FINAL REPORT

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Virginia Wine Board

Managing Apple Maturity and Post-Harvest Regimes to Increase the Quality of Virginia's Ciders

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A. INTRODUCTION

The increased popularity of hard apple cider in recent years has created the opportunity for both large and small brands alike to compete in the alcoholic beverage market. As with beer and wine, there are ciders of varying quality and styles to appeal to a variety of consumers. Relatively little research has been done in cider production, especially when compared to the body of research-based knowledge available to commercial producers of beer and wine. In order for Virginia cidermakers to compete in the cider market, it is important that their cider production practices be informed by research specific to cider production. We aim to better understand the relationship between cider production practices and resulting product quality in order to provide practical resources and suggestions.

One area of interest to cider producers is the relationship between harvest maturity and cider quality. Decades of research have been dedicated to wine grape production practices, including harvest maturity parameters, and the impact of these decisions on the resulting wines, but there is a lack of these studies for apples and ciders. It is therefore difficult to assess the extent to which orchard management practices influence cider quality. Apples at varying stages of maturity have different chemical compositions, with riper apples having higher sugar levels, higher levels of aroma compounds, and lower acidity. However, unripe apples may have a greater long-term storage potential due to lower ethylene concentrations at the onset of storage. Apples may be stored for long periods of time before processing, but the chemistry and quality of apples may also change during storage, making it necessary to understand the extent to which storage will affect apple, juice, and cider quality.

B. OBJECTIVE

Overall Objective: To understand how fruit maturity at harvest and post-harvest storage time and conditions affect the quality of the fruit, juice, and resulting cider in order to optimize processing conditions and desired cider characteristics.

Specific Objective 1: Increase fruit quality attributes (e.g. sugar, acid, flavor) and tannin content of cider apples by adjusting the harvest timing of apple fruit.

Specific Objective 2: Increase fruit quality attributes (e.g. sugar, acid, and flavor) and tannin content of cider apples by optimizing postharvest fruit storage.

C. SUMMARY

The overarching goal of this research program is to better understand how production and pre-processing practices impact cider quality and how these practices can be applied for optimized cider characteristics. As outlined in the grant proposal, *Managing Apple Maturity and Storage to Increase the Quality of Virginia's Hard Ciders*, three cultivars were selected to study both harvest maturity and post-harvest

storage of fruit and the resulting juices. Results from the first year of the study have been included in a previous report. During the second year of the study, three cultivars were processed into hard cider. Fruit, juice, and cider were analyzed for specific physical and chemical attributes.

For the harvest maturity study, three treatments and four biological replicates were implemented per cultivar, resulting in a total of 36 individual ciders between three cultivars. For the post-harvest storage study, four treatments and four biological replicates were implemented per cultivar, resulting in a total of 48 individual ciders between three cultivars. Therefore, throughout the 2016-2017 year of the study, a total of 84 individual ciders were produced and analyzed for this project.

The data collected in Year 1 (reported previously) indicated that the experimental treatments resulted in substantial differences in both the fruit and juice from both studies, with fewer differences persisting into the final ciders. The preliminary data from the first year of this study suggests that though harvest maturity and post-harvest storage of apples may significantly impact fruit and juice quality, these factors may not result in similarly important quality differences in the final cider product. However, in Year 2, greater differences among treatments persisted into the final cider. This finding provides insight as to the extent to which harvest maturity and postharvest storage practices impact cider quality.

D. MATERIALS & METHODS

Fruit: Dabinett, Binet Rouge, and Gold Rush apples were harvested from Cornell University's Research Orchard in Lansing, NY. All cultivars were evaluated for fruit, juice, and cider quality.

Experimental Treatments: To evaluate the impact of harvest maturity, three experimental treatments were implemented: fruit harvested 2 weeks before maturity, fruit harvested at maturity, and fruit harvested 2 weeks after maturity. "Maturity" harvest date was determined based on standard fruit maturity parameters for dessert fruit production. The treatments are illustrated in Figure 1.

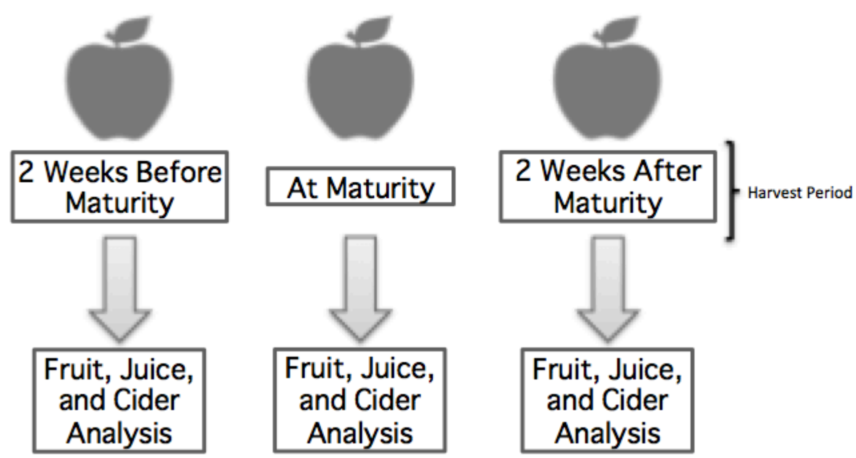

Figure 1: Outline of Harvest Maturity Experiment

To evaluate the impact of postharvest storage, four experimental treatments were implemented. The experimental treatments are outlined in Figure 2. Briefly, fruit was harvested at standard dessert fruit maturity and then stored according to the assigned treatment as follows: after two weeks of storage at 4℃, after six weeks of storage in 1℃ conditions plus 24 hours at room temperature, after six weeks of storage in 10℃ conditions plus 24 hours at room temperature, and after six months of storage in 1℃ conditions plus 24 hours at room temperature. At the end of the treatment period, the fruit were analyzed, processed into juice and cider, which were also analyzed, as illustrated in Figure 2.

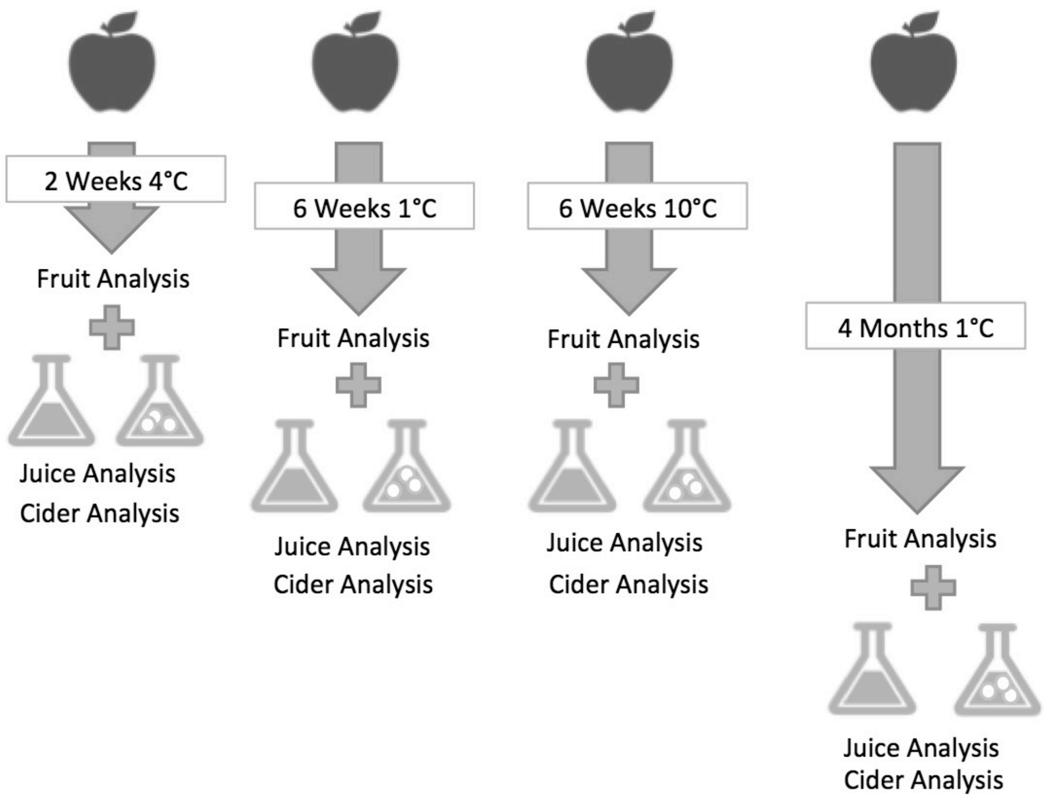

Figure 2: Outline of Post-Harvest Storage Experiment

Quality Parameters: Fruit quality was analyzed by measuring fruit firmness, fruit weight, starch-iodine index, color, and ethylene concentration.

Juice quality was analyzed by measuring soluble solid concentration (SSC), pH, titratable acidity (TA), SSC to TA ratio (SSC:TA), total polyphenols, primary amino nitrogen (PAN), and ammonia.

Cider quality was analyzed by measuring residual sugar (RS), pH, TA, total polyphenols, total procyanidins, individual polyphenols, PAN, ammonia, free sulfites, and total sulfites.

Cider Fermentation: Juice was clarified with pectinase followed by settling overnight. Aliquots of 750mL of clarified juice were then racked into 1L flasks. Prior to fermentation, the juice was treated with potassium metabisulfite, per standard commercial cidermaking practice. Then, the juice was inoculated using EC1118 yeast and a Fermaid K nutrient addition, per the yeast manufacturer's standard recommendations. The flasks were sealed using airlocks and then placed in an 18℃ temperature-controlled environmental chamber. Fermentation was monitored by weighing the flasks daily to measure CO_2 loss then determining residual sugar levels when the rate of mass loss approached zero. Flasks were stirred daily throughout the duration of the fermentation.

E. RESULTS AND DISCUSSION

Objective 1: Harvest Maturity

Fruit Quality

Table 1. 2016 Effects of Harvest Date on Fruit Maturity and Quality. Mean separation was analyzed separately for each cultivar. Values are represented as mean ± standard error for n=4 replicates.

	Harvest	Fruit Firmness (N)	Fruit Weight (g)	Starch-Iodine Index (1-8)	Color*	Ethylene (ppm)
Gold Rush	H1	83.5±0.9[a]	141.4±4.5[a]	2.2±0.2[c]	2.2±0.1[a]	0.10±0.01[c]
	H2	78.7±0.9[b]	147.3±4.4[a]	3.7±0.1[b]	1.9±0.1[a]	0.25±0.02[b]
	H3	77.7±0.9[b]	144.1±5.3[a]	5.0±0.2[a]	1.4±0.1[b]	0.69±0.08[a]
Dabinett	H1	-	53.2±2.1[b]	1.4±0.1[b]	47.7±3.5[b]	0.21±0.07[a]
	H2	97.4±1.0[a]	53.7±2.0[b]	1.8±0.2[b]	59.9±4.2[a]	5.80±3.94[a]
	H3	89.2±1.2[a]	66.0±2.3[a]	2.5±0.2[a]	67.1±2.8[a]	6.61±4.15[a]
Binet Rouge	H1	-	46.1±1.7[c]	2.1±0.2[b]	24.0±2.9[b]	3.65±2.96[a]
	H2	87.9±1.7[a]	52.3±1.8[b]	2.6±0.2[ab]	50.1±3.7[a]	3.12±2.57[a]
	H3	82.2±1.4[a]	60.5±2.0[a]	3.2±0.2[a]	46.0±3.4[a]	10.01±5.06[a]

* For Dabinett and Brown Snout, Red Color is measured on a 0-100% scale, and for Gold Rush, Green Background Color is measured on a 1-4 scale.

As shown in Table 1, differences in several quality parameters were observed between treatments. Fruit weight increased with later harvest dates in Dabinett and Binet Rouge cultivars. Starch-iodine index values increased with later harvest dates for all three cultivars. Green color in Gold Rush fruit decreased during maturation, and red color in Dabinett and Binet Rouge cultivars increased. Ethylene concentration significantly increased in the Gold Rush fruit with maturation. Ethylene concentration in the Dabinett and Binet Rouge fruit did not significantly increase statistically, however, there was still an observable increase when comparing means. These findings are consistent with previous apple maturity studies [1-4].

Juice Quality

Table 2. 2016 Effects of Harvest Date on Juice Quality. Mean separation was analyzed separately for each cultivar. Values are represented as mean ± standard error for n=4 replicates.

	Harvest	SSC (°Brix)	pH	TA (g/L Malic Acid)	SSC:TA	Total Polyphenols (mg/L GAE)	Total Procyanidins (mg/L PC B2 equivalents)	PAN (mg N/mL)
Gold Rush	H1	6.5 ± 0.6^{b}	3.5 ± 0.0^{a}	6.1 ± 0.2^{a}	1.1 ± 1.1^{a}	516 ± 17^{b}	102 ± 12^{b}	25 ± 6^{b}
	H2	8.7 ± 0.1^{b}	3.4 ± 0.0^{ab}	7.4 ± 1.1^{a}	1.2 ± 0.2^{a}	575 ± 28^{b}	108 ± 3^{b}	33 ± 5^{b}
	H3	12.4 ± 0.9^{a}	3.4 ± 0.0^{b}	8.7 ± 0.8^{a}	1.5 ± 0.2^{a}	670 ± 17^{a}	157 ± 5^{a}	74 ± 4^{a}
Dabinett	H1	9.6 ± 1.1^{a}	4.6 ± 0.0^{a}	2.1 ± 1.0^{a}	7.3 ± 2.2^{a}	1421 ± 122^{a}	372 ± 64^{a}	36 ± 5^{b}
	H2	6.9 ± 1.1^{a}	4.6 ± 0.0^{a}	0.9 ± 0.1^{a}	7.8 ± 1.7^{a}	1306 ± 53^{a}	400 ± 52^{a}	78 ± 16^{a}
	H3	8.7 ± 0.6^{a}	4.6 ± 0.0^{a}	2.2 ± 1.3^{a}	7.3 ± 2.2^{a}	1315 ± 89^{a}	313 ± 83^{a}	51 ± 6^{ab}
Binet Rouge	H1	8.7 ± 0.1^{a}	4.4 ± 0.0^{a}	1.2 ± 0.2^{a}	7.8 ± 1.0^{a}	1243 ± 47^{a}	31 ± 6^{a}	53 ± 10^{a}
	H2	10.9 ± 0.6^{a}	4.4 ± 0.0^{a}	1.2 ± 0.1^{a}	9.5 ± 1.0^{a}	1029 ± 62^{ab}	90 ± 28^{a}	43 ± 11^{a}
	H3	9.3 ± 0.8^{a}	4.4 ± 0.0^{a}	1.2 ± 0.1^{a}	8.1 ± 0.5^{a}	993 ± 71^{b}	88 ± 11^{a}	26 ± 2^{a}

As shown in Table 2, soluble solids concentration increased with maturity for Gold Rush juice, but did not significantly differ between treatments in Dabinett or Binet Rouge juice. The juice pH decreased with maturity for Gold Rush juice, but there were no significant differences in pH between treatments in York and Dabinett apples. Total polyphenols increased with maturity for Gold Rush juice, but decreased with maturity for Binet Rouge juice. Titratable acidity (TA) and SSC:TA did not statistically differ among treatments for all cultivars. There were no significant differences in polyphenol concentrations for Dabinett juice. Procyanidin concentrations increased with maturity for Gold Rush treatments, but there were no significant differences in procyanidin concentrations in Dabinett and Binet Rouge treatments. PAN concentrations increased with maturity for Gold Rush juice. In Dabinett juice, PAN concentrations were lowest in the early harvest treatment. There were no significant differences in PAN concentrations in Binet Rouge juice.

Cider Quality

Table 3. 2016 Effects of Harvest Date on Cider Quality. Mean separation was analyzed separately for each cultivar. Values are represented as mean ± standard error for n=4 replicates.

	Harvest	pH	TA (g/L Malic Acid)	Total Polyphenols (mg/L GAE)	Total Procyanidins (mg/L PC B2 equivalents)	Ethanol
Gold Rush	H1	4.1±0.0[a]	6.6±0.1[a]	439±11[a]	142±9[a]	5.2±0.2[b]
	H2	4.1±0.0[a]	7.6±0.1[a]	454±27[a]	80±7[b]	7.5±0.4[a]
	H3	4.1±0.0[a]	7.8±0.4[a]	520±21[a]	109±10[ab]	7.7±0.4[a]
Dabinett	H1	4.3±0.0[a]	1.7±0.1[a]	1164±68[a]	201±38[a]	3.7±0.2[b]
	H2	4.3±0.1[a]	2.0±0.3[a]	1114±93[a]	245±48[a]	4.5±0.4[ab]
	H3	4.3±0.1[a]	2.1±0.2[a]	1108±53[a]	219±60[a]	5.1±0.1[a]
Binet Rouge	H1	4.1±0.0[a]	2.1±0.1[a]	1070±49[a]	87±37[a]	4.5±0.1[a]
	H2	4.1±0.0[a]	2.0±0.2[a]	996±60[a]	101±42[a]	5.2±0.4[a]
	H3	4.1±0.0[a]	2.3±0.1[a]	838±101[a]	83±19[a]	5.3±0.7[a]

As reported in Table 3, no differences in cider pH, TA, or total polyphenols was observed among treatments for any of the three cultivars evaluated. Total procyanidin concentrations were higher in the early maturity treatment and lower in the mid-maturity treatment for Gold Rush ciders, but concentrations of procyanidins did not statistically differ among Dabinett and Binet Rouge ciders. Ethanol concentrations generally increased with fruit maturity for Gold Rush and Dabinett ciders. Though not statistically significant, there was an observable increase in ethanol concentration with fruit maturity for Binet Rouge ciders as well.

Summary of Objective 1 Results

Several differences between harvest maturity treatments were observed in the fruit and juice, consistent with previous findings. However, few chemical differences persisted into the resulting cider made from fruit harvested at different stages of maturity.

Objective 2: Post-Harvest Storage

Fruit Quality

Table 4. 2016 Effects of Post-Harvest Storage Duration and Temperature on Fruit Quality. Mean separation was analyzed separately for each cultivar. Values are represented as mean ± standard error for n=4 replicates.

	Storage Condition	Fruit Firmness (lbs)	Fruit Weight (g)	Starch (1-8)	Color*	Ethylene (ppm)
Gold Rush	2W-4C	79.8±0.8[a]	138±4[ab]	3.2±0.1[d]	2.3±0.1[a]	0.17±0.01[c]
	6W-1C	76.3±0.7[b]	146±4[a]	4.6±0.1[c]	1.8±0.1[b]	3.00±0.92[c]
	6W-10C	72.8±1.0[c]	149±5[a]	7.5±0.1[b]	1.5±0.1[bc]	152.46±15.01[a]
	4M-1C	68.2±0.7[d]	126±4[b]	7.8±0.0[a]	1.2±0.4[c]	61.57±4.83[b]
Dabinett	2W-4C	95.7±0.9[a]	55±2[a]	1.8±0.2[c]	51.5±4.4[ab]	9.04±5.68[b]
	6W-1C	88.2±1.1[b]	56±2[a]	4.8±0.2[b]	57.7±3.1[a]	146.90±11.88[b]
	6W-10C	67.2±1.0[c]	55±2[a]	7.5±0.1[a]	58.3±3.2[a]	568.18±54.83[a]
	4M-1C	71.5±1.0[d]	57±2[a]	8.0±0.0[a]	42.2±3.0[b]	668.09±68.04[a]
Binet Rouge	2W-4C	85.8±1.7[a]	52±2[a]	2.9±0.2[c]	38.5±3.9[ab]	2.2±1.5[c]
	6W-1C	86.0±2.1[a]	51±2[a]	4.3±0.3[b]	47.7±3.9[a]	14.9±2.1[b]
	6W-10C	73.3±2.4[b]	46±2[a]	7.4±0.1[a]	47.6±5.0[a]	43.5±11.3[a]
	4M-1C	72.7±2.0[b]	46±2[b]	7.7±0.1[a]	30.2±3.6[b]	23.9±5.8[b]

* For Dabinett and Brown Snout, Red Color is measured on a 0-100% scale, and for Gold Rush, Green Background Color is measured on a 1-4 scale.

As reported in Table 4, fruit firmness generally decreased with increased storage time and temperature for all cultivars. For Gold Rush and Binet Rouge fruit, fruit weight was lowest for the 4M-1C treatment. Fruit weight did not significantly differ for the Dabinett treatments. Starch-iodine index values generally increased with increased storage time and temperature for all cultivars. Green background color in Gold Rush fruit decreased with increased storage time. Red color in Dabinett and Binet Rouge fruit also generally decreased with increased storage time. Ethylene concentrations were highest in the 6W-10C treatments for Gold Rush and Binet Rouge fruit compared to other treatments. Dabinett fruit had highest ethylene gas concentrations in the 6W-10C and 4M-1C treatments.

Juice Quality

Table 5. 2016 Effects of Post-Harvest Storage Duration and Temperature on Juice Quality. Mean separation was analyzed separately for each cultivar. Values are represented as mean ± standard error for n=4 replicates.

	Storage Condition	SSC (°Brix)	pH	Titratable Acidity (g malic acid/L)	SSC:TA	Total Polyphenols (mg/L GAE equivalents)	Total Procyanidins (mg/L PC B2 equivalents)	PAN (mg N/L)
Gold Rush	2W-4C	7.4±0.4[b]	3.5±0.0[a]	6.2±0.4[a]	1.2±0.1[b]	505±32[b]	124±14[a]	16±1[ab]
	6W-1C	10.4±0.9[ab]	3.7±0.2[a]	6.6±0.4[a]	1.6±0.2[b]	642±29[ab]	89±10[a]	19±1[ab]
	6W-10C	13.1±0.7[a]	3.7±0.0[a]	5.2±0.2[a]	2.5±0.2[ab]	624±47[ab]	87±10[a]	14±1[b]
	4M-1C	12.0±0.7[a]	3.6±0.0[a]	3.2±0.7[b]	4.3±1.0[a]	717±27[a]	91±13[a]	21±2[a]
Dabinett	2W-4C	6.3±0.7[ab]	4.7±0.0[a]	1.1±0.1[a]	6.0±0.5[a]	1278±104[b]	425±44[b]	52±9[a]
	6W-1C	5.9±0.4[b]	4.5±0.0[b]	1.1±0.1[a]	5.6±0.9[a]	1710±56[b]	591±79[b]	54±12[a]
	6W-10C	8.5±0.4[ab]	4.5±0.1[b]	1.0±0.2[a]	9.3±1.7[a]	2603±134[a]	939±81[a]	50±17[a]
	4M-1C	9.4±1.2[a]	4.5±0.0[b]	1.4±0.1[a]	6.7±0.6[a]	2645±162[a]	484±32[b]	45±7[a]
Binet Rouge	2W-4C	5.7±0.3[c]	4.4±0.0[ab]	1.7±0.2[a]	3.5±0.5[b]	1225±211[a]	88±40[b]	51±7[a]
	6W-1C	7.4±1.1[bc]	4.3±0.0[b]	1.7±0.4[a]	4.7±0.8[b]	1286±110[a]	171±14[b]	54±10[a]
	6W-10C	9.9±0.4[ab]	4.4±0.0[ab]	1.5±0.0[a]	6.6±0.2[b]	1931±204[a]	347±24[a]	27±8[a]
	4M-1C	11.9±1.2[a]	4.6±0.0[a]	1.1±0.1[a]	10.6±1.2[a]	1973±242[a]	190±19[b]	34±8[a]

As reported in Table 5, soluble solids content generally increased with increased fruit storage time for all three cultivars. The pH did not significantly differ between Gold Rush juice treatments, but in Dabinett juice, the pH of the 2W-4C was statistically higher than all other treatments, although the magnitude of the difference observed is relatively small, in practical terms. In Binet Rouge juice, the pH was lowest for the 6W-1C treatment and highest for the 4M-1C treatment. TA did not significantly differ among treatments for Dabinett and Binet Rouge juices, but the TA was significantly lower for the 4M-1C Gold Rush juice. SSC:TA did not differ between treatments for Dabinett juice, however, for Gold Rush and Binet Rouge juices, the SSC:TA was highest in the 4M-1C treatments. For Gold Rush and Dabinett juices, total polyphenol concentration generally increased with increased storage time and temperature, but there were no significant differences in total polyphenol concentrations between treatments for Binet Rouge juices. Total procyanidin concentrations did not significantly differ between treatments of Gold Rush juice. However, procyanidin concentrations were highest in the 6W-10C treatments for both Dabinett and Binet Rouge juices. PAN concentration in Gold Rush juice was lowest in the 6W-10C treatment and highest in the 4M-1C treatment. PAN concentration did not significantly differ among Dabinett and Binet Rouge juice treatments.

Cider Quality

Table 6. 2016 Effects of Post-Harvest Storage Duration and Temperature on Cider Quality. Mean separation was analyzed separately for each cultivar. Values are represented as mean±standard error for n=4 replicates.

	Storage Condition	pH	TA (g/L)	Total Polyphenols (mg/L GAE equivalents)	Total Procyanidins (mg/L PCB2 equivalents)	Ethanol (%v/v)
Gold Rush	2W-4C	3.4±0.0^{c}	7.8±0.4^{a}	359±30^{a}	123±14^{a}	4.6±0.2^{b}
	6W-1C	3.5±0.0^{b}	6.7±0.3^{ab}	444±29^{a}	89±10^{a}	6.6±0.3^{a}
	6W-10C	3.5±0.0^{b}	6.2±0.3^{b}	475±38^{a}	87±10^{a}	6.5±0.4^{a}
	4M-1C	3.6±0.0^{a}	5.8±0.4^{b}	478±47^{a}	91±13^{a}	6.5±0.6^{a}
Dabinett	2W-4C	4.3±0.0^{a}	1.6±0.1^{c}	1120±104^{c}	425±44^{b}	4.7±0.2^{b}
	6W-1C	4.1±0.0^{b}	2.9±0.1^{a}	1308±173^{bc}	591±79^{b}	4.7±0.5^{b}
	6W-10C	4.1±0.0^{b}	2.3±0.2^{b}	1688±112^{ab}	939±81^{a}	5.9±0.2^{ab}
	4M-1C	4.1±0.0^{b}	2.5±0.1^{ab}	1871±77^{a}	484±32^{b}	6.2±0.2^{a}
Binet Rouge	2W-4C	4.1±0.0^{a}	3.1±0.1^{a}	807±42^{b}	88±40^{b}	3.9±0.1^{c}
	6W-1C	4.1±0.0^{a}	3.2±0.0^{a}	899±43^{b}	171±14^{b}	4.5±0.3^{bc}
	6W-10C	4.0±0.1^{a}	1.8±0.3^{b}	1344±91^{a}	347±23^{a}	6.4±0.9^{ab}
	4M-1C	4.1±0.0^{a}	2.1±0.1^{b}	1567±65^{a}	190±19^{b}	7.9±0.4^{a}

As shown in Table 6, cider pH was statistically higher in the 2W-4C treatment in the Dabinett ciders, although this difference was relatively small. Total polyphenols did not significantly differ between Gold Rush cider treatments but generally increased with storage time and temperature in the Dabinett and Binet Rouge ciders. Total procyanidins did not significantly differ between Gold Rush cider treatments. Procyanidin concentrations were highest in the 6W-10C Dabinett and Binet Rouge cider treatments. Ethanol concentrations generally increased with storage time and temperature in ciders made from each cultivar.

Summary of Objective 2 Results

There were several differences between treatments in fruit measurements as well as juice and cider chemistry. These results demonstrate that fruit storage temperature and duration can impact cider chemistry, indicating the potential for postharvest storage practices to impact cider quality.

F. CONCLUSIONS AND FUTURE WORK

The results of this project indicate that harvest maturity and post-harvest storage treatments of apples influence fruit, juice, and cider quality, to varying degrees. We will continue to analyze the individual polyphenol compounds in the cider samples to gain a better understanding of the nature of the differences observed in total polyphenols in ciders made from apples stored at different temperature and duration. In addition, we will compare the results from Year 1 of the study to Year 2 of the study to draw final conclusions, and publish these findings in an appropriate peer-reviewed scientific journal.

G. IMPACT STATEMENT

The results of Year 1 of the study were presented to 60 commercial apple growers and cider makers on June 16, 2016 at a Commercial Cider Production Workshop organized by Dr. Greg Peck of Cornell University, Dr. Amanda Stewart of Virginia Tech, Mark Sutphin of Virginia Cooperative Extension, and Brianna Ewing, Washington State University - formerly Virginia Tech. The workshop was held at the Virginia Tech Alson H. Smith, Jr. Agriculture Research and Extension Center near Winchester, VA. Year 1 results were also presented at CiderCon 2017 in Chicago, IL. Research findings and research-based recommendations regarding the influence of orchard management and pre-processing practices on cider quality are not currently available, and as such this project has been of interest to growers and cider makers. This research project represents an important first step toward developing practical research-based recommendations for cider makers, taking into account both crop production and processing systems. The results of this project are currently in preparation for publication in a peer-reviewed scientific journal.

H. PUBLICATIONS/PRESENTATIONS OF THIS AND RELATED RESEARCH

Ewing, B.L.; Peck, G.M.; Neilson, A.P.; Stewart, A.C. *Managing Harvest Maturity and Post-Harvest Storage to Improve Hard Cider Quality*. 2/2017. CiderCon Research Poster Session., Chicago, IL.

Ewing, B. *Effect of Harvest Maturity and Post-Harvest Storage on Fruit, Juice, and Cider Quality.* Food Science and Technology Poster Session. 4/2016. Virginia Tech.

Ewing, B. *Effect of Harvest Maturity and Post-Harvest Storage on Fruit, Juice, and Cider Quality*. 6/2016. Commercial Cider Production Workshop. Virginia Tech Cooperative Extension. Winchester, VA

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