Project Title: Improving Apple Fruit Quality and Postharvest Performance

Report Type: No-cost extension

Primary PI: **Manoella Mendoza**
Organization: WA Tree Fruit Research Commission
Telephone: (509)669-4750
Email: manoella@treefruitresearch.com
Address: 1719 Springwater Ave.
Address 2:
City/State/Zip: Wenatchee, WA 98801

Cooperators: Peter Balk (Wageningen University and Research), Luca Galatro and Raffaele Romano (Vertigo Technologies), Loren Honaas (USDA – ARS). Dave Rudell (USDA - ARS) and Stemilt.

Project Duration: 3 Years

Total Project Request for Year 1 Funding: $ 36.661
Total Project Request for Year 2 Funding: $ 39,802
Total Project Request for Year 3 Funding: $0

Other related/associated funding sources: in-kind contributions = $30K.
Notes: Stemilt conducts the application of SmartFresh and donates and applies postharvest fungicides. The WA 38 apples are harvested from two Stemilt blocks. Vertigo-Tech provided the microwave sensor prototype. USDA is providing CA storage (chambers). The industry donates other miscellaneous supplies (trays, boxes, bags, etc.). The Dutch government, via Orchard of the Future collaboration: "Developing bilateral innovation projects (BIS) for technology development and application," provides funding for Vertigo Tech (traveling, machine shipping).

Item	**2023**	**2024**	**2025**
Salaries			
Benefits			
Wages	$24,802.00	$27,011.00	
Benefits	$10,629.00	$11,576.00	
RCA Room Rental	$1,180.00	$1,215.00	
Shipping			
Supplies			
Travel			
Miscellaneous			
Total	$36,611.00	$39,802.00	$0.00

Footnotes: Wages/Benefits: calculated based on expected staff wage adjustments.

Justification

One of the WTFRC internal program targets is to tackle high-priority industry needs that are not covered elsewhere. The Commission has used this project structure for several years, which enables us to respond swiftly to significant industry topics related to apple quality and postharvest issues. This includes the development of variety-specific starch scales (e.g., Honeycrisp, WA 38), testing various methodologies (e.g., bitter pit prediction methods for Honeycrisp), products (e.g., NSure sampling kit, Accuvin malic acid test), and equipment (e.g., Felix F750, DA meter).

This project structure is also beneficial for reducing required funding, as harvest and quality analysis for multiple objectives are conducted concurrently. In this funding cycle, the WA 38 was used for the starch degradation and the Fresco testing. Additionally, a new objective was added, and data was collected for the Granny software (WA 38, Honeycrisp, and Gala) at no additional cost, as it was integrated into the Fresco testing protocol. Granny Smith apples were also harvested this season and used for testing the Fresco and the Granny Software. The outcomes of this project lead to straight-forward, directly actionable results benefitting both organic and conventional growers, regardless of the size or scale of their operations.

Objectives

1. Evaluate new technologies to assess fruit quality parameters
    a. Testing Fresco (microwave sensor) to measure apple quality parameters non-destructively
    b. **(New)** Collaborate with Honaas lab to test the Granny software (image-based analysis) for starch degradation
2. Investigate the effect of 1-MCP on WA 38 starch degradation during RA and CA storage
3. Assess the influence of 1-MCP on WA 38 fruit flavor

Significant Findings

Fresco Microwave Sensor

- Wavelengths correlated with firmness, soluble solids, and titratable acidity were identified in the microwave spectra region
- Positive correlation of soluble solids, firmness, and titratable acidity is weak, moderate, and strong, respectively, when predicting quality parameters for a randomly selected set of apples, unseen by the model
- Soluble solids prediction was affected by the narrow distribution range, but the mean absolute percent error (MAPE) and bias are low, indicating that the error between prediction and observed value is low.
- The best-fitting model was for titratable acidity, with a coefficient of determination above 0.7 and low error metrics.

WA 38 Research

- WA 38 starch clearance rate and variability are influenced by tree age, with fruit from mature trees displaying a more homogeneous starch degradation compared to fruit from young trees
- Fruit from young trees (2 and 3 years) might need additional time in storage to achieve 90% of the fruit with a starch clearance of 5.0 required for packing and shipping

- 1-MCP treatment and CA storage did not impact the starch degradation rate
- 1-MCP had an adverse effect on the flavor of fruit harvested from mature trees in 2023, while fruit from mature trees that were not treated with 1-MCP was preferred among all tree age and treatment combinations

NOTE: The WA 38 research was concluded in 2024, and the findings were incorporated into the preceding report. As there are no new developments during this reporting cycle, I will refrain from reiterating the results here. All pertinent information regarding this project will be included in the final report. Progress on the Granny Software will be reported by the PI.

1. Evaluation of new technologies

a. **Fresco microwave sensor**

Methods

Fresco is a new sensor developed by Vertigo Tech, a startup, spin-off of Delft University of Technology in the Netherlands, and part of the Orchard of the Future Dutch-USA collaboration. The sensor is a hand-held device that uses low-energy microwaves to non-destructively measure fresh fruit quality parameters such as Brix, titratable acidity, firmness, juiciness, and dry matter. One differential is that microwaves penetrate deeper into the fruit flesh in comparison with, for instance, NIR sensing. The sensor is in the pilot stage, with prototypes tested by Vertigo Technologies, the Wageningen University in the Netherlands (part of the Next Fruit 4.0 Cool data), and the WTFRC.

In 2023, one bin each of Gala, Honeycrisp, and WA 38 was harvested at commercial maturity and treated with postharvest fungicide before storage. The WA 38 and Gala were stored in a Stemilt RCA room (RA, 33°F), and Honeycrisp was conditioned and stored in the WTFRC cold room at 37°F. Fruit was not treated with 1-MCP. A total of 700 apples per variety were sampled during four sessions, from January to April. The apples were taken out of storage the day before quality assessment, numbered, placed in trays, and left at room temperature for one day. Each apple was processed individually.

In this first phase, we collected data for three apple quality parameters: firmness (lb.), soluble solids content (% Brix), and titratable acidity (% m.a.). The goal was to use the data to pinpoint the wavelength associated with each quality parameter and test the accuracy of the prediction by comparing the results of the destructive measurements with the values predicted by Fresco. The Fresco measurements were taken on the sun-exposed and shaded sides of each apple, at the same location where firmness was measured with the Fruit Texture Analyzer. The Brix and titratable acidity were measured from the apple juice made with the sun-exposed and shaded pieces. The Felix 750 produce quality meter was used to collect non-destructive Brix values, and the results will be compared with the Brix predictions provided by Fresco. Peter Balk at Wageningen University also evaluated the same quality parameters as the WTFRC for two apple varieties (Gala and Elstar), with the addition of dry matter assessment.

To analyze the 2023 data, a partial least square (PLS) analysis was conducted to appraise the correlation between prediction (non-destructive) and destructive methods and to assess the accuracy of the non-destructive method. The regression model was validated using a K-fold and a Train/Test split. A 10-fold cross-validation performs the fitting procedure ten times, with each fit being performed on a training set consisting of 90% of the total training set selected at random, with the remaining 10% used as a "hold-out" set for validation. When using Train/Test split, part of the data is not used in training but only as a test set, unseen by the model.

UPDATE

In 2024, *Granny Smith* apples were incorporated into the experiment to expand the data range, with particular emphasis on soluble solids content (°Brix) and titratable acidity (TA). Pre-harvest samples were collected from all apple varieties to assess the potential of the Fresco device as a pre-harvest evaluation tool. In 2025, dry matter content was added as an additional quality parameter and evaluated during storage (January to March) alongside the other fruit quality measurements.

The dataset was analyzed using a neural network approach, with 80% of the data allocated for model training, 10% for validation, and 10% for testing. However, a substantial portion of the 2024 data could not be used because the probe accumulated dirt during continuous use without adequate cleaning, which caused signal drift (see Figure 1). *As a result, a no-cost extension was requested to allow for additional data collection during the 2025 season, enabling the development of a more robust apple quality model that can be validated in the subsequent year.*

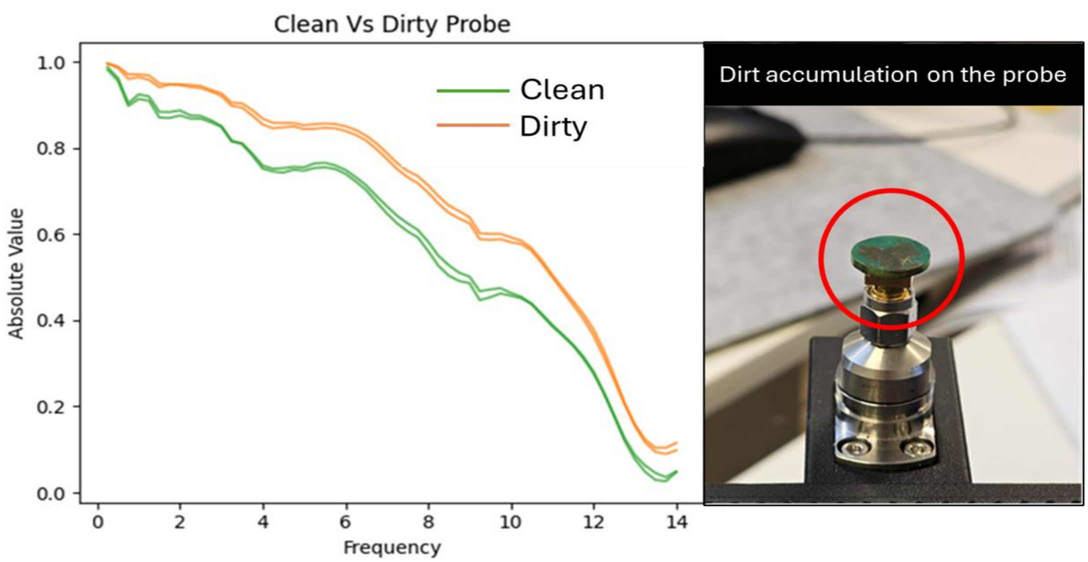

Figure 1. Comparison of the absolute value at different frequency points (GHz) for measurements taken with a clean (green, lower values) and dirty (orange, higher values) probe.

The results and discussion section is based on the updated statistical analysis of the 2023 dataset and a small portion of the 2024 data that was not affected by signal drift.

Results and discussion

Figure 1 shows the data distribution of soluble solids (A), firmness (B), and titratable acidity (C) assessed via destructive methods. The overall range of variability between time points is low, especially for soluble solids. This range restriction can affect the correlation coefficient. Titratable acidity showed the highest variability among apple varieties, but the mean values across sessions were similar, except for WA 38 and Gala at the first-time points.

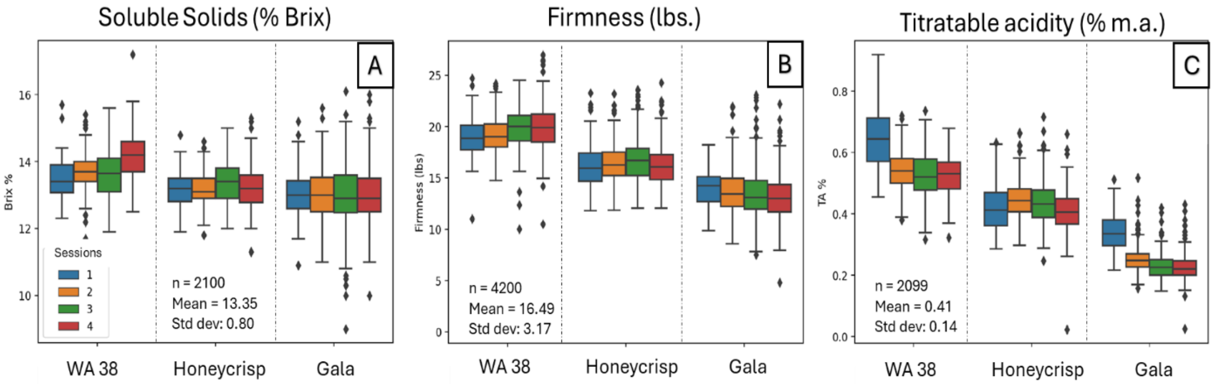

Figure 2. The data distribution of soluble solids (A), firmness (B), and titratable acidity (C) was measured using destructive methods for WA 38, Gala, and Honeycrisp apple varieties. Quality parameters were evaluated at four different times during the storage period. The graph shows the total number of data points (n) and the mean and standard deviation (Std dev) for each quality parameter.

The data from the three cultivars were combined to train, validate, and test the model for each quality parameter. Model training was conducted on 80% of the dataset, and validation and testing were conducted on the remaining 20%, split equally. Validation and testing were conducted on a portion of the dataset unseen by the model (Figure 3). The model training and testing scatterplots (Figure 3) and the correlation coefficient and error (Table 1) show variability in prediction accuracy between quality parameters.

Positive correlations for soluble solids, firmness, and titratable acidity are weak, moderate, and strong, respectively, when predicting quality parameters for a randomly selected set of apples unseen by the model. Among the three tested quality parameters, the best-fitting model was for titratable acidity. The predictions for the training set were equivalent to those for the testing set, with a coefficient of determination (R^2) above 0.7 and low error metrics (RMSE, MAE, and Bias) for both sets. For firmness, R^2 was lower and error metrics were higher for the testing set than for the model (Table 1), indicating that predictions were less accurate for the independent set of values.

Soluble solids have the lowest R^2 values for both the training and testing datasets. This can be attributed to the narrow Brix distribution in the dataset, which creates a notable data artifact known as range restriction. However, the MAPE and Bias are low, indicating that the model's estimator's expected value is close to the true underlying population parameter it aims to estimate. The MAE indicates that, on average, the difference between predicted and measured values is less than 0.5% Brix (Table 1). Increasing the range of soluble solids values might yield a higher coefficient of determination.

In 2023, the prediction of soluble solids was assessed using the Felix F-750 instrument based on a generic apple model (data not shown). The correlation coefficient for the Felix prediction was lower ($R^2 = 0.194$) than the Fresco prediction ($R^2 = 0.465$). It's important to emphasize that high correlation coefficients (above 0.7) can be achieved with the Felix instrument when developing a variety-specific model or conducting a Partial Least Squares (PLS) analysis using the data generated by Felix. However, this experiment evaluated the instrument's ability to deliver quality parameter results promptly without requiring further data manipulation by the user. Additional data analysis will be conducted throughout this project to better compare the predictive power of both instruments.

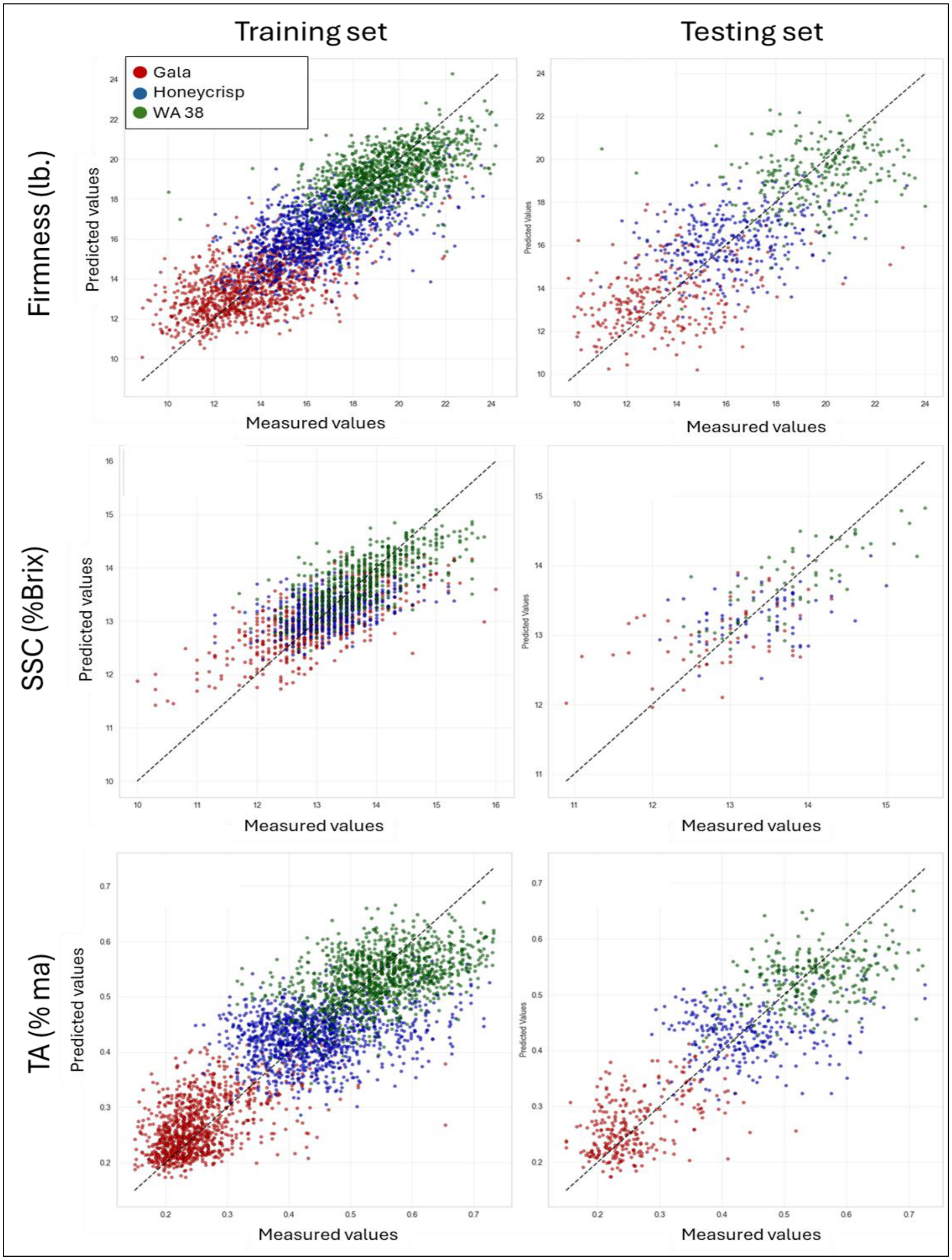

Figure 3. Soluble solids (%Brix), firmness (lbs.), and titratable acidity (% ma) correlation between non-destructive predicted values calculated by Fresco and destructive measurements (measured values) for model training and testing using Neural Network modeling.

Table 1. Coefficient of determination (R^2), root mean square error (RMSE), maximum absolute error (MAE), mean absolute percentage error (MAPE), and Bias for the sample sets used by Fresco in the model training and testing to predict soluble solids, firmness, and titratable acidity values.

Parameter	sample set	R^2	RMSE	MAE	MAPE	Bias
soluble solids (%Brix)	Training set	0.525	0.548	0.421	3.2%	0.015
	Testing set	0.465	0.575	0.450	3.4%	0.020
Firmness (lb.)	Training set	0.722	1.615	1.260	7.9%	0.070
	Testing set	0.563	2.066	1.623	10.3%	0.114
Titratable acidity (% malic acid)	Training set	0.738	0.072	0.056	14.3%	0.005
	Testing set	0.724	0.074	0.057	14.7%	0.006

Conclusion

The wavelengths associated with firmness, soluble solids, and titratable acidity were identified in the microwave spectra region. A positive correlation was achieved for the three quality parameters with a varying prediction power range. The strongest correlation was found for titratable acidity, followed by firmness and soluble solids concentration. The narrow distribution range affected the prediction of soluble solids, but the MAE and Bias are low, indicating a low error between the prediction and the observed value. Overall, the results are promising, but more data is needed to evaluate the instrument's accuracy.

Microwave sensor functionality updates

The Fresco sensor has been updated based on feedback from the WTFRC and other beta testers. Improved functions include reduced waiting time to reach optimal operating temperature, a cell phone connection to facilitate data entry, and a repositioned on/off switch.

In 2023, the system was limited to collecting and displaying spectral data as the sole measurement output. However, in 2024, we were able to select the measurement parameters, with results presented post-assessment. Data can now be uploaded directly to OneDrive using a Wi-Fi connection.

Upcoming work

In 2025, we conducted additional data collection for Honeycrisp, Gala, and Cosmic Crisp varieties. Granny Smith apples were incorporated into the experimental framework to enhance the diversity of data distribution. Pre-harvest samples were collected, and the potential for using Fresco as a pre-harvest assessment tool will be evaluated. In addition to the three quality parameters, dry matter will be evaluated during storage in 2026.