FINAL PROJECT REPORT **YEAR:** 3 of 2 (+1 NCE=3)
WTFRC PROJECT NUMBER: PR16-105

PROJECT TITLE: Dry matter assessment in pear and consumer perception

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Cooperators: Alex Goke (WSU –TFREC)

Total Project Request: Year 1: $ 51,655 **Year 2**: $ 56,172 **Year 3:** $0

Other funding sources: None
WTFRC Collaborative Expenses: None

Budget 1
Organization Name: WSU **Contract Administrator:** Kim Rains
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Item	**2016**	**2017**	**2018 (NCE)**
Salaries[1]	24,000	24,960	0
Benefits[2]	8,414	8,750	0
Wages[3]	2,880	2,995	0
Benefits[4]	289	300	0
Equipment	0	0	0
Goods/Services[5]	14,572	17,667	0
Travel[6]	1,500	1,500	0
Plot Fees	0	0	0
Miscellaneous	0	0	0
Total	**51,655**	**56,172**	**0**

Footnotes:
[1] Salary for a new hire 50% Research Intern (Serra-Musacchi) paid the other 50% on other grant.
[2] Benefit on salary at 31.5%
[3] One non-Student temporary for 12 wks: 20hrs/wk at $12/hr (Serra-Musacchi).
[4] Benefits on temporary at 10% (Serra-Musacchi).
[5] Labware/consumable, fruit sample reimbursement (Serra-Musacchi), sensory panel costs (consumable and incentive advertising), electronic tongue: sensors, chemicals and glassware (Ross).
[6] 2778 miles/year for domestic travel ($0.54/mile) to go to the orchard and to Pullman to meet co-pi and deliver fruit.

RECAP ORIGINAL OBJECTIVES

1. ***Determine the reliability of the Felix F-750 Produce Quality Meter and therefore if this non-destructive dry matter assessment tool can be used as at harvest sorting step for more consistent fruit quality categories.***
2. ***Assess if higher dry matter in pear translates into greater consumer liking and acceptability through consumer preference and sensory analysis studies.***

SIGNIFICANT FINDINGS

1. ***Determine the reliability of the Felix F-750 Produce Quality Meter and therefore if this non-destructive dry matter assessment tool can be used as at harvest sorting step for more consistent fruit quality categories.***
    - A d'Anjou specific model for dry matter was developed and sequentially improved from 0.79 to 0.92 coefficient of determination (R^2) and 0.45 to 0.34 root mean square error (RMSE) over the course of this project.
    - A Bartlett specific model was also developed for dry matter with an R^2 of 0.86 and RMSE of 0.34.
    - Models generally performed better when used on fruit similar to those used to build the model in terms of maturity and post-harvest stage, suggesting models may be limited in their utility depending on the composition of fruit in the calibration set.
    - Predictive models can be improved in terms of lower RMSE and higher R^2 by including larger amounts of fruit with broader maturity levels during calibration.
    - Models for use on-tree can be built up to two months prior to harvest with fair accuracy (0.20 to 0.95 % dry matter RMSE; 0.36 to 0.48 °Brix RMSE), though model accuracy suffers when model is applied to growth stages other than what it was calibrated for.
    - Using a combined model developed over several timepoints is a fair compromise for quality prediction on-tree in the field.
    - Distribution of fruit dry matter predicted at-harvest varied between orchards and years, presumably leading to down-stream differences in fruit quality and consumer liking.
    - When instrumentally evaluated for quality at < 1 and after 5 months of post-harvest, higher dry matter d'Anjou pears were significantly lower in I_{AD} index (more ripe) and greater in soluble solids content (SSC, °Brix) and actual destructive dry matter (DM %).

2. ***Assess if higher dry matter in pear translates into greater consumer liking and acceptability through consumer preference and sensory analysis studies.***
    - From two orchards and two harvest years, d'Anjou fruits were sorted at harvest into low (< 13 %), moderate (13 - 16 %), and high (> 16 %) predicted dry matter classifications using the Felix F-750 Produce Quality Meter.
    - Consumers significantly ($p < 0.05$) favored high dry matter fruits over moderate and/or low matter fruits in terms of perceived appearance, aroma, firmness, crunchiness, juiciness, sweetness, and pear flavor.
    - In terms of overall liking, high dry matter fruits were significantly ($p < 0.05$) and uniquely favored over moderate and low dry matter fruits.
    - Overall liking was driven primarily by liking of flavor, followed by sweetness, firmness, and then juiciness.
    - Consumers were willing to pay premium prices for higher dry matter fruits at an estimated $0.20/lb above average retail prices.

METHODS

1. ***Determine the reliability of the Felix F-750 Produce Quality Meter and therefore if this non-destructive dry matter assessment tool can be used as at harvest sorting step for more consistent fruit quality categories.***

D'Anjou pears used in this project were grown in three commercial orchards in Cashmere, Washington, USA and Monitor, WA, USA. The first orchard ("Orchard 1") consisted of central leader d'Anjou/OHF87 trees planted in 1998 and spaced 14 ft x 8 ft (389 trees/A, equal to 4.3 m x 2.45 m and 950 trees/ha). The second orchard ("Orchard 2") consisted of open vase d'Anjou/Bartlett seedlings planted in the 1970's and spaced 20 ft x 20 ft (109 trees/A, equal to 6 m x 6 m and 278 trees/ha). The third orchard, ("Orchard 3"), was a Bartlett/OH87 planted in 2012 at 12 ft x 5 ft (726 trees/A equal to 3.7 m x 1.5 m spacing and 1,800 trees/ha) trained to either a spindle or bi-axis system. Harvest of Orchard 1 occurred 18-19th of August in 2016 and 11-12th in September for 2017, and the 29th of August in 2016 and 6th of September in 2017 for Orchard 2. Orchard 3 was harvested in 2016 only on August 5th. Immediately following harvest, fruit were washed and placed in regular atmosphere cold storage (1 °C = 33.8 °F) for sorting and experimental purposes.

To enable the sorting procedure, several non-destructive dry matter models were built over the course of 2016 and 2017 – two for d'Anjou cultivar and one for Bartlett cultivar. For each model, spectral profiles of the opposing faces of 100 fruit were collected across three internal fruit temperatures (approximately 34, 68, and 90 °F) to reduce temperature-associated noise in the model, as temperature strongly influences absorption and emission by water in critical spectral areas. Two sections of each fruit were then destructively evaluated for dry matter and used to calibrate the model resulting in 200 fruit samples per model. A preliminary model was also built in 2015 for d'Anjou with only two temperatures and 50 fruit. The purpose of the successive d'Anjou models was to determine if the model could be improved by incorporating a larger variety of fruit maturity levels in to the calibration set. Accuracy was measured by calculating the coefficient of determination (R^2) and root mean square error (RMSE) between predicted and actual destructive values. Accuracy in this way was evaluated internally at calibration by comparing predicted values generated from the model to known values of the fruits used in model calibration and later destroyed, as well by applying models to external validation datasets from the instrumental evaluation of Orchards 1, 2, and 3 from 2016 harvest. Models were also compared across d'Anjou and Bartlett cultivars to evaluate model specificity.

In addition to models developed for sorting purposes, three on-tree models were developed for the purpose of monitoring fruit quality on the tree during development. For this, dry matter and soluble solids content prediction models were developed using growing fruit from Orchard 1 at 84, 112, and 140 days after full bloom (DAFB; 24 April 2017 as date of full bloom, alternatively 2, 1, and 0 months prior to harvest) on 24, 24, and 64 fruit samples for 84, 112, and 140 DAFB, respectively. Models developed at each time point were then applied to the respective data captured on-tree in order to estimate dry matter and soluble solids content through time as the fruit matured. Models were also compared across growing stage to evaluate model specificity.

For at-harvest sorting, fruit were non-destructively measured on opposing faces (two readings per fruit) by a Felix F-750 Produce Quality Meter to acquire average predicted fruit dry matter (%). From this average value, fruits were classified in to categories of dry matter (e.g. 13-13.99%, 14-14.99%, etc.) and randomly divided in to three evaluation periods; (1) instrumental quality evaluation < 1 month post-harvest, (2) instrumental quality evaluation ~5 months post-harvest, and (3) consumer sensory evaluation ~5 months post-harvest. For instrumental quality assessment, weight, I_{AD} index, firmness, soluble solids content (°Brix), dry matter (%), titratable acidity (% malic acid), and pH were evaluated after seven days of room-temperature ripening. Predicted dry matter classes were evaluated for differences in these parameters using ANOVA and SNK means separation.

2. ***Assess if higher dry matter in pear translates into greater consumer liking and acceptability through consumer preference and sensory analysis studies.***

   Following dry matter estimates as described above at harvest, stratified random samples of predicted dry matter were selected for consumer sensory testing. Due to variation in dry matter production between years, for the purpose of consumer evaluation dry matter classes were defined as low (< 13 %), moderate (13 – 16 %), and high (> 16 %) predicted dry matter. Fruit were held in regular atmosphere cold storage (≈ 1 °C) for over five months then ripened at ambient temperature for seven days prior to sensory evaluation. Sensory evaluations were conducted across four panel days both in February of 2017 (2016 harvest) and in February/March 2018 (2017 harvest) at the Washington State University Sensory Evaluation Facility (Ross's lab, Pullman, Washington, USA). For consumer evaluation, fruit were first washed then cut stem-to-calyx in one-eight slices with the seed core removed and randomly presented to consumers. Consumers used a nine-point hedonic scale (1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, and 9 = like extremely) to rate the slices for appearance, aroma, firmness, crunchiness, juiciness, sweetness, bitterness, pear flavor, and overall liking. Consumers were then asked a series of yes/no willingness to pay (WTP) questions, first presented with a premium bid of $1.73/lb, followed by a base rate of $1.36/lb if unwilling to purchase at the premium bid, and a discount bid of $0.99/lb if unwilling to purchase at the base bid. Rates were established based on Northwest USA market prices of fresh pears in February 2017. Responses were evaluated with ANOVA and post hoc Tukey HSD. Drivers of overall liking was investigated using multiple linear regression with sensory liking attributes as predictors. Mean WTP was estimated utilizing a contingent valuation model based on a utility difference approach.

RESULTS & DISCUSSION

1. ***Determine the reliability of the Felix F-750 Produce Quality Meter and therefore if this non-destructive dry matter assessment tool can be used as at harvest sorting step for more consistent fruit quality categories.***

   Table 1 shows a summary of model accuracy at the time of calibration among all sorting models developed in terms of coefficient of determination (R^2) and root mean square error (RMSE). **As shown, the d'Anjou specific model for dry matter were sequentially improved from 0.79 and 0.45 to 0.92 and 0.34 R^2 and RMSE**, respectively, over the course of this project. This is likely due to intentional stratified selection among various fruit maturities for inclusion in the model – we hypothesized that broader ranges of fruit in the calibration would increase model performance overall. The Bartlett model also performed well for dry matter with an R^2 of 0.86 and RMSE of 0.34. Soluble solids models performed poorer than dry matter counterpart for all developments. This is likely due to the non-specificity of dry matter (which by definition also includes soluble solids aka sugars), making it less sensitive to spectral interference by other compounds, whereas soluble solids would be more sensitive to such interference due to its narrower chemical definition.

Table 1: Calibration performance statistics for predictive models developed for d'Anjou and Bartlett variety pear harvested from Orchards 1, 2, and 3 in year 2016-2018.

Model	**Parameter**	**RMSE**	**R^2**
d'Anjou Preliminary Model	Dry Matter	0.45	0.79
d'Anjou First Generation	Dry Matter	0.29	0.92
	Soluble Solids	0.31	0.90
d'Anjou Second Generation	Dry Matter	0.36	0.94
	Soluble Solids	0.42	0.91
Bartlett	Dry Matter	0.39	0.86
	Soluble Solids	0.43	0.84

Beyond calibration, model performance varied greatly depending on the cultivar the model was developed on and the age of fruit being measured. Table 2 details accuracy of the second generation d'Anjou and Bartlett models used to predict dry matter in fruit from the full harvest of Orchards 1, 2, and 3 in 2016. Both models were used to predict dry matter in fruit that were destructively evaluated < 1 month and after 5 months of regular atmosphere cold storage. Predictions were then compared to actual dry matter values for each model, orchard, and evaluation period combination. Overall, all models largely performed acceptably in each application, though decreases in performance were apparent when a model developed on one variety was applied to a group of fruit of another variety. For instance, d'Anjou model performed between 0.799-0.957 R^2 and 0.434-0.709 RMSE on d'Anjou fruit from Orchards 1 and 2, but performance was reduced to 0.777-0.845 R^2 and 0.581-0.779 RMSE when used on Bartlett fruit from Orchard 3 (Table 2). There also appears to be an influence of storage stage on model performance as well. For instance, d'Anjou model when applied to d'Anjou fruit from Orchard 2 was more accurate when applied to fruit that were stored for less than 1 month (0.957 R^2 and 0.462 RMSE) relative to when fruit were measured following 5 months of cold storage (0.903 R^2 and 0.570 RMSE, Table 2). These errors are likely due to differences in fruit characteristics between those selected for use in building the models (at a uniform storage stage) and those used in this validation exercise (e.g. fruit of both varieties held in storage for either < 1 or ~ 5 months). Model performance for use on both varieties could likely be improved by incorporating both varieties in the calibration, as well as different maturity stages and storage stages.

Table 2: External validation performance statistics of predictive models developed for d'Anjou and Bartlett variety pear applied to fruit from Orchard 1 and 3 evaluated at harvest (less than one month of cold storage) or post-storage (after 5 months of cold storage).

Validation Set	Model	Evaluation	n	RMSEP	R^2
Orchard 1 (Bartlett)	Bartlett	Pooled	120	0.781	0.777
		At-Harvest	60	0.732	0.733
		Post-Storage	60	0.415	0.921
	d'Anjou	Pooled	120	0.779	0.777
		At-Harvest	60	0.719	0.743
		Post-Storage	60	0.581	0.845
Orchard 1 (d'Anjou)	Bartlett	Pooled	203	0.836	0.722
		At-Harvest	108	0.692	0.813
		Post-Storage	95	0.405	0.914
	d'Anjou	Pooled	203	0.709	0.799
		At-Harvest	108	0.663	0.821
		Post-Storage	95	0.434	0.901
Orchard 2 (d'Anjou)	Bartlett	Pooled	75	0.742	0.874
		At-Harvest	45	0.444	0.960
		Post-Storage	30	0.482	0.931
	d'Anjou	Pooled	75	0.659	0.900
		At-Harvest	45	0.462	0.957
		Post-Storage	30	0.570	0.903

Similar trends were found for models developed for purpose of on-tree monitoring during fruit growth (Fig. 1). For both dry matter and soluble solids models, the lowest RMSE was obtained when applied the model to fruit of the same age (e.g. the 112 DAFB applied to 112 DAFB fruit). When applying a model to a fruit of a different age, RMSE would drastically increase (e.g. the dry matter model developed at 84 DAFB and applied at 140 DAFB suffers an 0.53 increase in RMSE). This effect was more pronounced for dry matter than soluble solid predictions. One solution for this problem would be to combine all models together, resulting in better performance through time by accommodating different fruit in the calibration. However, the combined model for dry matter did not substantially improve the longitudinal accuracy of the model. Only the combined soluble solids model was stable (flat line) over time (Fig. 1). This would indicate that changes in fruit tissue ultrastructure and water content throughout development strongly impact model performance, much more so for dry matter than soluble solids content. Further work could address this limitation by evaluating different combinations of NIR spectral data to account for changes in fruit ultrastructure with the goal of making the models less sensitive to fruit changes over time.

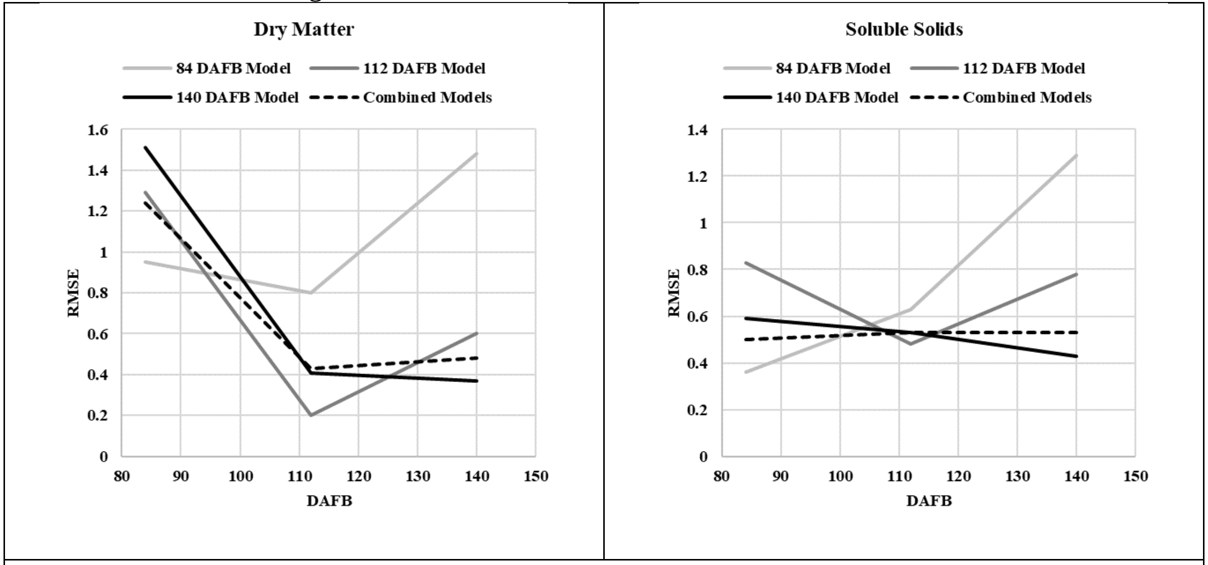

Figure 1: Dry matter (left) and soluble solids content (right) predictive model performance measured as root mean squared error (RMSE) as a function of time of calibration (DAFB) and application of the model.

As determined from first d'Anjou cultivar specific dry matter models in 2016 and second generation model in 2017, Figure 2 depicts distributions of predicted dry matter of representative subsamples of fruits harvested among years and orchards (≈ 2400 in 2016 and 1480 in 2017 picked from 20 or more trees sampled from harvest bins across varying degrees of coloring, size, and canopy position as proxies for maturity). Most of the harvest fruit exhibited moderate levels of predicted dry matter (e.g. 13-13.99, 14-14.99, and 15-15.9%), while comparatively fewer fruits were produced above and below this range (respectively high and low predicted dry matter categories). Distribution of predicted dry matter for Orchard 2 was notably skewed higher than that of Orchard 1 for both harvests. These orchards varied in terms of age, tree architecture, rootstock, and the cultural practices that have been applied to them – any of which could cause the observed differences. Additionally, the 2016 harvest tended to produce higher predicted dry matter fruits compared to 2017 harvest. As a result, very few higher predicted dry matter fruits were harvested from Orchard 1 in 2017. This may be due to the anomalous 2017 growing season characterized by a late bloom and shorter season. These observations highlight the need for non-destructive determinations of quality-related parameters at harvest such as dry matter prediction, as fruit can deviate substantially between orchards and years in maturity and quality and harvest which substantially impacts consumer-side sensory experiences.

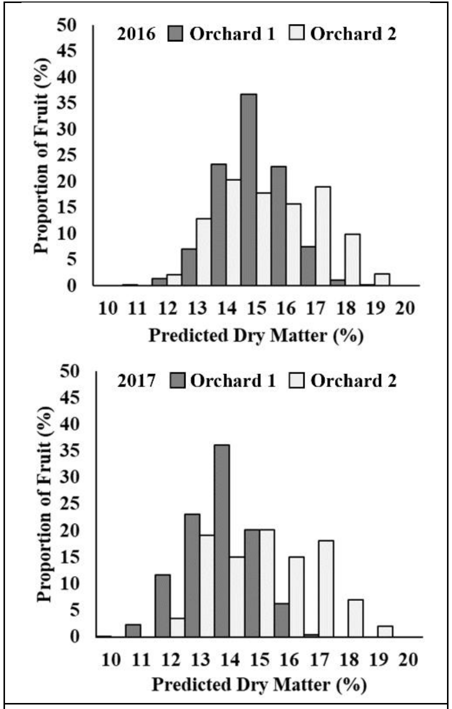

Figure 2: Distribution of predicted dry matter (%) of d'Anjou fruit harvested in Cashmere, WA, from Orchard 1 (dark gray) and Orchard 2 (light gray) in 2016 (upper) and 2017 (lower) among predicted dry matter ranges.

Table 3: Instrumental fruit quality parameters among predicted dry matter classes < 1 and after 5 months post-harvest from 2016 and 2017 harvests of Orchard 1. Different letters long columns indicate significant difference in means ($p < 0.05$, SNK). Model significance is not reported for simplicity.

Evaluation	Predicted Dry Matter Range (%)	Weight (g)		I_{AD} Index		Firmness (kg)		SSC (°Brix)		Destructive Dry Matter (%)		pH		Titratable Acidity (% Malic Acid)	
Harvest 2016 < 1 mo. Post-Harvest	**11-12.99**	156	C	2.04	A	7.49	AB	11.6	F	13.9	F	4.04	B	0.33	B
	13-13.99	195	B	1.98	A	7.64	A	12.7	E	15.2	E	3.97	BC	0.35	AB
	14-14.99	207	AB	1.89	B	7.43	AB	13.6	D	15.9	D	3.86	D	0.36	A
	15-15.99	221	A	1.80	C	7.31	AB	14.2	C	16.7	C	3.86	D	0.35	AB
	16-16.99	217	A	1.67	D	7.28	AB	14.9	B	17.5	B	3.95	C	0.32	B
	17-17.99	201	AB	1.51	E	7.08	B	15.9	A	18.6	A	4.10	A	0.29	C
Harvest 2016 ~5 mo. Post-Harvest	**11-12.99**	169	CD	1.36	A	0.89	CD	12.2	F	13.5	F	4.14		0.25	
	13-13.99	187	BC	1.03	B	0.78	D	13.3	E	14.1	E	4.07		0.25	
	14-14.99	205	AB	0.89	C	0.85	CD	14.0	D	15.0	D	4.07		0.24	
	15-15.99	217	A	0.82	CD	0.95	BC	14.6	C	15.7	C	4.07		0.24	
	16-16.99	205	AB	0.74	DE	1.07	B	15.4	B	16.7	B	4.07		0.24	
	17-17.99	165	D	0.63	E	1.31	A	16.6	A	18.3	A	4.03		0.23	
Harvest 2017 < 1 mo. Post-Harvest	**10-11.99**	163	D	1.89	A	5.79	AB	10.5	E	12.5	E	4.20	A	0.28	B
	12-12.99	188	C	1.84	AB	6.20	A	11.6	D	13.7	D	4.06	B	0.31	AB
	13-13.99	208	B	1.79	B	6.05	A	12.5	C	14.3	C	3.98	C	0.33	A
	14-14.99	231	A	1.69	C	5.38	B	13.4	B	15.5	B	3.92	C	0.33	A
	15-15.99	242	A	1.68	C	5.32	B	14.5	A	16.2	A	3.95	C	0.33	A
Harvest 2017 ~ 5 mo. Post-Harvest	**10-11.99**	158	C	1.54	A	1.93	A	10.7	E	12.2	E	4.44	A	0.22	AB
	12-12.99	191	B	1.42	A	1.85	A	12.0	D	13.2	D	4.39	AB	0.23	AB
	13-13.99	209	AB	1.09	B	1.14	B	12.8	C	13.8	C	4.26	BC	0.24	A
	14-14.99	226	A	1.00	B	1.05	B	13.6	B	14.7	B	4.17	C	0.24	A
	15-15.99	204	AB	0.98	B	1.32	B	14.6	A	16.0	A	4.36	AB	0.20	B

From the classes determined at harvest, Table 3 details the results of instrumental quality evaluation < 1 and after 5 months post-harvest of the 2016 and 2017 harvests of Orchard 1. For I_{AD} index, soluble solids, and actual destructive dry matter, trends were consistent over years and evaluation periods – higher dry matter fruits were significantly lower in I_{AD} index (more ripe) with greater soluble solids and dry matter. Firmness was also negatively related to dry matter with the exception of 2016 ~5 months post-harvest fruit, where the greatest firmness was interestingly found in higher dry matter fruits, though the magnitude between greatest and lowest firmness was only ~ 0.5 kg. Higher dry matter fruit also appeared generally larger (greater weight), though this was not entirely consistent between dry matter classes. Titratable acidity and pH did not demonstrate any clear relationship to dry matter class, though differences were often significantly different with the exception of 2016 ~5 months post-harvest fruit.

2. ***Assess if higher dry matter in pear translates into greater consumer liking and acceptability through consumer preference and sensory analysis studies.***

Table 4: Mean consumer liking scores (1 = dislike extremely, 9 = like extremely) of sliced fruit samples between low (< 13 %), moderate (13 – 16%), and high (> 16 %) predicted dry matter categories of pears harvested in 2016 and 2017 from Orchard 1 and Orchard 2 in Cashmere WA. Different letters in a column indicate statistically significant difference in mean liking among predicted dry matter categories at $p < 0.05$ (Tukey HSD).

Predicted Dry Matter	**Sliced Fruit Sensory Attributes**							
	Appearance	**Aroma**	**Firmness**	**Crunchiness**	**Juiciness**	**Sweetness**	**Bitterness**	**Flavor**
Low	6.47 c	6.23 c	6.08 c	5.80 c	5.64 b	5.36 c	5.32 b	5.51 c
Moderate	6.61 b	6.55 b	6.56 b	6.19 b	6.82 a	6.52 b	5.76 a	6.60 b
High	6.87 a	6.89 a	6.85 a	6.53 a	6.93 a	7.04 a	5.96 a	6.97 a

Table 4 depicts mean liking of consumer sensory parameters across low, moderate, and high predicted dry matter categories for fruit harvested in 2016 and 2017 from Orchards 1 and 2. As shown, high predicted dry matter fruits were favored by consumers for all attributes evaluated. For many attributes, high dry matter fruits were significantly ($p < 0.05$) and uniquely more favored – most notably in terms of liking of perceived firmness, sweetness, and flavor.

Figure 3 represents mean overall liking across low, moderate, and high predicted dry matter categories for fruit harvested in 2016 and 2017 from Orchards 1 and 2. As shown, high predicted dry matter fruits were rated significantly more favorable than both moderate and low predicted dry matter fruits. This would seem to indicate a strong positive relationship between dry matter and consumer preferences – as dry matter increases, so does overall consumer liking in addition to liking of perceived sensory attributes including appearance, aroma, firmness, crunchiness, juiciness, sweetness, bitterness, and flavor.

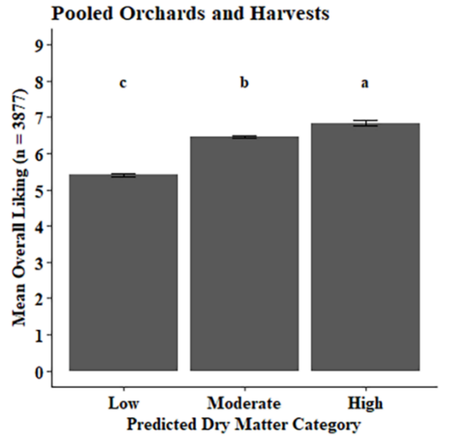

Figure 3: Mean consumer overall liking (1 = dislike extremely, 9 = like extremely) for both ("pooled") orchards and harvest years (2016 and 2017). Different letters indicate statistical difference in mean overall liking at significance $p < 0.05$ (Tukey HSD). Bars indicate standard error.

Table 5: Multiple linear regression and relative contribution of sensory liking scores on overall liking of pears harvested in 2016 and 2017 from Orchards 1 and 2.

Parameters		**Estimate**	**SE**	**Relative Contribution (%)**
Sensory Scores				
	Appearance	0.04***	0.01	2.48
	Aroma	-0.01	0.01	4.12
	Firmness	0.15***	0.01	9.69
	Crunchiness	0.06***	0.01	7.35
	Juiciness	0.13***	0.01	16.09
	Sweetness	0.23***	0.01	22.31
	Bitterness	0.07***	0.01	9.54
	Flavor	0.46***	0.01	28.41
Model				
	Intercept	-0.81***	0.07	
	R^2	0.85		

Liking attributes did not contribute equally to overall acceptance (Table 5). Overall liking was best associated with liking of flavor ($\beta = 0.46$***), followed by sweetness ($\beta = 0.23$***), firmness ($\beta = 0.15$***), then juiciness ($\beta = 0.13$***). Relative contribution of these terms to the overall model fit was 28.41, 22.31, 9.69, and 16.09 %, respectively, placing more emphasis on juiciness than firmness. Flavor, as a complex sensory outcome of numerous physical properties and chemical compounds, is immensely difficult to measure instrumentally. Dry matter may serve as a surrogate for flavor quantification in that it encompasses not only sugars, but other compounds (fibers, minerals, acids, etc.) that may contribute to flavor either directly or indirectly through biochemical evolution during storage and ripening. This is supported by liking scores compared among predicted dry matter classes (Table 4) which shows high predicted dry matter fruits being significantly more favored in terms of flavor relative to moderate and low predicted dry matter fruits.

Table 6: Willingness to pay (WTP) estimated means and 95% confidence intervals in dollars per pound ($/lb) among predicted dry matter groups (low, < 13 %; moderate, 13 – 16 %; high, > 16 %) of fruit harvested in 2016 and 2017 from Orchard 1 and 2 in Cashmere, WA. Price premiums shown as difference between mean estimate and base retail price of $1.36/lb.

	WTP Estimate		
Predicted Dry Matter	**Mean** ($/lb)	**95 % Confidence Interval ($/lb)**	**Price Premium ($/lb)**
Low	1.25	1.22-1.28	-0.11
Moderate	1.49	1.47-1.51	0.13
High	1.56	1.52-1.62	0.20

As for consumers' willingness to pay for increases in dry matter, Table 6 describes estimated WTP among predicted dry matter categories for fruit harvested in 2016 and 2017 from Orchards 1 and 2. Mean WTP increased from low to moderate to high dry matter, with low being valued below average retail price ($1.36/lb) and moderate and high predicated dry matter valued above market price at a magnitude of $0.13/lb and $0.20/lb, respectively. This finding may have particularly strong implications for an industry evolving towards targeted consumer-oriented strategies such as quality threshold-based trademarking and value-added products, where there may exist an opportunity to segregate fruit at harvest in to various tiers of quality that are then marketed accordingly at a higher purchasing price.

EXECUTIVE SUMMARY

Fruit dry matter is increasingly recognized as a reliable indicator of fruit quality and consumer acceptance for numerous commodities, though this relationship has yet to be thoroughly explored in European pears. The use of NIR spectroscopy, recently popularized for quality control in many horticultural products, may be used as a non-invasive tool for the determination of internal quality parameters but prior to this work has suffered from a lack of proof of concept demonstrations in soft-ripening pears. This project gave us the possibility to address these limitations through the investigation of the importance of dry matter in summer and fall/winter pears (Bartlett and d'Anjou) and its impact on consumer preference in Washington State. The use of a non-destructive tool as Felix F750 Quality Meter based on NIR spectroscopy allowed us to develop cultivar specific models to predict with fairly good accuracy the fruit dry matter and soluble solids. Particular effort was made to evaluate the accuracy of models applied to fruit of varying maturity levels and post-harvest storage stages as well on-tree. This approach gave us the opportunity to work on a meaningful larger number of fruit than would be possible using the traditional destructive methods for dry matter evaluation. This technology was employed to sort pears at harvest with the goal to create more homogenous groups of fruit for increased consumer liking. These results can have practical applications in the PNW Pear industry and be a good resource to increase pear consumption by delivering high quality product to the pear market.

PROJECT OUTCOMES

Publications:

Goke A., Serra S.*, Musacchi S. (2018). "Postharvest Dry Matter and Soluble Solids Content Prediction in d'Anjou and Bartlett Pear Utilizing NIR Spectroscopy". *HortScience* 53(5), pp.669-680.

Serra S.*¥, Goke A. ¥, Diako C., Vixie B., Ross C., Musacchi S. (xxx) "Consumer perception of dry matter in d'Anjou pear determined at harvest using near-infrared spectroscopy". *International Journal of Food Science and Technology* (submitted).

Serra S., Goke A., Musacchi S. (xxx) "Manipulation of Fruit Dry Matter via Seasonal Pruning and its Relationship to Growth, Yield, and Quality of d'Anjou Pear" (in preparation).

Presentations:

Serra S., Musacchi S., Ross C., Goke A.: "Dry matter assessment in pear and consumer perception (continuing report)," WTFRC-NWPB, Hoodriver, OR February 16, 2017.

Serra S.: "DA Meter and Dry Matter". Invited oral presentation in IFTA session IV: New Instrument Panel discussion. 2017 IFTA Annual Conference, from bud to bin, Wenatchee WA (23 February 2017).

Serra S., Goke A., Knerl A., Sheick R., Musacchi S.: "Non-destructive dry matter prediction in d'Anjou pears: a new sorting tool?" (Oral presentation by Serra S.) ASHS annual meeting, Pomology 1 - Waikoloa, Hawaii, 20th September 2017.

Goke A., Knerl A., Serra S., Musacchi S.: "Utilizing handheld NIR for on-tree quality assessment in developing d' Anjou pear". (Oral presentation by Goke A. during "Research News Flash 2017") at 113th Washington State Tree Fruit Association Annual Meeting. Kennewick, WA, December 2017.

Serra S., Musacchi S., Ross C., Goke A.: "Dry matter assessment in pear and consumer perception (continuing report)," WTFRC-NWPB, Wenatchee, WA, February 15, 2018.

Serra S., Goke A., Knerl A., Sheick R., Ross C., Vixie B., Musacchi S.: "d'Anjou pear sorting by predicted dry matter and its effect on consumer preference" (Oral presentation by Serra S.). XIII International Pear Symposium, Montevideo, Uruguay, December 4th-7th 2018.

Serra S., Goke A., Knerl A., Sheick R., Ross C., Vixie B., Musacchi S.: "d'Anjou pear sorting by predicted dry matter and its effect on consumer preference" (Oral presentation by Serra S.). 73rd Lake Chelan Horticulture Day – January 21, 2019, Chelan, WA.

FUTURE DIRECTIONS

- Further explore the influence of maturity, storage period, and ripeness on NIR model accuracy.
- Match consumer responses to dry matter on a per-fruit basis to determine exact thresholds for fruit quality groupings at harvest.
- Expand dry matter and soluble solids prediction models to production scale with an NIR-equipped packing line to sort fruit aimed towards maximizing consumer satisfaction.