FINAL PROJECT REPORT **YEAR**: 2 of 2
WTFRC Project Number:

Project Title: Impact of harvest timing on fruit quality of sweet cherry cultivars

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Cooperators: None

Total project funding request: **Year 1**: $24,226 **Year 2**: $25,079

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WTFRC Collaborative expenses: None

Budget 1 Todd Einhorn
Organization Name: OSU-MCAREC **Contract Administrator:** Dorothy Beaton
Telephone: 541 737-3228 **Email address:** dorothy.beaton@oregonstate.edu

Item	**2009**	**2010**	
Salaries	3,947	4105	
Benefits	2,053	2,199	
Wages			
Benefits			
Equipment			
Supplies	500	500	
Travel	1,500	1,500	
Miscellaneous			
Total	$8,000	$8304	

Footnotes: Salaries include ¼ time Associate in Research to organize field sites, follow crop phenology, manage and collect data at harvest and throughout cold storage. Travel is for regional orchard monitoring to determine bloom dates, follow development and harvest.

Budget 2: Lynn Long
Organization Name: Wasco County Extension **Contract Administrator:** Dorothy Beaton
Telephone: 541-737-3228 **Email address:** dorothy.beaton@oregonstate.edu

Item	**2009**	**2010**	
Salaries			
Benefits			
Wages[1]	4,500	4,680	
Benefits (10%)	450	468	
Equipment			
Supplies			
Travel[2]	1,000	1,000	
Miscellaneous			
Total	$5,950	$6,148	

Footnotes:
[1] Time-slip assistance for harvest, data collection, and fruit quality analyses
[2] Travel to plots and cold storage

Budget 3 Matthew Whiting
Organization Name: WSU-Prosser **Contract Administrator:** Mary Lou Bricker
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Item	**2009**	**2010**	
Salaries			
Benefits			
Wages	8,000	8,320	
Benefits	776	807	
Equipment			
Supplies	500	500	
Travel	1,000	1,000	
Miscellaneous			
Total	$10,276	$10,627	

Footnotes:

Objectives

1) Quantify and identify changes in quality attributes of ten cultivars, ranging from early to late season ripening, throughout final fruit growth and ripening in OR (Einhorn/Long) and WA (Whiting).
2) Determine the effect of harvest timing on quality throughout storage, including pitting incidence (Einhorn, Whiting, Long).
3) Determine the value of growing degree day models to predict growth, development and maturity of cherry varieties growing at different sites (Einhorn, Whiting, Long).
4) Develop extension materials (e.g., color charts) for identifying optimum harvest timing for new cultivars (Long).

Significant Findings

- Significant variability in cherry skin color was observed during mid-harvest timing (commercial harvest) for most cultivars. Variability was greatest at early harvest timing, but quality associated with early harvests was suboptimal
- Skin color darkened with advancing harvest dates. Rate of darkening was cultivar dependent.
- All quality attributes tested (soluble solids, total acids, firmness, stem retention force, fruit size and mesocarp color) were significantly related to skin color (e.g., variability of any given quality attribute could be explained to a high degree by skin color)
- In general, as fruit persist on the tree- skin color, mesocarp color, sugars, and fruit size increase, while firmness, and retention force decrease
- Soluble solids content of fruit increased linearly with darkening skin color.
- Cherry quality attributes were well-maintained for up to 28 days post-harvest
- Cherry fruit firmness typically increased with storage time, irrespective of cultivar
- Sugars and weight did not change appreciably with storage time
- Stem retention force and total acids changed inconsistently
- 2009 and 2010 pitting severity of 'Sweetheart' was unrelated to harvest timing

Results and Discussion

Harvest timing: Several analyses were run to describe the effect of harvest timing on individual quality attributes. Pooling all data (years and cultivars) produced very intriguing results describing general cherry ripening behavior (Table 1).

Table 1. The effects of harvest timing on mean fruit quality attributes, pooled for all cultivars, and both years. Attributes analyzed were: mesocarp color [CTIFL scale (1-light pink, 7-black)], average fruit size (weight and diameter), firmness, stem retention force, soluble solids (SS) and total acids (TA).

Harvest (timing)	Mesocarp color (1-7)	Avg.fruit sz. (g)	Avg.fruit sz. (mm)	Firmness (g/mm)	Retention force (g)	SS (%)	TA (%)
Early	3.1c	10.3c	28.3c	286a	731a	18.6c	0.81a
Mid	3.9b	10.5b	28.4b	275b	618b	19.8b	0.75c
Late	4.4a	11.2a	29a	272b	566c	21.6a	0.79b

Nearly all attributes progressively changed relative to the duration of time that fruit remained on the tree. In fact, one could draw the general conclusion that as cherry harvest timing is delayed, skin color, mesocarp color, size, and sugars all increase, while pedicel retention force and fruit firmness decrease (Table 1). These trends were apparent each year, though the absolute value of given attributes significantly changed from year to year (data not shown). This can be attributed to a myriad of environmental regulators, of which cropload and climatic factors are dominant. Another interesting observation is the order of magnitude that different attributes change with advancing harvest time (Table 1).

Similar trends are evident for individual quality attributes relative to incremental changes in skin color (years, cultivars and harvests combined) (Table 2); sensible given that cherry skin color darkens

Table 2. The effect of skin color [CTIFL scale (1-light pink, 7-black)] averaged over all cultivars, years and harvest timings on mean fruit quality attributes. Attributes analyzed were: mesocarp color, average fruit size (weight and diameter), firmness, stem retention force, soluble solids (SS) and total acids (TA).

Skin Color (1-7)	Mesocarp color (1-7)	Avg.fruit sz. (g)	Avg.fruit sz. (mm)	Firmness (g/mm)	Retention force (g)	SS (%)	TA (%)
1	1g	7.4d	25.3f	344a	1650a	12.9g	na
2	1.8f	8.9c	26.9e	314b	902b	14.9f	0.76c
3	2.5e	10.2b	28.5bc	296c	704c	17.3e	0.76c
4	3.2d	10.9a	28.8ab	280d	638c	19d	0.77gc
5	4.2c	11.1a	28.9a	277d	611c	20.8c	0.78bc
6	5b	10.8a	28.4c	264e	541c	22.5b	0.8b
7	6a	10.2b	27.7d	229f	541c	24.9a	0.88a

as harvest is delayed. But, only sugars, mesocarp color and firmness (in one out of two years) continued to respond linearly with changes in skin color, while other attributes, such as fruit size and retention force were best explained by a polynomial function (Fig 1). Since harvest timing reflects

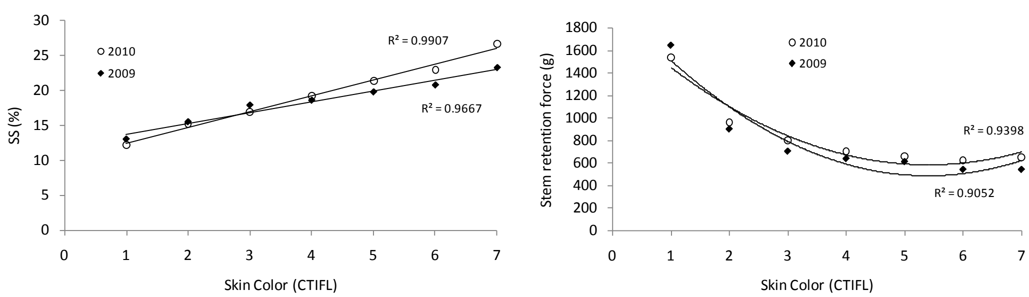

Figure 1. Relationship between soluble solids (left) and stem retention force (right) and cherry skin color (CTIFL). Data are averages of all cultivars, harvest timings and years.

the average skin color, it is less influenced by inclusion of highly under-mature fruit (CTIFL 1 and 2; unmarketable fruit) at early timings, or the presence of fruit which are quite advanced (CTIFL 7) at late timings. When fruit quality attributes are related to CTIFL color class, the extreme ends of the scale tend to deviate from the linearity observed between 3-6 CTIFL, which constitutes the commercial range.

Fruit size increased with each subsequent harvest date to a CTIFL score of 5-6 (Table 1), although, in general, darker fruit (CTIFL 7) were accompanied by a reduction in fruit size. ‘Bing’, and to a lesser degree ‘Regina’ and ‘Chelan’ comprised the entirety of the CTIFL 7 color class, and with the exception of ‘Regina’ these cultivars were not the largest fruited cultivars tested. Softening in cherry has been suggested to develop at the onset of stage III development. Although cherry is classified as a non-climacteric fruit (primarily due to the poor correlation between ripening, protein synthesis, fruit respiration and generation of internal ethylene), recent research shows several cell wall degrading enzymes to increase in activity during cherry softening. Because fruit softening is predominantly an enzymatically controlled process it should lend itself to first order kinetic analysis. A model to describe softening using temperature data for the final weeks leading up to harvest might help to explain differences from year to year. For instance, 2009 firmness values were ~20 % lower than those of 2010 [248 and 301 g/mm for 2009 and 2010, respectively] (data not shown). A predictive model could aid in harvest timing decisions when high temperatures are experienced and/or forecasted throughout the harvest period. Mean and maximum temperatures were higher in 2009 than 2010 although the lower firmness values observed in 2009 were likely confounded by the generally higher croploads. In several recent cropload studies on ‘Lapins’, ‘Sweetheart’ and ‘Skeena’ we have observed significantly softer fruit for the heavy treatments relative to the light croploads (Einhorn, unpublished).

Accumulation of soluble solids in cherries coincides with stage III of fruit development, and is a function of translocation of fixed carbohydrates from leaves. Because other competing sinks in cherry are relatively weak during stage III of fruit development, fruit are at an advantage for accumulating sugars. In fact, in terms of soluble solids fruit continued to increase sugars linearly as skin color darkened (Fig 1). Although absolute sugar content varied across genotypes, a significant relationship was observed for all cultivars studied (data not shown). Differences from year to year are likely attributed to differences in cropload. Allowing cherries to persist for longer periods of time on the tree will result in increased sugar content, though this must be balanced against potential adverse effects such as fruit softening and, in specific cultivars, lower stem retention force.

Despite the strong predictive nature of the relationships between skin color and quality attributes, on a whole-canopy basis cherry fruit ripening is inherently variable. Frequency distributions of the number of fruit falling into specific color classes for each of three successive harvest dates is shown for ‘Benton’ and ‘Skeena’ (Fig. 2). Similar variability was observed for other cultivars. The mid harvest timing for ‘Skeena’ alone (concurrent with the commercial harvest of the block) had ~1/3rd of the fruit in each of CTIFL 3, 4, and 5-6 class (Fig. 2). The average CTIFL score of the harvest was 3.9. In terms of internal quality of the fruit comprising the mid 2010 ‘Skeena’ harvest, sugars increased ~ 10 % with each increase in color class between CTIFL 3 and 5 (17.7, 19.7 and 21.5 %), while firmness values all remained > 350 g/mm. Additionally, both skin and mesocarp color darkened to an average CTIFL score of 4.3 for the late timing.

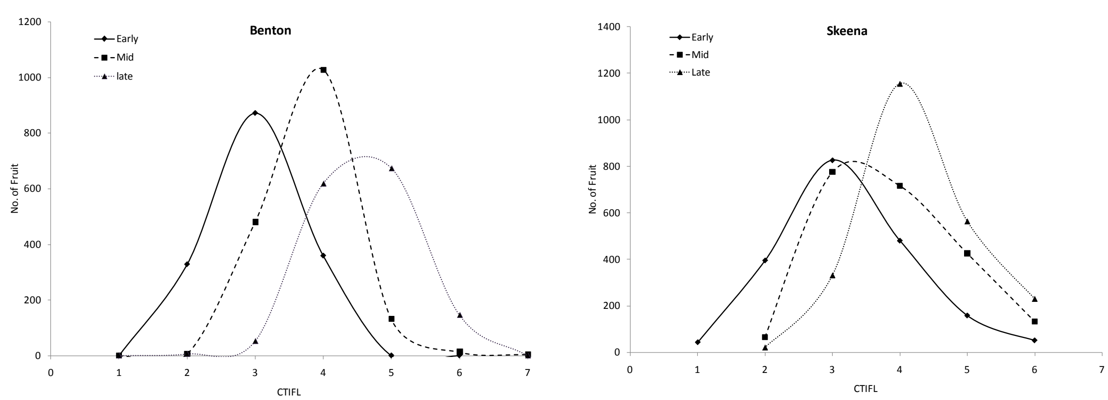

Figure 2. Frequency distribution of ‘Benton’ (left) and ‘Skeena’ (right) skin color using the CTIFL color scale (1-light pink, 7-black), for three separate harvest dates (early, mid and late). On each date, one tree representative of the orchard was strip-picked, and each fruit was classified according to its skin color. Total number of fruit analyzed per successive harvest was 1,559, 1,661 and 1,497 for ‘Benton’, and 1,953, 2,113 and 2,304 for ‘Skeena’.

Future identification of sources of variability, and the development of practices which reduce this variability, will be of primary importance if greater consistency is to be gained in fruit quality. Assuming that pests, nutrition and irrigation are well managed, sources of variability of cherry fruit quality include cropload, flower timing [Fig 3], light environment, age of wood, and climatic factors.

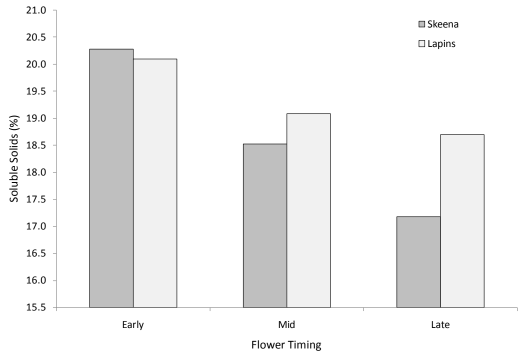

Figure 3. Effect of flower timing on soluble solids content of ‘Skeena’ and ‘Lapins’ fruit. Fruit were harvested at the commercial harvest date. Sixty flowers were tagged per replicate (4) on each date.

Additionally, there are likely unidentified contributing factors, and we are simultaneously investigating the role of cellular development via microscopy techniques to determine whether we can adequately identify limitations to fruit growth throughout ontogeny. Good horticultural practices (training and pruning to enhance good light penetration and distribution, renewal of fruiting wood, application of PGRs, etc.) likely aid in reducing some of this variability, and as rate of adoption of efficient, planar canopy architectures (such as UFO) increases, it is plausible that a larger portion of this variability will be removed. Furthermore, research efforts aimed at identification of metabolites associated with ripening, and the genetic factors that regulate them, may result in the future development of cultivars which ripen more evenly. Interestingly, for all of the limitations associated with ‘Regina’ fruit set, ripening occurred over a very narrow range of CTIFL classes in both years of this study (data not shown).

Quality attributes of individual cultivars responded uniquely to harvest timing. Importantly, excellent relationships between skin color and fruit quality attributes were observed, despite the use of multiple sites as is shown for ‘Benton’ (Fig 4). Although absolute differences were observed between sites (associated with climate, lab instrumentation, etc.), equations and slopes describing the relationships were similar (Fig 4). Data compilation and analysis is ongoing. Recommendations for individual cultivars cannot yet be ascertained until data are analyzed for all years and sites. We will disseminate the results of these analyses, prior to, or during the 2011 NW Cherry research review.

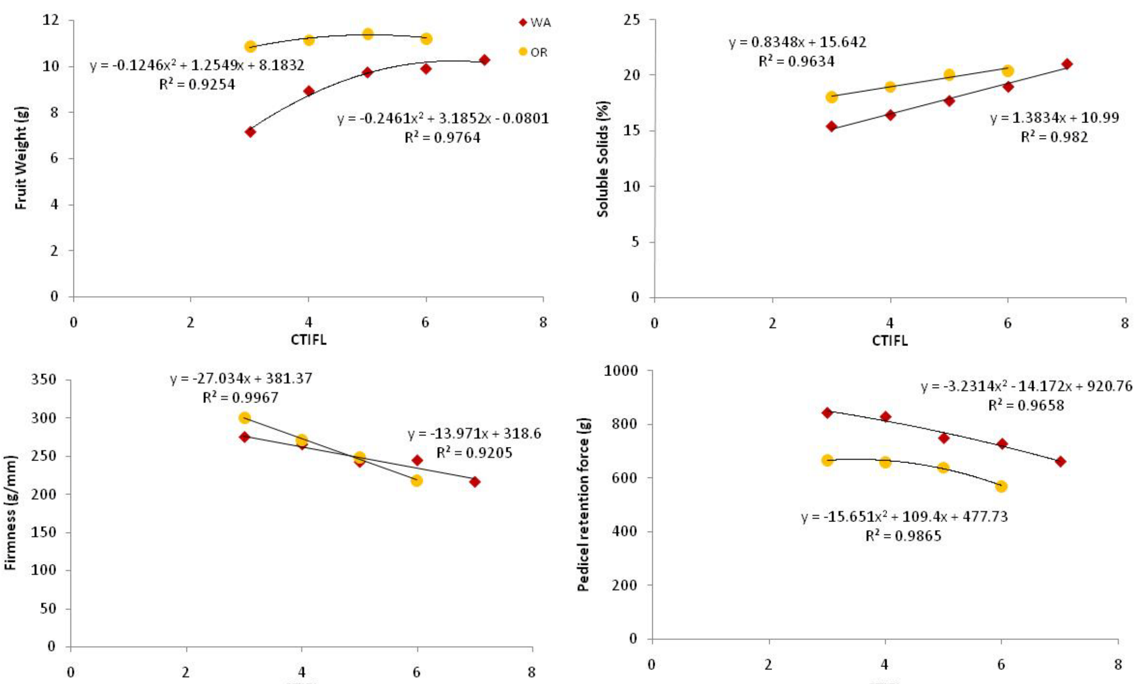

Figure 4. Relationships between skin color (CTIFL; 1-light pink, 7-black) and quality attributes (fruit weight, soluble solids, firmness and retention force) for ‘Benton’ fruit harvested in OR and WA.

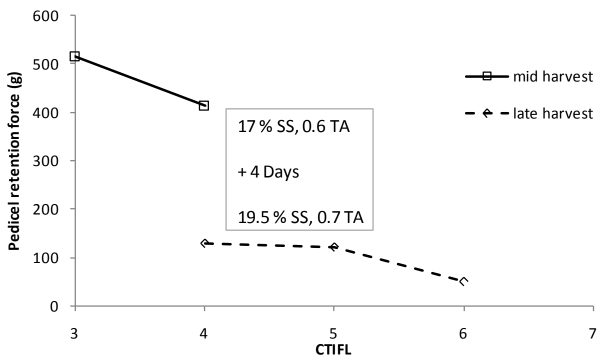

Figure 5. The effect of increasing skin color on 'Selah' stem retention force. The four days between mid and late harvests were characterized by high mean and max temperatures.

In 2009 we reported that quality attributes associated with a given color class and cultivar can be markedly different depending on harvest date. This suggests that maturity and/or ripening can proceed exclusive of changes in surface color, and is likely the case for attributes such as stem retention force, which are highly influenced by temperature (Fig 5).

Storage: Assuming that the fruit evaluated were fair representations of the cultivars, these data will tend toward the optimal end of the post-harvest fruit quality scale, since fruit were spared the hardships of the packing process. As we observed in 2009, fruit firmness either remained constant, or consistently increased up to 28 days of storage. The reason for this phenomenon is not entirely clear. Fruit were allowed to warm to room temperature prior to analysis, since cherry fruit rigidity increases when the temperature of fruit tissue is lowered. This places importance on knowing the firmness values of the fruit upon entry into cold storage. Furthermore, disparity between firmness of fruit entering storage and arrival at destination markets can likely be attributed to temperature fluctuations during transit. In fact, future research could address the relationship between fruit quality and temperature alteration (simulating transportation scenarios) throughout the post-harvest life of the fruit. Soluble solid content was largely unaffected by storage time, and so long as fruit dehydration is kept to a minimal (determined in the present study by changes in fruit weight), levels of soluble solids should not change much from their harvested levels. Total acids typically degraded as storage time lengthened, though this was not consistently observed in all cultivars. A slight darkening of skin color seemed apparent as storage time increased, but this was not documented. We did not qualify stem attributes in this project.

Pitting: For pitting we chose to focus our efforts on 'Sweetheart', given the large area planted to this cultivar, and its documented propensity for pitting. In both 2009 and 2010 'Sweetheart' fruit were harvested at different levels of maturity in enough volume to run over a commercial packing line. In 2009 four harvest timings were conducted (average CTIFL skin color classes were 3.8, 4, 4.3 and 5, for the early, early-mid, mid and late picks, respectively). Pits were counted for the entire contents of 20 lb cherry boxes. There was no relationship found between pitting incidence and skin color of 'Sweetheart' (data not shown). Two harvest timings in 2010 also yielded poor relationships between color and surface injuries (Table 3).

Table 3. Effect of harvest timing (Early or Late) on skin color (CTIFL scale; 1= pink, 7 =black) and pitting incidence, reported as average number of injuries on fruit for three different classifications of injuries [1-Pits, 2-Creases, and 3-Compressions]. All injuries present on fruit were measured and categorized into three size classes; 0.1-2 mm, 2.1-4 mm, 4.1-6 mm. Fruit were harvested commercially, run over a packing line and packaged into 20 lb cherry boxes (OVF). Two hundred fruit were chosen randomly at 21 days post-harvest (31 °F) from each of three 20 lb cherry boxes per harvest timing.

Treatment		Pit size class			Crease size class			Compression size class		
	CTIFL	0-2 mm	2-4mm	> 4mm	0-2 mm	2-4mm	> 4mm	0-2 mm	2-4mm	> 4mm
Early	**4.1 B**	1.9	1.2	1.1	**0.2 B**	0.9	1.5	0	0.4	1.3
Late	**5.0 A**	2.1	1.1	1.4	**0.4 A**	0.8	1.1	0.2	0.5	1.7
$LSD_{0.05}$	0.84	0.64 (ns)	0.17 (ns)	1.13 (ns)	0.19	0.67 (ns)	1.17 (ns)	0.27 (ns)	0.34 (ns)	1.04 (ns)

Means within columns followed by different letters are significantly different by LSD at P=0.05 level

Regression analysis (1,200 fruit) confirmed these observations, yielding a regression coefficient of 0.05 (e.g., can be interpreted as only 5 % of the variability associated with pitting can be explained by skin color). From a practical point of view, these results imply that within the typical skin color range of a commercial harvest of 'Sweetheart' [CTIFL 3.5-5], differences in level of pitting may not be quantifiable, though care should be taken with this interpretation since fruit were only studied at one site.

Methods

Objective 1: Ten cultivars were evaluated: 'Chelan', 'Tieton', 'Benton', 'Cowiche', 'Bing', 'Lapins', 'Skeena', 'Regina', 'Selah', and 'Sweetheart'. Two sites were used for each cultivar (one in WA and one in OR), with the exception of 'Cowiche', due to a lack of bearing trees identified in OR. For each cultivar, three similar trees were identified as representative of the general state of the orchard. The first of three successive harvest dates began when fruit entered the very early end of the commercial range. On each harvest date, occurring several days apart and determined by the rate that skin color changed, one entire tree was strip-picked, fruit were brought to the lab, and each fruit was classified according to its skin color using a CTIFL color scale (1, pink-7, black). Within each CTIFL class, five replicates of five fruit (25 total fruit) each were randomly selected for evaluation of quality attributes. Quality attributes assayed were: titratable acidity (TA), soluble solids (SS), fruit firmness (FF), stem retention force (g), fruit weight, fruit diameter, row size, and mesocarp fruit color.

Objective 2: For the methods outlined above, 200 fruit were chosen randomly from each CTIFL class of each harvest date, for all cultivars. Fruit were placed in poly liners, boxed and held at 1° C. Beginning one week from the harvest date, 25 fruit were chosen from each CTIFL class and analyzed, as discussed above, weekly for a one month period (10 cultivars* 3 harvest dates * 4 post-harvest sampling dates * 2 sites for each = 240 sampling periods, each comprised of multiple CTIFL classes). Two methods for evaluating pitting incidence and severity were employed: 1) artificial pitting using a tool ('Bing' and 'Lapins') [2009], and 2) a commercial packing line ('Sweetheart') [2009-2010]. For 'Bing' and 'Lapins', pits were induced opposite the suture side on the equatorial region of fruit using an instrument (developed and provided by F. Kappel) designed to mimic the occurrence of impact injury by dropping a 10 gram steel ball on the fruit surface. Following the mid harvest timing, fruit was immediately cooled to 4° C, separated into CTIFL classes (125 fruit for each class), pitted, then placed in 1° C storage and evaluated weekly for one month. Pits were classified according to the diameter of the pit. A four point scale was used to report pit severity (4 = severe, 1= no pitting), based on a previously published correlation between visual assessment of pit severity and pit diameter (Toivonen et al., 2004). For 'Sweetheart', whole bins of fruit harvested at four harvest timings, chosen when trees reached a pre-determined average CTIFL, were handled commercially, run over a packing line, placed in lined boxes, and held at 1° C until evaluated. Evaluations were performed following 21 days postharvest. Entire contents of 20 lb cherry boxes were analyzed for pitting in 2009. Briefly, total fruit per box were divided into CTIFL color classes, and pits were counted on all fruit within each color class. Further, twenty-five fruit were then chosen from each pit severity category, and each pit was measured (diameter). In 2010, 200 fruit were analyzed per replicate box, per treatment.

Objective 3: Full bloom and harvest dates were recorded for each cultivar. Orchards with meteorological stations present, or nearby were selected. Growing degree day models will be constructed from these data. Data analysis is ongoing.

Objective 4: Digital images were taken of fruit cultivars at each CTIFL score. Images will be compiled for extension education materials.

Executive Summary

A study was initiated to relate skin color (common commercial harvest indicator), harvest timing, and internal fruit quality attributes of ten commercially viable sweet cherry cultivars. Cultivars were studied over a two-year period at multiple sites. In addition, we investigated the effect of duration of cold storage on these quality attributes.

With successive harvest dates, skin color of sweet cherry cultivars darkened. The relationships between skin color and fruit weight, diameter, mesocarp color, soluble solids, firmness and stem retention force, were all highly significant. Total acids did not consistently change with skin color. Fruit firmness and stem retention force declined with advancing skin color, however the rate of change varied from year to year, and in the case of retention force was augmented by high temperatures. Although the averages of individual quality attributes steadily changed relative to harvest timing, individual harvests comprised a wide range of cherry skin colors. Our results concur with previous reports demonstrating inherently high variability in sweet cherry skin color at harvest. We examined the role of flower timing on final fruit quality, and observed an increase in soluble solids and size with early blooming flowers. We have also observed a clear cropload interaction with fruit quality, and are presently investigating the role of cropload on cell division and growth relative to fruit size throughout ontogeny. Future research efforts need to focus on identifying sources of cherry variability.

Individual cultivars yielded excellent relationships between skin color and quality attributes. In fact, despite differences in absolute values between sites (associated with climate, lab instrumentation, etc.), equations and slopes describing the relationships between skin color and quality attributes of a given cultivar were similar. If internal quality is sought to be optimized by lengthening the time that fruit persist on the tree, a balance must be struck between positive (increasing soluble solids and fruit size) and adverse (fruit softening, lower stem retention force) effects. These relationships vary slightly with cultivar. It is evident that these factors are also modulated by environment and we are continuing efforts to explain these changes using growing degree day models.

Storage of fruit at 1 °C, for up to 28 days, did not result in a marked decline in fruit quality. Fruit firmness was consistently observed to increase with storage time, irrespective of cultivar. Total acids typically degraded as storage time increased, but the rate of decline was cultivar dependent, and the response was not observed for all cultivars tested. Sugar content was not influenced by duration of storage, likely due to good humidity control and maintenance of fruit water content (evaluated by fruit weight). We also investigated the relationship between skin color and post-harvest pitting incidence of ‘Sweetheart’. Skin color did not relate to severity of pitting for ‘Sweetheart’ in each of two years of studies.