FINAL PROJECT REPORT

Project Title: Increasing decision confidence in cultivar development and adoption

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Other funding sources

Agency Name: USDA-CSREES National Research Initiative
Amount awarded: $400,000 (2009-2011)
Notes: "Functional gene markers for Rosaceae tree fruit texture" PI: Cameron Peace. Co-PIs and major collaborators: include Evans, van de Weg, McFerson. Supplied valuable information on cultivar genetic potential provided by key ethylene and related texture markers.

Agency Name: WTFRC Apple Review
Amount awarded: $635,201 (2009-2011)
Notes: "Apple Scion Breeding" PI: Kate Evans. Co-PIs include Peace. The foundation program on which this project was built. Develops new cultivars and engages the IAC.

Agency Name: USDA-CSREES, Specialty Crop Research Initiative
Amount awarded: $7,200,000 + same matched by universities and industry (Sep 2009 – Aug 2013)
Notes: "RosBREED: Enabling marker-assisted breeding in Rosaceae". PI: Amy Iezzoni. Co-PIs include Peace, Evans, Main, Bink, and van de Weg. Useful outputs included *Ma* locus haplotype categorization and socio-economic knowledge on trait values.

Total Project Funding:

Budget History:

Item	**2011**		
Salaries			
Benefits			
Wages	$ 4200		
Benefits	$ 630		
Equipment			
Supplies	$ 5000		
Travel	$ 4000		
Plot Fees	$10,000		
Miscellaneous	$73,000[1]		
Total	**$96,830**		

[1] $48,000 for co-PI Craig Hardner (40% time, $1000 computer supplies, $7000 for 2 x Aus-WA), $10,000 for co-PI Marco Bink (50 hours time), and $15,000 for project-culminating workshop in Wenatchee.

RECAP ORIGINAL OBJECTIVES

Overall goal: Improve release and adoption decisions about the WA apple breeding program's new cultivars by revealing and communicating genetic potential for commercial performance.

Specific objectives:
1. Improve efficiency and predictability of advanced/elite selection trials by optimizing field experimental design.
2. Put rapidly accumulating DNA information to immediate use for WA apple growers by describing genetic potential of new cultivars in the context of commercial production.
3. Demonstrate the efficacy of a combined field-design and DNA-based approach and opportunities to the WA apple industry.

SIGNIFICANT FINDINGS

- The most important genetic-based drivers of grower adoption of new cultivars are consumer appeal, biotic stress resistance, yield, packout, and timing and length of the harvest and market windows.

- The WABP's current P2 trial design efficiently identifies genetic potential in selections for most fruit quality traits, but we have identified opportunities for improvement.

- Differences in performance among selections are relatively stable across P2 locations, and so the WABP can confidently predict orchard performance, but P3 data on postharvest performance is essential.

- Trial location, season, tree age, and storage each affect most fruit quality traits by increasing or decreasing the observed mean, but rarely change the relative ranking among varieties.

- Genetic potential for most fruit quality traits can readily be determined in few years, and selections that fail to perform well in early years of a trial can be safely discarded early.

- Effects of trial location, season, tree age, and storage must be calculated and adjusted for before genetic potential of a selection can be determined from a dataset that contains multiple levels of one or more of these factors.

- For certain traits that are highly unpredictably influenced by environmental conditions, such as sweetness, enhanced replication is required to obtain robust estimates of genetic potential.

- Available DNA tests currently used in the WABP can help predict performance for texture traits within and across WA growing regions.

- Pre-screening of parents and seedlings with predictive DNA tests for any traits currently evaluated in P1-P3 field trials is especially valuable for improving breeding efficiency.

- Opportunities exist to incorporate more DNA information for increasing decision confidence in new cultivar development.

- Multiple avenues of information delivery to growers and feedback to the WABP on new cultivar genetic potential for commercial success are important to maintain.

RESULTS & DISCUSSION

Choice of scion-rootstock combinations is the single most profit-influencing decision that a grower can make. While planting standard scion cultivars is an option to mitigate risk, new cultivars from breeding efforts provide sustained genetic solutions to flaws in standard cultivars or to address market opportunities. Successful genetic improvement of apples for the Washington industry does not end with the release of superior new regionally adapted cultivars from the Washington apple breeding program (WABP). To have industry impact, a cultivar must first be adopted by growers and shippers and then managed effectively to maximize its genetic potential. For long-standing cultivars, genetic potential has mostly revealed itself to the industry over a multitude of orchards and seasons, and hopefully this practical information base has been complemented by objective cultivar-specific research and effective outreach. However, to make planting and management decisions on *new* cultivars, limited commercial experience with these cultivars means decisions rely on other sources of information to predict genetic potential: orchard and storage performance in multi-year breeding trials in representative locations with commercially relevant horticultural management, pedigree knowledge, and confidence in the breeder's rigor in selection. Strong experimental design of evaluation trials in breeding programs enables the genetic potential of selection under commercial conditions to be predicted with optimal time- and resource-efficiency. Also, the accuracy of evaluation trials, determination of pedigree, and selection may each be enhanced with genetic information at the DNA level – a more direct predictor of genetic potential. Finally, information gained on genetic potential from multiple sources needs to be appropriately compiled and delivered to the industry to allow sufficiently informed cultivar planting and management decisions that maximize the probability that profitable production outcomes can be achieved.

The original proposal posed the following:

> **The key question underlying selection decisions made by breeders and growers is:**
> ***How well do different sources of information predict cultivar performance in commercial orchards?***

Many approaches were taken in 2011 to answer this question, and a project-culminating Workshop was held in December to discuss and finalize our understanding. The following describes how well each of 20 sources of information predict cultivar performance in commercial orchards. More detailed reports developed in 2011 on some of these topics are available on request.

1. Information from grower feedback

Grower, including IAC, feedback on selection performance and potential for commercial release provides a valuable source of advice for the WABP and for other growers. To date, this information has been provided subjectively, and would benefit from a formal, systematic method of obtainment allowing objective incorporation with other information sources to improve confidence in breeding decisions. The "comfortable redundancy" in number of trial locations (point 7 below), especially in Phase 3 (P3), has the added benefit of enhancing opportunities to engage growers locally in selection evaluation. P4 evaluations are another critical information source on optimal tree management, fruit handling, and market targeting of new WABP cultivars. Currently, existing WSU and WTFRC personnel are stretched thin across this bottleneck in the system. A dedicated WSU expert in technology transfer focusing on elite selection and new cultivar evaluation for the Washington production environment is a strategic necessity to the WABP-industry's continuum of new cultivar development, adoption, management, and superior product delivery.

2. **Information from P3 trials**

For the few elite selections showing outstanding performance in P2, P3 trials use heavy replication with the aim to efficiently obtain estimates of genetic potential for harvest window, yield, storability, and packout. With effective preceding P2 trials, P3 can emphasize those traits that critically contribute to field operations, market performance, and return on investment but are highly sensitive to environmental conditions, very expensive or laborious to evaluate for each selection, and/or for which minor differences have large effects on the bottom line. Selection rejections in P3 to date appear to have mostly been for reasons that have later revealed themselves to be important to the current industry (e.g., a flavor profile that doesn't fit the industry's expectation of a Washington apple) rather than for poor performance that was not detected in traits evaluated in P1 and P2. Replication of each elite selection involves at least fifty of trees over at least four locations and with at least three years of fruiting trait evaluation. For practical reasons, fruit samples for a selection within a season at a location are bulked over trees, comparison to standard cultivars is ad hoc and depends on what is already growing in adjacent orchards, and management regimes are different across locations – all of which may limit conclusions that can be made on estimates of genetic potential. A rigorous quantitative genetics statistical examination has yet to be undertaken on the power of the current P3 trial design to predict commercial genetic potential of elite selections for P3-evaluated traits.

	Gala/Vantage	WA 2/Quincy			
	Aug. 27	1st pick Sept. 29	2nd pick Oct. 7	3rd pick Oct. 13	4th pick Oct. 20
Firmness (pounds)	20.1	20.3	19.6	19.4	19.5
Diameter (inches)	3.2	3.3	3.4	3.5	3.4
Weight (grams)	247.0	263.0	289.0	317.0	287.0
Color (1-5)	5.0	3.3	3.3	3.4	3.4
Starch (1-5)	3.0	2.4	2.8	2.6	3.9
Sugar (Brix)	11.4	12.7	11.7	13.0	12.3
Acid (percent malic acid)	0.370	0.558	0.546	0.537	0.538

Figure 1: Example of performance information provided on new WABP cultivars from P3 trials Excerpt is from article in Good Fruit Grower*, Aug 2011: "Apple selections evaluated for postharvest performance" by Ines Hanrahan, Tom Auvil, and Kate Evans.*

3. **Information from P2 trials**

For dozens of promising selections to date, P2 uses some replication with the aim to efficiently obtain estimates of genetic potential for productivity, tree health, fruit quality, and susceptibility to storage disorders. Of these, only fruit quality is also previously evaluated in P1. The empirical observation that P3 rejections are for reasons other than poor performance for fruit quality traits evaluated in P1 and P2 gives confidence that P2 is effective. In other words, relative performance of selections observed from P2 provides a good estimate of genetic potential for commercial production environments for those traits evaluated in P2.

In addition to providing decision confidence for selection advancement decisions, P2 trials provide extensive, deeper performance data for fruit quality and productivity traits that influence P3decisions of selection advancement to commercial release. P2 replicated trials are currently conducted with annual plantings at three locations of several new selections randomized with up to five "check" cultivars, with five trees of each variety (selection or check cultivar), and evaluation of fruiting traits for at least three years. Analytical efforts in 2011 on relative magnitudes of sources of variation in WABP trials (points 6-12 below) focused on P2 as there are fewer varieties in P3 trials and no replication in P1 trials.

4. **Information from P1 trials**

P1 single-tree trials on thousands of new seedlings per year provide an opportunity to eliminate genetically inferior seedlings prior to significant resource investments (in P2 and beyond) that are required to gain information on performance for certain traits. P1 evaluations are therefore for those that are cheap and simple to conduct for each seedling, are little influenced by non-genetic factors, and/or are critical but only a low proportion of seedlings meet the designated threshold. Because the reasons for selection rejection in P2 include poor performance for traits that are or could be evaluated in P1, P1 can be considered to be somewhat "leaky" and some adjustments may be possible to improve overall efficiency. Pre-screening with predictive DNA tests for any traits currently evaluated in P1-P3 field trials would be especially valuable – thus the investment in establishment of marker-assisted breeding capability for the WABP over the last five years.

5. **Information from bulked sampling in P2**

A design element of P2 trials to date limits conclusions that can be made about genetic performance differences at specific locations. Bulked sampling is used, where the single samples obtained for a variety from each pick date are pooled across five trees to evaluate fruit quality traits. While it allows streamlined fruit handling and evaluation, this bulked sampling method does not allow the critical determination of differences among varieties at a location to be made because there is no independent replication of a variety at each location. Differences among varieties for the single observation of a trait at a single location are confounded by variation in the trait within a variety among its trees and among fruit on a single tree.

This sampling design also does not provide sufficient information to allow alternative sampling designs to be evaluated. The estimates of repeatability of the single observation across pick-dates are only useful for examining the adequacy of the number of pick-dates. However, as long as the statistical interaction of Genotype x Location (GxL) is not a significant source of variation (which it isn't for at least some traits – see point 7 below), this sampling may be an efficient design for predicting average genetic potential across the growing region by using the mean across three locations. Significant differences were detected among selections and standard cultivars for most traits, suggesting that three locations is a sufficient number for selection trialing.

6. **Information from comparisons to standard cultivars**

Comparisons with particular standard cultivars are used in P2 to calibrate trial performance to known commercial performance. Probabilities can be assigned to whether each selection performs better (or worse) than each standard cultivar for each trait (Figure 2; Table 1). Confidence in the genetic potential of selections could be increased if there were more varieties (selections and/or standard cultivars) in common planted in each year to improve connectedness among trials and allow effects of age and season to be accurately identified and adjusted for. In 2009 and 2010, the same five standard cultivars were planted in each location in each year, which is expected to provide strong genetic potential discernment. However, two other ways to increase connectedness among plantings would be to (1) include elite selections from P3 or new cultivars from P4 rather than additional standard cultivars, or (2) planting P2 trials only every second year, thereby combining the selections that would otherwise have been planted separately in two annual plantings, and halving the number of standard cultivar trees need. Given the long term activity that is apple breeding, it is unlikely the loss of a year of evaluation for those selections delayed a year would be a major detriment.

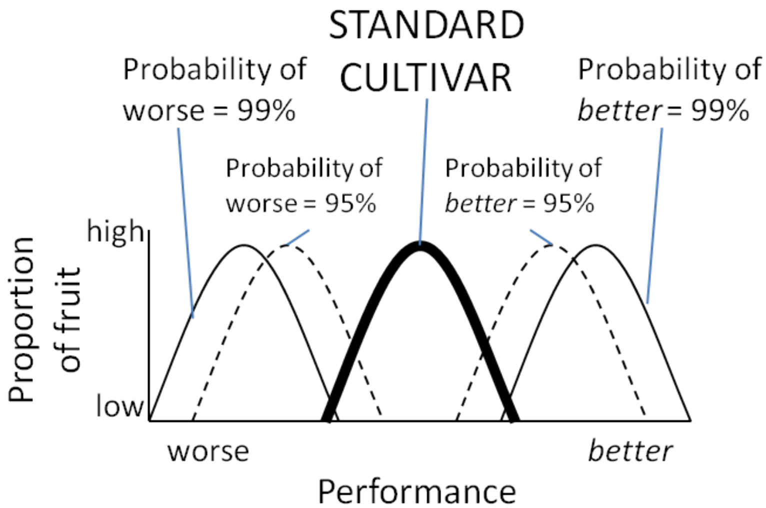

Figure 2: Visualization of what it means for a selection to outperform or underperform in comparison to a check cultivar. Probabilities can be quantified as to whether a selection's evaluated fruit (or some other important attribute) are statistically significantly better or worse than a standard cultivar. The standard cultivar is included in the same trials as selections.

No. of P2 selections	Probability of performance relative to standard cultivar				Example cultivar also evaluated
	Honeycrisp	Gala	Cripps Pink	Gala	
1	equal	*99% better*	*99% better*	*99% better*	
2	equal	*95% better*	*99% better*	*99% better*	
12	equal	equal	*99% better*	*99% better*	Honeycrisp, Gala
3	equal	equal	*95% better*	*99% better*	Braeburn
2	equal	equal	*95% better*	*95% better*	
2	equal	equal	equal	*95% better*	
4	95% worse	equal	*99% better*	*99% better*	
1	95% worse	equal	equal	*95% better*	
2	95% worse	equal	equal	equal	
1	99% worse	equal	equal	*95% better*	
1	99% worse	equal	equal	equal	
2	99% worse	95% worse	equal	*95% better*	
1	99% worse	equal	equal	equal	
4	99% worse	99% worse	equal	equal	Golden Delicious, Cripps Pink, Fuji

Table 1: Adjusted mean performance (= genetic potential) for sensory crispness of WABP selections, 2004-2010 Phase 2 trials. Sensory crispness was measured on a 1-5 scale, where the adjusted (according to location, year, and storage) mean for standard cultivars were Honeycrisp = 3.8, Gala = 3.4, Cripps Pink = 2.3, and Fuji = 2.1.

7. **Information from multiple trial locations**
Performance at breeding trial locations appears predictive of commercial performance. Although P2 trial locations used are reasonably diverse, relative performance of varieties across those locations was stable for most fruit quality traits (and thus GxL [GxE] appears to be low). Because genetic correlations are therefore high among variety means across locations, and growers appear satisfied that one or more of these trial locations represent their own location, performance information from these multiple locations is likely to be predictive of performance in commercial orchards. This conclusion wouldn't have been valid if we'd found that one site was not well correlated with others – in that case the WABP couldn't tell what was "typical" and would need to replicate across more locations.

Although stability across locations indicates redundancy of locations, the current design has comfortable redundancy: evaluation over multiple locations provides insurance against unforeseen events leading to loss of information at any one location in a given year. Furthermore, relatively accurate predictions can be made for most fruit quality traits on less replication if resources in a given year are reduced.

8. **Information from particular trial locations**
A strong main effect of location was identified for all fruit quality traits examined. This finding underlies a strong recommendation for the WABP to determine and take into account the location mean effect when establishing genetic potential of selections. Not doing so would lead to incorrect estimates of genetic potential. An example of the implications: The current practice in P3 of comparing selections with standard cultivars growing in nearby orchards or at other locations rather than being established in the same planting may lead to under- or over-estimation of the true genetic potential of selections if there are environmental differences between the orchards (which according to our analyses is likely).

9. **Information from multiple years (season and tree age)**
As for locations, strong main effects of season and tree age were observed, and therefore these effects need to be calculated and adjusted for when establishing genetic potential of selections. Ranking of varieties appeared stable over seasons (and thus GxY [GxE] appears to be low). However, we were not able to separate the effect of tree age from the effect of season on the ranking of varieties.

Although an extensive examination was not undertaken due to time constraints, initial results suggest that fruit sampled from 2nd leaf trees are more variable than fruit sampled from older trees. It could not be determined if the apparent greater variation in fruit from the younger trees was due to ontological changes, improvement in the ability of field assessors to select mature fruit, or the greater number of mature fruit at later years enabling only mature fruit to be selected for assessment. However, the consistent ranking of varieties over assessment years suggests that the relative performance of varieties does not vary with age. Further investigations should be undertaken in this area.

One implication of the consistency of the ranking of varieties among seasons is that it may not be necessary to assess selections over many seasons. Another is that the current practice of eliminating some selections due to inferior performance in early years of P2 trialing appears suitable because it is unlikely that eliminated selections would start to show superiority in other seasons.

10. **Information on fruit maturity**
Fruit maturity should be either carefully standardized or else accurately measured for each sample and a mean-adjustment made when establishing genetic potential of selections for sensitive traits. A

main effect of fruit maturity, as ascertained by starch levels, was generally more pronounced for instrumental traits than sensory, perhaps because starch ratings are assessed on fruit that are also used for instrumental evaluation while sensory evaluations are done on separate sample of fruit from the same bulk. Certain traits were especially sensitive to fruit maturity (such as instrumental firmness and acidity and sensory sweetness). These relationships were generally consistent across varieties.

In the few location-year trials where sensory crispness had a significant relationship with fruit maturity, it was observed that crispness increased with fruit maturity – an interesting result indicating that WABP evaluations have successfully uncoupled the measurement of firmness and crispness at least for sensory measures.

It would be useful to examine how accurately the current sampling design estimates the starch rating of the bulk sample. Despite the intention to harvest fruit with the same maturity across pick dates, the starch rating of fruit from 2^{nd} leaf trees increased with harvest date. However, this confounding relationship was generally avoided in older trees, probably because the greater number of fruit on older trees allows more careful choice of consistent fruit. Therefore, evaluations in 2^{nd} leaf are not likely to be accurate for determining a selection's harvest window; efforts to establish the harvest window could be shifted to older trees only.

11. **Information on storage treatment**

Genetic potential of selections should not be calculated from an average of pre- and post-storage performance for traits that were sensitive to storage (such as firmness and acidity). In contrast, traits like shape, russet, lenticels, skin color, and even sensory tartness and crispness, were independent of storage condition. Only a few traits (especially instrumental firmness) showed evidence that storage affected the ranking of varieties, meaning that the relative genetic potential of varieties for a trait depends on if the apple is consumed fresh or after storage. Further investigations are required to identify if only particular varieties are susceptible to different storage conditions or it is a general re-ranking of all varieties.

For the majority of traits that didn't exhibit any interaction with storage, the ranking of varieties is essentially the same for fresh fruit as for fruit after storage. This lack of re-ranking under storage indicates that it may be inefficient to evaluate fruit quality both pre- and post-storage in P2 trials. As storage provides a useful indicator of susceptibility to storage disorders, fruit quality evaluation only after storage might be more efficient than the current practice. However, at-harvest fruit quality data collected in P2 provides an important baseline and depth of performance data in later years for decision confidence regarding handling and advancement of P3 elite selections.

12. **Information from multiple pick dates**

Multiple pick dates are used to help determine the length of the optimal harvest window – how long fruit can be harvested from a selection to provide superior or sufficient quality fruit to the market. P2 selections are picked at two to three pick dates that are a week apart. For those traits with high repeatability across pick dates, such as acidity and firmness (Figure 3), the P2 performance observed at any given harvest of ripe fruit (i.e., any pick date) is a good indicator of performance in general. Conversely, for those traits with low repeatability across pick dates, such as sensory sweetness, SSC, and sensory aroma (Figure 3), more replication is required. However, such replication should not be via additional pick dates as this is re-sampling of the same trees and thus is not independent replication. The next point describes improved replication strategies to gain a better measure of genetic potential for traits with low repeatability.

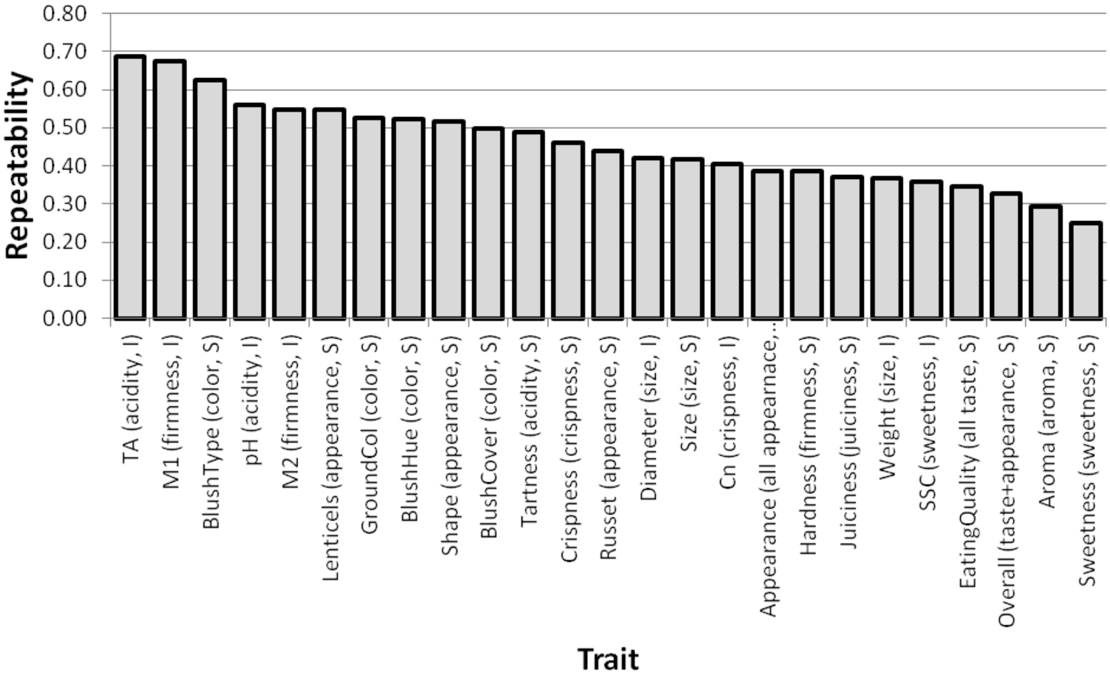

Figure 3: Repeatability of various fruit quality traits as determined from analysis of multiple pick dates in P2 trials from 2004-2010. "I" refers to traits determined from instrumental *measures, while "S" refers to* sensory *measures.*

13. **Information on trait heritability**

Heritability of a trait indicates the strength of genetic effects in determining the mean of a variety, once known environmental effects such as location, season, etc. have been adjusted for, compared to the strength of unpredictable environmental conditions. For highly heritable traits, the performance of a variety relative to other varieties observed at any given location, season, tree age, maturity, and storage condition is unlikely to change when the same varieties are observed under another situation, and so is a good indicator of performance in general (genetic potential). Conversely, for traits highly and unpredictably influenced by environmental conditions, the WABP needs greater replication than currently used to be confident that the observed adjusted mean is indicative of genetic potential.

Although the trial design did not allow assessment of heritability, multiple published studies have indicated that fruit firmness and acidity (and harvest date) have high heritability. Repeatability across pick dates, described in the previous point, was highest for instrumental measures of these same traits. Similar to published studies of heritability, we identified that sweetness (sensory and SSC) and aroma were more affected by undetermined environmental effects than all other examined fruit quality traits. Therefore, more replication is needed for gaining valid estimates of genetic potential for sweetness. Because of the bulked sampling method used in P2, the relative merits of increasing fruit number, tree number, or pooled sample number could not be determined, but one of these would be an efficient means of gaining a better estimate of genetic potential for this type of trait. Other replication-increasing approaches, such as more picks, locations, or years, would be less statistically robust or much more resource-consuming and thus less efficient.

14. **Information on each trait**

Some traits and performance levels for them are more important than others for commercial viability of a new cultivar. The WABP needs confidence that a selection performs above the minimum for all traits (= achieves “essential”/baseline levels). The WABP also needs confidence that a selection performs exceptionally for one or more traits (= contains one or more “bells & whistles”). A trait target checklist has been developed (and is being refined) to allow systematic evaluation of such performance levels, especially for decisions regarding selection advancement out of P2 and P3.

15. **Information on genetically correlated traits**

Opportunities may exist for information on one trait to predict performance of another. Analyses of genetic correlations among traits to assess this have not yet been performed. For example, if TA and sensory acidity were calculated to be very highly genetically correlated, it would indicate that selection decisions need only take into account one of these measures of acidity. A high genetic correlation between a pair of traits would also indicate that measurements on both at the same time would be redundant and so dropping one would allow gain in efficiency (depending on the relative ease of such measurements and the opportunity/resource cost of missing other trait evaluations).

16. **Information from trained sensory and consumer panel evaluations**

Detailed evaluations of elite selections conducted by Carolyn Ross’s program focus on fine-scale determinations of differences among selections and check cultivars for fruit quality traits (trained sensory panels) and consumer preferences for fruit quality traits and trait combinations (consumer panels). Information from Dr. Ross’s studies has established a sensory profile baseline and identifies gaps in the current market portfolio of varieties. The information could be used in establishing objective trait priorities/weights at earlier stages of the WABP selection process. Measures obtained from trained sensory panels and preferences from consumer panels could be examined for correlation with P1 and P2 trait measures (sensory and instrumental) to determine how well the same traits are being evaluated. Such analyses have not yet been conducted.

17. **Information from the *Ma* locus**

Initial results indicate that the *Ma* locus is predictive for the traits of sensory crispness, sensory and instrumental firmness, and sensory juiciness at harvest. The test explained 28%-48% of the observed genetic variation for these traits and this was relatively stable across trial locations. Unexpectedly, the test provided no prediction of TA/tartness levels in selections, perhaps because of the truncated upper range in this elite germplasm. The test was also not predictive of instrumental crispness (Cn) or overall eating quality. The genetic test therefore appears to be a useful tool for guiding crossing and P1 seedling culling decisions for some fruit quality traits via marker-assisted selection, to help enrich progeny populations and their field-planted subsets with individuals that are expected to reach and in some cases exceed required baseline levels of texture genetic potential.

While there is evidence that some haplotypes were significantly better or worse than others for certain fruit quality traits at harvest, an alternative hypothesis is also plausible that the extreme haplotypes are due to alleles at other loci from specific sources. For example, the best two haplotypes for crispness are both from Honeycrisp, but superior Honeycrisp alleles elsewhere in the genome than the *Ma* locus may be providing superior crispness in its descendant selections. If the *Ma* locus does not contribute to the superiority calculated for Honeycrisp’s haplotypes, the worst the WABP can do by selecting for seedlings (grandchildren of Honeycrisp) carrying these haplotypes is lose seedlings with unknown genetic potential. However, the monetary cost of using the *Ma* locus test when the same seedlings have already been screened for other markers is marginal, and if the initial number of seedlings is greater than the WABP’s P1 capacity, there is little to be lost and much to be potentially gained by *Ma* locus screening. Furthermore, general use of the test to screen against poor haplotypes appears justified because the two poorest were single haplotypes from two different parental sources.

The *Ma* locus analysis provided the first quantitative genetics examination of predictive marker effects for WABP replicated trials, opening the door for further trait loci to be examined.

18. **Information from other trait loci**
We expect that other available genetic tests can be used to help predict genetic potential for fruit texture by explaining some of the genetic variation not covered by the *Ma* locus. However, the *ACS* and *ACO* gene tests were not very predictive of most traits in P2 trials. While the previously known alleles contributing low fruit ethylene levels tended to be associated with better firmness, especially at the Wenatchee trial location, their effects on texture were not anywhere as strong as those of the *Ma* locus. Combined analysis of the effects of the three trait loci on texture components may reveal that certain combinations of alleles are particularly predictive, but such analyses have yet to be performed. Several other potentially predictive genetic tests of fruit quality are available now but have yet to be tested for their predictability of P2 performance. From massive advances in 2011, the RosBREED project is poised in the first half of 2012 to discover and validate many new markers for apple fruit quality. Heavy involvement of the WABP in the RosBREED project will ensure these scientific breakthroughs are efficiently transferred to Washington apple industry benefit.

19. **DNA information from across the genome**
We expect to eventually build up comprehensive information from multiple trait loci to most accurately predict variety performance. Trait locus marker-based approaches as described above can be used to capture genetic variation explained by those markers. But in the meantime, while available trait locus markers explain only some of the observed genetic variation among varieties, a promising new approach called genomic selection (GS) may allow us to capture the majority of useful genetic variation for important traits to predict performance. The availability of many markers across the whole genome (such as the >5000 informative SNP markers from the RosBREED project's new genome scanning capability) makes GS possible. This promising approach should complement the WABP's existing MAB capability and to take advantage of advances in genomics technology. The accuracy of GS to predict new cultivar performance in commercial orchards depends on the size and comprehensiveness of the training dataset of performance information. Historical WABP performance data from P2 and P3 trials is a good start, and should be bolstered by existing cultivar trial data and RosBREED data. Performance-evaluated individuals in the latter have already undergone the necessary genome scanning (approx. $70 per individual if part of a larger coordinated effort). GS algorithms have yet to be developed for the WABP.

20. **DNA information on parentage and identity**
Performance is often viewed in light of the parentage of a selection/cultivar. DNA marker data (especially from genome scans) are useful to confirm or deduce parentage. In the absence of information on particular alleles at trait loci inherited from parents, parentage in general plays an as-yet unquantified role in new cultivar adoption decisions. Parentage is very important in breeding decisions – not in selection advancement decisions (unless a selection was intended to be descended from a unique trait source) but in crossing decisions. Even if the *Ma* locus is not predictive, our analyses in 2011 indicate that Honeycrisp is an excellent parent for crispness! Similarly, from other observations, Cripps Pink is an excellent parent for precocity, and many other traits have superior parental sources. The WABP would benefit from a systematic evaluation to determine the value of each parent and parental combination for providing particular levels (useful to approach this from the viewpoint of essential vs. bells & whistles) of each trait, which can be determined via calculations of general and specific combining abilities. Also, such information will be amplified in value for the WABP through use of RosBREED's Cross Assist tool (coming soon!) that directly uses such information to refine crossing possibilities.

Finally, simply confirming the identity of a selection or cultivar is a useful application of DNA testing and is a critical contributor to decision confidence for growers and the breeder when identity of a set of propagated trees is in any doubt.

EXECUTIVE SUMMARY

In 2011, a scoping project was undertaken to identify sources of information about genetic potential that can increase decision confidence in new cultivar development (breeding) and adoption (uptake by industry). Once identified and debated among project participants in various forums, we investigated methods to obtain within the breeding program and deliver to growers the most relevant decision-influencing information.

Some major findings in 2011 were that:

- The most important genetic-based drivers of grower adoption of new cultivars are consumer appeal, biotic stress resistance, yield, packout, and timing and length of the harvest and market windows.
- The WABP's current P2 trial design efficiently identifies genetic potential in selections for most fruit quality traits, but we have identified opportunities for improvement.
- Differences in performance among selections are relatively stable across P2 locations, and so the WABP can confidently predict orchard performance, but P3 data on postharvest performance is essential.
- Trial location, season, tree age, and storage each affect most fruit quality traits by increasing or decreasing the observed mean, but rarely change the relative ranking among varieties.
- Genetic potential for most fruit quality traits can readily be determined in few years, and selections that fail to perform well in early years of a trial can be safely discarded early.
- Effects of trial location, season, tree age, and storage must be calculated and adjusted for before genetic potential of a selection can be determined from a dataset that contains multiple levels of one or more of these factors.
- For certain traits that are highly unpredictably influenced by environmental conditions, such as sweetness, enhanced replication is required to obtain robust estimates of genetic potential.
- Available DNA tests currently used in the WABP can help predict performance for texture traits within and across WA growing regions.
- Pre-screening of parents and seedlings with predictive DNA tests for any traits currently evaluated in P1-P3 field trials is especially valuable for improving breeding efficiency.
- Opportunities exist to incorporate more DNA information for increasing decision confidence in new cultivar development.
- Multiple avenues of information delivery to growers and feedback to the WABP on new cultivar genetic potential for commercial success are important to maintain.

The 2011 project identified many opportunities for increasing decision confidence that warrant immediate attention in 2012 – some to refine and enact within the breeding program for impact in 2012, others to explore, test, and adapt to WSU's new cultivar development, release, and management program.

Engagement among all stakeholders in regional apple crop improvement is critical. Regular and systematic feedback between breeding and support program personnel and industry members, especially growers, is essential to the sustained success of the Washington apple breeding program and will amplify the return on investment and effort.