6.4	0.4 - 0.6	0.3 - 0.4	0.2 - 0.3	0.2 - 1.5	0.7 - 1.8	0.6 - 1.2	3.4 - 11
Coral Champagne	2.4 - 4.9	0.5 - 0.7	3.2 - 5.4	0.3 - 0.4	0.2 - 0.3	0.2 - 0.4	0.3 - 1.8	0.1 - 2.3	0.6 - 1.4	1.3 - 7.7
Skeena	1.9 - 3.4	0.6 - 0.9	2.9 - 6.3	0.3 - 0.4	0.2 - 0.4	0.2 - 0.4	0.2 - 0.9	0.1 - 1.5	0.5 - 1.2	3.7 - 21
Range	**1.9 - 5.0**	**0.5 - 0.9**	**2.9 - 6.3**	**0.3 - 0.4**	**0.2 - 0.4**	**0.2 - 0.4**	**0.2 - 1.8**	**0.1 - 2.3**	**0.5 - 1.4**	**3.7 - 21**
Literature	2.7 - 11.7	1.50	7.60	0.40	-	-	-	-	-	-

Postharvest differences

Postharvest condition and disorders were influenced by the site, cultivar, and year. In this report, we focus on key finding and their relationship with fruit nutrient levels.

Firmness after storage varied between 234 and 497 ($g.mm^{-1}$), with Chelan showing higher firmness compared to Coral Champagne and Skeena (Table 6). In 2021, site 1 and 2 had firmer fruit, whereas in all other cultivars and years, firmness was higher in 2023. Soluble solids (SS) were largely influenced by the cultivar, with Skeena showing the highest levels (mean: 21 Brix), and Chelan and Coral Champagne being similar (17 – 18 Brix). Year had a lesser influence, with the lowest SS observed in 2022. Stem retention was strongly influenced by both year and cultivar, with these variables explaining 78% of the variability (data not shown). Overall, Chelan required twice the force compared to Coral Champagne and Skeena, and stem retention was consistently higher in 2022 across all cultivars and sites (Table 6).

Stem decay was more influenced by the cultivar than by the year, with Skeena showing the highest level (3.5 N) and Coral champagne the lowest (2.1 N). Differences between years and sites were inconsistent. The incidence of pitting varied between 10% to 93% across all sites, years, and cultivars, being highly influenced by year and cultivar (accounting for 61% of the variability). Pitting was two to three times higher in 2021 compared to 2022 and 2023, respectively. Chelan and Skeena experienced twice as much pitting as Coral Champagne. Interestingly, differences between sites were inconsistent in Chelan, nonexistent for Coral Champagne, and higher in Skeena site 4 when comparing across years (data not shown).

Fruit splits were higher in 2022, ranging from 13% in Skeena to 16% in Chelan, but no differences were observed between cultivars (data not shown). In 2021 and 2023, split percentage were below 3%. However, differences appeared when comparing split incidence by site and year (Table 6). For example, Chelan Site 1 had 16% splits in 2021 but 0% in 2022, while Chelan Site 3 had 0% in 2021 and 18% in 2022. This variability suggests that environmental factors, rather than management, play a key role in fruit splitting.

Mechanical damage varied widely, from 0 to 54%, with Chelan showing the highest percentage compared to Skeena and Coral Champagne. Similar to fruit splits, the incidence of mechanical damage varied across sites and years, without a consistent relation to any variable (Table 6).

Other fruit defects were observed at lower incidence or not every year (data not shown). Bruising was only observed in 2021, but at a low percentage (<5%). Fruit decay was also generally low (< 1%) across years and cultivars. However, in 2023, Skeena site 1 and 2 had 28% decay, much higher than the other sites. Sunburn damage was observed only in 2021, ranging from 2.8% to 30%, and its incidence was closely related to site and cultivar. Russet and browning were observed only in 2022, but at low levels (mean: 2.4%). Soft shoulders ranged from 1% to 28%, being highest in 2021 (mean: 18%) and in Coral Champagne (mean: 28%), while not detected in 2023. Similarly, shrivel ranged from 1% and 31%, with the highest level in 2021 and 2022 (mean: 8%), and more prominent in Chelan (mean: 13%) and Coral Champagne (mean: 8%) compared to Skeena (< 1%). Lizard skin was highly influenced by the year, being highest in 2023 (mean: 32%) and being more severe in Chelan and Coral Champagne (averaging 17%), with four orchards showing more than 35% incidence.

Postharvest relation with nutrients

Given the strong influence of the cultivar in most postharvest attributes, correlation with nutrient levels were conducted by cultivar. Here we report only on strong correlations ($r < -0.55$, or > 0.55). In Chelan, a positive relationship was found between K:Ca and SS ($r = 0.64$), soft shoulder ($r = 0.63$) and pitting ($r = 0.71$) (Figure 3), while negative relation with lizard skin ($r = -0.62$). Pitting incidence also correlated positively with N:Ca ($r = 0.58$) and negatively with N ($r = -0.57$), P ($r = -0.55$), Ca ($r = -0.67$) and Mg ($r = -0.61$). Fruit P also correlated positively with lizard skin ($r = 0.60$). Fruit browning showed strong positive correlation with K ($r = 0.84$), dry matter ($r = 0.62$), Mg ($r = 0.67$) and N ($r = 0.57$). Fruit stem retention force was positively correlated with dry matter ($r = 0.72$).

In Coral Champagne, fruit K:Ca correlated with SS ($r = 0.55$). Stem decay correlated negatively with Ca ($r = -0.58$) and Mg ($r = -0.55$), and stem retention force correlated strongly and positively with dry matter ($r = 0.69$), N ($r = 0.88$), K ($r = 0.69$), Mg ($r = 0.62$) and S ($r = 0.71$). Fruit browning correlated positively with dry matter ($r = 0.59$), N ($r = 0.77$), K ($r = 0.78$), Mg ($r = 0.56$) and S ($r = 0.78$), while pitting was negatively correlated with dry matter ($r = -0.79$), K ($r = -0.58$), Ca ($r = -0.63$) and Mg ($r = -0.56$).

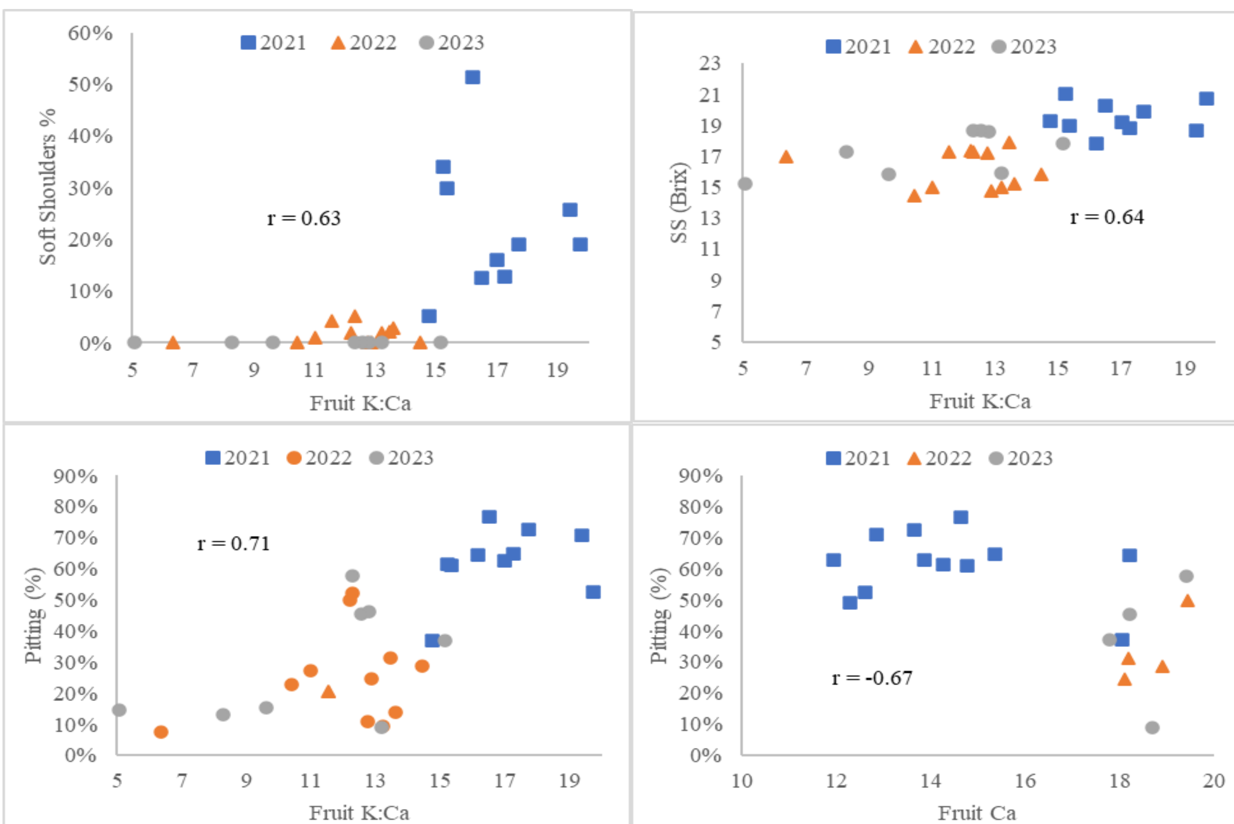

Figure 3. Top: correlation between fruit K:Ca with soft shoulder (left) and soluble solid SS (right), and bottom: correlation between pitting and fruit K:Ca (left) and Ca (right), in 2021 (●), 2022 (▲), and 2023 (■). Correlation across all years represented by r ($p < 0.001$).

Table 6. Fruit quality and condition across cultivars, sites and years, after four weeks of storage at 39 F and regular atmosphere. Different letters in the same column indicate significant differences within cultivar and site (Tukey test p<0.05).

Cultivar	Site	Year	Firmness AVG (gr/mm2)	SS (Brix)	Stem retention (N)	Stem Decay (1-5)[1]	Pitting %		Splits %		Mechanical Damage %	
Chelan	S1	2021	484 a	19.3 a	1.6 b	2.9	56%		2%	b	38%	b
		2022	300 b	17.5 b	6.6 a	3.0	38%		13%	a	79%	a
	S2	2021	441 a	16.1 b	7.3 a	3.3 a	10%	b	16%	a	9%	b
		2022	390 b	19.5 a	3.8 b	3.3 a	59%	a	0%	b	30%	b
		2023	398 b	16.1 b	2.3 c	2.1 b	13%	b	5%	b	74%	a
	S3	2021	379 b	19.6 a	3.1 b	3.3 a	69%	a	0%	b	17%	b
		2022	352 b	15.0 b	7.0 a	2.6 b	26%	c	18%	a	62%	a
		2023	472 a	18.5 a	4.2 b	2.9 ab	47%	b	1%	b	33%	b
Coral	S1	2021	350 b	19.3 a	1.4 b	2.5 a	47%	a	2%	ab	10%	b
		2022	371 ab	15.1 b	7.2 a	1.7 b	12%	b	5%	a	3%	b
		2023	392 a	19.0 a	0.9 b	2.3 a	16%	b	0%	b	35%	a
	S2	2021	273 b	18.2	1.4 b	2.3	36%	a	1%	b	66%	a
		2022	316 a	18.8	5.2 a	2.1	12%	b	6%	a	8%	b
	S3	2021	336 b	18.1 a	1.1 b	2.4 a	43%	a	1%	b	28%	a
		2022	313 c	15.4 b	4.0 a	1.8 b	10%	b	29%	a	1%	b
		2023	383 a	15.5 b	1.6 b	1.8 b	23%	b	2%	b	35%	a
Skeena	S1	2021	358	20.5 a	1.2 b	2.5 b	60%	a	0%	b	17%	c
		2022	327	18.8 b	3.6 a	2.8 b	24%	b	16%	a	51%	a
		2023	337	21.1 a	1.2 b	4.0 a	9%	c	2%	b	32%	b
	S2	2021	301 b	20.0 b	4.2	3.5 b	56%		8.9%		23%	
		2022	356 a	24.5 a	4.3	4.7 a	73%		15.4%		14%	
	S3	2021	317	21.0	2.3 b	2.9 b	56%	a	1%	b	7%	b
		2022	331	20.7	3.9 a	2.3 c	28%	d	16%	a	30%	a
		2023	354	19.5	1.9 b	4.0 a	0%	c	9%	ab	30%	a
	S4	2021	257 b	24.7 a	3.4 a	4.0 b	69%	a	3.1%		24%	
		2022	272 b	21.7 b	3.0 ab	2.7 c	68%	a	4.9%		25%	
		2023	372 a	24.3 a	2.1 b	4.6 a	27%	b	6.4%		32%	
	S5	2021	255 b	21.1 a	2.4	2.9	57%	a	2%	b	34%	b
		2022	344 a	18.2 b	3.2	4.1	13%	b	13%	a	56%	a

[1]Stem decay scale 1 to 5, with 1 being green stem with no decay and 5 being brown stems with severe decay.

In contrast, there were no strong correlations between nutrient levels and Skeena postharvest quality and condition (data not shown).

Executive Summary

Project Title: Nutrient management for high quality sweet cherries

Key words: sweet cherry nutrients, firmness, size, postharvest, calcium

The project aimed to enhance nutrient management strategies for sweet cherries by analyzing the relationship between fruit nutrient levels, and fruit quality parameters such as size, firmness, and storability. The key objectives were to identify optimal nutrient conditions for sweet cherry quality, determine the nutrient demand for Chelan, Coral Champagne and Skeena and improved fruit quality and storability. We found yearly differences explained 12% of fruit firmness and 15% of size variability. Cultivar differences had a minimal effect on firmness and size across years, explaining only 5% of the variance, but the interaction between year and variety increased to 20% and 23%, respectively.

Very soft fruit (<200 g•mm^{-1} firmness) showed consistently lower nitrogen (N) and sulfur (S) concentrations, but there was no strong correlation between fruit nutrient levels and fruit quality beyond this firmness level. Nutrient extractions were consistent across varieties and sites, values provided by this study can be utilized to estimate the rate of nutrients required per ton of fruit produced with greater confidence.

Postharvest attributes such as stem retention and firmness, varied significantly across cultivars and years. For instance, Chelan fruit had higher firmness and stem retention than Coral Champagne and Skeena. Also, retention was two to three times higher in 2022. Fruit disorders such as pitting, mechanical damage, fruit splits, and other defects were influenced by year, variety, and site. Pitting, for example, was higher in Chelan and Skeena and was most severe in 2021. Postharvest defects such as browning, soft shoulders, and pitting were linked to nutrient levels, especially in Chelan and Coral Champagne. But no strong nutrient correlations were found for Skeena.

Managing variability in fruit quality within orchards is crucial for growers. In Washington, nutrient levels were either within or above the reported adequate ranges for sweet cherry, which might explain the lack of relationship. Nutrient levels, especially K:Ca ratio were related to postharvest disorders. Note that relations do not represent causation, however they could be utilized as indicators to predict storability.