STUDIES ON FRUIT AND HARD CIDER CHEMISTRY OF EASTERN WASHINGTON

Abstract

Until recently, there has been little information on the chemistry of hard cider derived from fruit sourced in eastern Washington. Only a few studies have been published concerning tannin tests for cider apple juices or hard ciders within the northwestern United States.

Our current study examines apple fruit chemistry, including tannin assays, in which several common apple varieties were analyzed. These include dessert apples, three English apple varieties, and an 'F1-hybrid crab' blend. Two trials were conducted in our study using apple varieties grown on an organic, low-density orchard and apple varieties grown on a high-density, intensively managed, conventional orchard. In both trials, at harvest, individual juice extracts as well as blended ciders were analyzed for percent titratable acidity (TA), percent sucrose (Brix), and percent procyanidins (tannin levels). The organic trial showed 'Golden Russet' having the highest percent TA and Brix in juice. 'Major' had the highest juice tannin level. The 'Improved Red McIntosh'-'Golden Russet' cider blend displayed a high percent TA during bottle aging. However, 'Improved Red McIntosh'-'Dabinette' cider had the highest tannin level during aging. The conventional trial revealed the 'F1-hybrid crab' apple had the highest percent TA as well as the highest tannin level. The 'Golden Delicious'-'F1-hybrid crab' cider blend maintained the highest percent TA during bottle aging. The tannin level was similar during aging between 'Golden Delicious'-'F1-hybrid crab' and 'Ok Red McIntosh'-'Dabinette' at one and six months of age. The most significant result in this study was that conventionally grown 'Ok Red McIntosh'-'Dabinette' had higher tannin levels at both one and six months versus a similar varietal blend grown organically.

Introduction

Recent Hard Cider Data in Washington State

According to recent reports, the U.S. hard cider industry and special drinks is predicted to continue growing beyond 2023 (Statista 2019). Washington State produced 137.3 million boxes of dessert apples in 2019 at a revenue of 3.0 billion (Fruit Growers News 2020). In 2011 it was reported that 256 acres of apple trees in Washington State were cultivated exclusively for cider making (Galinato and Miles 2017). Cultivation of cider-only apples in the United States remains a small fraction of the total domestic apple production (U.S. Apple Association 2021). Currently, 71 hard cider businesses are registered or licensed in Washington State, and it is unknown how many businesses grow their own cider-making apples (American Cider Association 2020).

Historical Hard Cider Attributes

Although dessert variety apples are used in U.S. hard cider making, these fruits are primarily cultivated for consumption (Lea 2016). True cider apples are desired for their higher levels of acidity and tannins, which provide desired sensory attributes in the final cider (Lea and Drilleau 2003). A list of hard cider apple varieties is shown by Miles et al. (2015) and Watson (2013), and these apple varieties are described as "Sharp," "Bittersharp," "Bittersweet," and "Sweet," classifications first used by Barker 1903 (adapted by Lea, 2008).

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Latest Hard Cider Chemical Information in Washington

Information about the hard cider chemistry from the northwestern United States is mostly limited to data from Mt. Vernon, Washington (Moulton et al. 2010). More recently, Alexander et al. (2016a) have shown juice chemistry data for 'Brown Snout' using machine or hand harvest and regional variation among four cultivars for juice chemistry. Also, for Mt. Vernon, Washington, Miles et al. (2017) described juice chemistry data for 18 cider apple cultivars at 5 to 14 years of study. As for chemical cider apple data or hard cider data in eastern Washington, the information is limited to just one minor study: *Condensed Tannin Measurements in Eastern WA Cider Juices and Hard Cider* (Mattinson 2018).

Objective

For our study, two trial plots were involved. One trial plot was located at the WSU-Tukey orchard and consisted of organically grown 'Improved Red McIntosh' ('IRM'). A second group of varieties were harvested at a commercial orchard consisting of 'Dabinette,' 'Major,' and 'Golden Russet.' These apples were considered organically grown and were harvested at full ripe. A second trial plot involved a conventionally grown trial harvest of 'Ok Red McIntosh' ('ORM'), 'Dabinette,' 'Golden Russet,' 'F1-hybrid crab,' and 'Golden Delicious' at full ripe from an eastern Washington grower. This study attempted to analyze and compare juice and cider chemistry in an organic trial over three years for 2017, 2018, and 2019 and a similar analysis within the conventional trial over two years for 2018 and 2019.

Methodologies

Trial 1: Organically Grown Apples

Apple harvest occurred at a local grower (Steury Orchards, Potlatch, Idaho) as well as WSU-Tukey and then the apples were maintained in regular atmosphere (RA) storage prior to being pressed at the WSU-Pullman campus (study was three seasons). The total liquid pressed in each variety and then subsampled as a blend was precisely 0.789 gallons. The blends consisted of 'IRM,' 'Dabinette,' 'Major,' and 'Golden Russet.' Each of the three blends were prepared before fermentation as a 1:1 mixture of 'IRM' with each of the three English varieties. Fermentations were performed at 64°F for four to five weeks using the yeast isolate DV-10, a nutritional supplement of fermaide K, and K^{+}meta $(SO_4)_2$. Afterwards, ciders were racked and supplemented with pectinase (0.0091 oz/gallon) for one to two weeks, followed by additional sugar (0.072 oz/gallon), and then bottled. Ciders were either aged for four to six weeks or six months. The initial juices as well as one-month and six-month fermented ciders were subsampled and stored in four falcon tubes at 32°F.

Trial 2: Conventionally Grown Apple

Apple harvest occurred at a local grower (Bishop's Orchards, Garfield, Washington) and then the fruits were maintained in RA storage prior to being pressed at the WSU-Pullman campus (study was two seasons). 'Golden Delicious' was harvested at the WSU-Tukey orchard, while the 'F1-hybrid crab' selections were harvested from a mini orchard on the WSU-Pullman campus. The Garfield apples, 'ORM' and 'Dabinette,' were blended as a 1:1 mixture in volumes of up to 0.789 gallons. 'Golden Delicious' was fermented singly at 0.789 gallons or blended with a multi 'F1-hybrid crab' apple selection at four parts 'Golden Delicious' to one part 'F1-hybrid crab.' The fermentations were performed the same as Trial 1.

Chemical Analysis of Juices and Hard Ciders

The samples from juice pressings and cider were analyzed for pH, percent TA, and Brix, as described by Moulton et al. (2010). A subset of the samples was analyzed for percent tannins as procyanidin per the Porter assay (Porter et al. 1986) and modified in our lab (Mattinson 2018). The chemical data were tabulated in MS Excel, and the data values were statistically analyzed using JMP-14 for one-way ANOVA by time.

Results

Trial 1: Juice and Cider Chemistry of Organically Produced English Apples

The visual results for the tannin assay used in Trial 1 are shown in Figure 1. Figure 1 displays a micro plate used for reading the absorbance at λ550 nm. The left three cells were replicates containing HCl, the middle three cells contained no HCl, and the two far-right cells contained all reagent chemistry, but no heat, which was utilized as the blank in the assay. Especially notable is the degree of red color developed from the top to the bottom of the plate, indicating differences in the apple variety tannins (Figure 1). The assay details are outlined in *Condensed Tannin Measurements in Eastern WA Cider Juices and Hard Cider* (Mattinson 2018).

Figure 1. Porter assay showing juices of 'F1-hybrid crab' in row A, 'IRM' in row B, 'Dabinette' in row C, and 'Golden Delicious' in row D. Left to right indicates assay with HCl, assay without HCl (a blank), and the final blank. The reddish color indicates a high, low, or zero level of tannin as anthocyanidin. The absence of HCl in the blank or middle section implies less background flavan-3-ols which convert to anthocyanidins, the final reaction product. Photo by D.S. Mattinson.

The percent TA data for the juices revealed that 'Golden Russet' has higher values for this parameter than the other varieties (Table 1), which is in line with previous literature, including Moulton et al. (2010) who showed percent TA values of 0.79 and 0.63 in consecutive seasons and 0.66 percent over five seasons (Miles et al. 2017). Also, 'Golden Russet' is classified as "Sharp" by Barker (1903) (adapted from Lea, 2008). 'Golden Russet' juice also had higher Brix value than other cultivars (Table 1), although this is not a previously established attribute in the literature. 'Dabinette' is a known bittersweet variety (Miles et al. 2015), and, while it did show a low percent TA, it had a medium Brix level (Table 1).

The one-month post-fermentation data for blends of 'IRM' with English apple varieties ('IRM'-'Major' as a 1:1 blend and 'IRM'-'Golden Russet' as a 1:1 blend) resulted in "sharp" hard cider with high percent TA (Table 2). The 'IRM'-'Dabinette' blend had a much lower percent TA. Each blend had a "dry" sugar result with a Brix value near 6.0 (Table 2). Brix value is not a regularly reported attribute for finished hard cider; however, it is a common suggestion to begin with juice Brix values from 10 up to 15 or above for most hard cider blends (Lea 2016). Therefore, a finished hard cider should indicate a much lower Brix value than at initial fermentation.

Similarly, after six months of bottle aging, the 'IRM'-'Dabinette' blend was again lower in percent TA. Both blends of 'IRM'-'Major' and 'IRM'-'Golden Russet' had a significantly higher percentage TA compared to 'IRM'-'Dabinette' (Table 3). At six months, all blends were close in value at approximately 6.0 Brix (Table 3).

The tannin level was high in 'Major' juice (Figure 2) at 0.139% procyanidin, which was significantly higher than that of 'Dabinette,' 'Golden Russet,' and 'IRM.' Similar data for 'Brown Snout' juice was reported recently by Alexander et al. (2019), with 0.042% procyanidin detected using a total tannin protein precipitation assay. The values are in accordance with original values of 0.04% given by Lea (1990) for 'Dabinette' juice analyzed using high performance liquid chromatography.

After one month of fermentation, the procyanidin content of 'IRM'-'Dabinette' was at 0.045%, similar to that of 'IRM'-'Major,' which was at 0.039% (Figure 3). The data are in accordance with Alexander et al. (2019) in which a similar assay was used to reveal a procyanidin content of 0.02% for singly fermented 'Brown Snout' cider. The tannin content of bottle-aged ciders after six months was slightly higher than at five weeks fermentation. 'IRM'-'Dabinette' and 'IRM'-'Major' were above 0.055%; both European varieties are considered bitter (Figure 4). The 'IRM'-'Golden Russet' cider at six months was not statistically different than the other cider blends (Figure 4); however, the blend at six months was different than after one month of fermentation (Figure 3).

Table 1. Percent TA and Brix values (and standard deviation) for juice from three years of study using pressed batches of organically managed English apple varieties from eastern Washington.

	% TA	Brix
'Improved Red Mac'	0.622 ± 0.08 **B**	9.80 ± 0.54 **C**
'Dabinette'	0.248 ± 0.01 **C**	14.4 ± 0.52 **B**
'Major'	0.521 ± 0.04 **B**	15.0 ± 0.18 **B**
'Golden Russet'	0.973 ± 0.04 **A**	17.9 ± 0.51 **A**

Note: Letters after the values in each column represent the statistically significant difference at an α = 0.05 level of significance.

Table 2. Percent TA and Brix values (and standard deviation) for one month post-fermentation cider blended at a 1:1 juice ratio over three years.

	% TA	Brix
'Improved Red Mac'-'Dabinette'	0.570 ± 0.006 **B**	5.8 ± 0.07 **A**
'Improved Red Mac'-'Major'	0.844 ± 0.030 **A**	6.1 ± 0.28 **A**
'Improved Red Mac'-'Golden Russet'	0.877 ± 0.015 **A**	6.7 ± 0.11 **A**

Note: Values are for trials with organically managed English apple varieties from eastern Washington. Letters after the values in each column represent the statistically significant difference at an α = 0.05 level of significance.

Table 3. Percent TA and Brix values (and standard deviation) for six-month-old, post-fermentation, bottle-aged cider blended at a 1:1 juice ratio over two years.

	% TA	Brix
'Improved Red Mac'-'Dabinette'	0.647 ± 0.04 **B**	4.9 ± 0.28 **A**
'Improved Red Mac'-'Major'	1.06 ± 0.32 **A**	6.3 ± 1.30 **A**
'Improved Red Mac'-'Golden Russet'	1.13 ± 0.133 **A**	6.0 ± 0.86 **A**

Note: Values are for trials with organically managed English apple varieties from eastern Washington. Letters after each value within the column represent the statistically significant difference at an α = 0.05 level of significance.

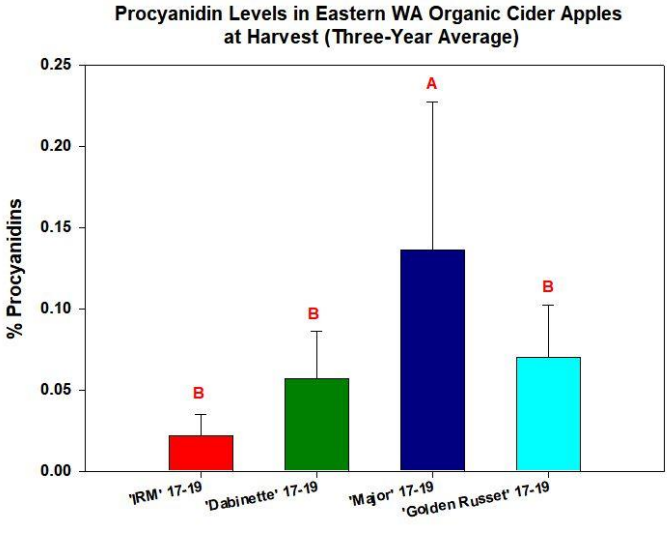

Figure 2. Data from the juice tannin analysis (represented as % procyanidins) assessed using the Porter assay and presented as the mean over three years. Letters above each column indicate the statistically significant difference at the α = 0.05 level.

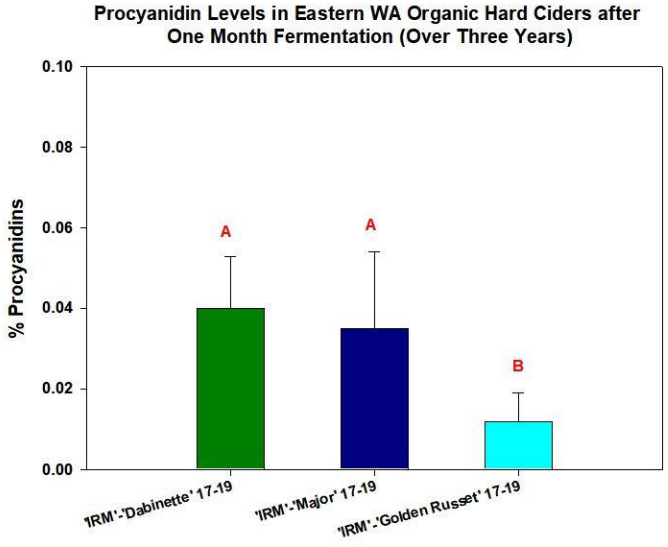

Figure 3. Data from the cider blend tannin analysis (represented as % procyanidins) assessed using the Porter assay one month post-fermentation and presented as the mean over three years. Letters above each column indicate the statistically significant difference at the α = 0.05 level.

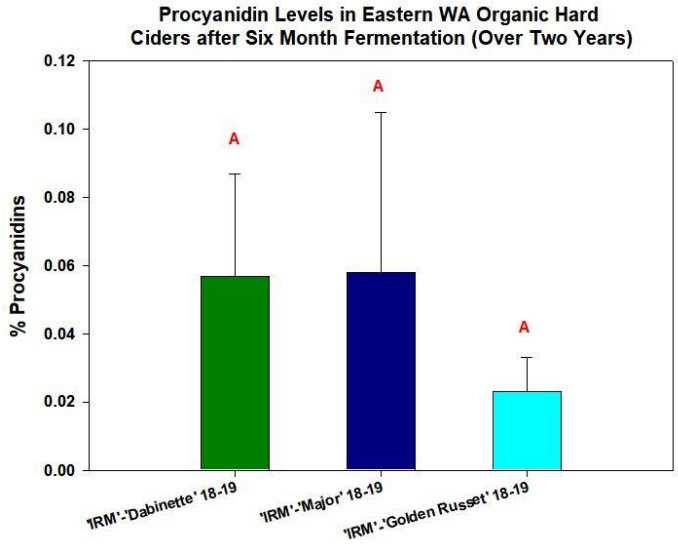

Figure 4. Data from the tannin analysis (represented as % procyanidins) assessed using the Porter assay on various cider blends after six months bottle storage and presented as the mean over two years. Letters above each column indicate the statistically significant difference at the α = 0.05 level.

Trial 2: Juice and Cider Chemistry of Conventionally Grown Hard Cider Apples

The primary goal in studying apples grown from a conventional orchard was to observe any differences in juice chemistry and the final cider. The comparison was done on fruit grown under conventional management. The 'Ok Red McIntosh' were free standing trees, and the 'Dabinette' were trained using Bud 9 rootstocks within a trellis. 'Golden Delicious' trees were freestanding, and the 'F1-hybrid crab' were grown from seed, planted in pots, and allowed to grow freestanding. The percent TA for 'Dabinette' juice was 0.188%, significantly low compared to 'Ok Red McIntosh' or 'Golden Delicious' (which both had a percent TA of 0.610) and much lower than 'F1-hybrid crab' at 2.80% (which was significant—'F1-hybrid crab' had the highest value observed) (Table 4). The juice Brix levels from all the apple varieties were not significantly different, although 'Dabinette' had the highest levels at 15.5 Brix and developed true bittersweet characteristics with low percent TA

and higher Brix (Table 4). These results are new with regards to analysis of eastern Washington cider apple fruit.

The cider blends after five weeks of fermentation revealed that the 'Golden Delicious'-'F1-hybrid crab' blend at a 3:1 ratio was significantly higher in percent TA than the 'ORM'-'Dabinette' blend or 'Golden Delicious' as a single cider (Table 5). Surprisingly, the 'Golden Delicious' single cider revealed a percent TA of 0.891. The Brix levels after one month of fermentation were lower (near 5.5), which is consistent with a dry cider (Table 5). At six months of bottle aging, a similar pattern in percent TA was observed for the 'Golden Delicious'-'F1-hybrid crab' blend, which was significantly higher (1.15%) than the singly fermented 'Golden Delicious' (0.88%) (Table 6). The 'ORM'-'Dabinette' cider did increase in percent TA from one month fermentation (0.77%) up to 0.965% at six months (Table 5 and Table 6). The Brix values at six months of aging were nearly identical to those at one month fermentation (Table 3).

The tannin levels in pressed cider juices are shown in Figure 5 for the conventionally managed orchard. The 'F1-hybrid crab' blend had the highest procyanidin level at 0.401%, which was greater than 'Dabinette' at 0.188%; both had higher levels than 'Ok Red McIntosh' or 'Golden Delicious' (~0.02%) (Figure 5). After one month of fermentation, the 'ORM'-'Dabinette' blend had significantly higher tannin levels than the 'Golden Delicious'-'F1-hybrid crab' blend, at 0.087% versus 0.072%, respectively (Figure 6). Singly fermented 'Golden Delicious' had a tannin level of 0.007% (Figure 6). The dessert apple 'Golden Delicious' is known to have very low tannin levels and has been reported by the Long Ashton Research Station (which began tracking data from 1905 to 1975) to contain 0.006% procyanidins per the Lowenthal assay (Lea 1996).

After six months of bottle aging, tannins increased in comparison with the one month aged samples, and no differences were observed between the 'ORM'-'Dabinette' blend (0.101%) and the 'Golden Delicious'-'F1-hybrid crab' blend (0.132%). Both blends had significantly higher tannin levels than 'Golden Delicious' (0.0078%) (Figure 7).

Table 4. Percent TA and Brix values (and standard deviation) for juice sampled in two years of study using pressed batches of conventionally managed English apple varieties in eastern Washington.

	% TA	Brix
'OK Red McIntosh'	0.610 ± 0.083 **B**	12.8 ± 0.15 **A**
'Dabinette'	0.188 ± 0.021 **C**	15.5 ± 2.70 **A**
'Golden Delicious'	0.610 ± 0.004 **B**	11.9 ± 0.84 **A**
'F1-hybrid crab' blend	2.80 ± 0.171 **A**	12.0 ± 3.70 **A**

Note: Letters after the values in each column represent the statistically significant difference at an α = 0.05 level.

Table 5. Percent TA and Brix values (and standard deviation) for one month post-fermentation cider blended at a juice ratio of 1:1 for 'Ok Red McIntosh' and 'Dabinette,' 3:1 for 'Golden Delicious' and 'F1- hybrid crab,' and singly for 'Golden Delicious' over two years.

	% TA	Brix
'Ok Red McIntosh'-'Dabinette'	0.771 ± 0.007 **B**	5.35 ± 0.510 **A**
'Golden Delicious'-'F1-hybrid crab' blend	1.23 ± 0.189 **A**	5.70 ± 1.320 **A**
'Golden Delicious'	0.891 ± 0.131 **B**	4.62 ± 0.370 **A**

Note: Values are for conventionally managed English apple varieties from eastern Washington. Letters after the values in each column represent the statistically significant difference at an α = 0.05 level.

Table 6. Percent TA and Brix values (and standard deviation) for six months post-fermentation cider blended at a juice ratio of 1:1 for 'Ok Red McIntosh' and 'Dabinette,' 3:1 for 'Golden Delicious' and 'F1-hybrid crab,' and singly for 'Golden Delicious' over two years.

	% TA	Brix
'Ok Red McIntosh'-'Dabinette'	0.965 ± 0.199 **A, B**	5.25 ± 0.412 **A**
'Golden Delicious'-'F1-hybrid crab' blend	1.150 ± 0.098 **A**	5.90 ± 1.500 **A**
'Golden Delicious'	0.880 ± 0.088 **B**	4.70 ± 0.460 **A**

Note: Values are for conventionally managed English apple varieties from eastern Washington. Letters after the values down the column represent the statistically significant difference at an α = 0.05 level.

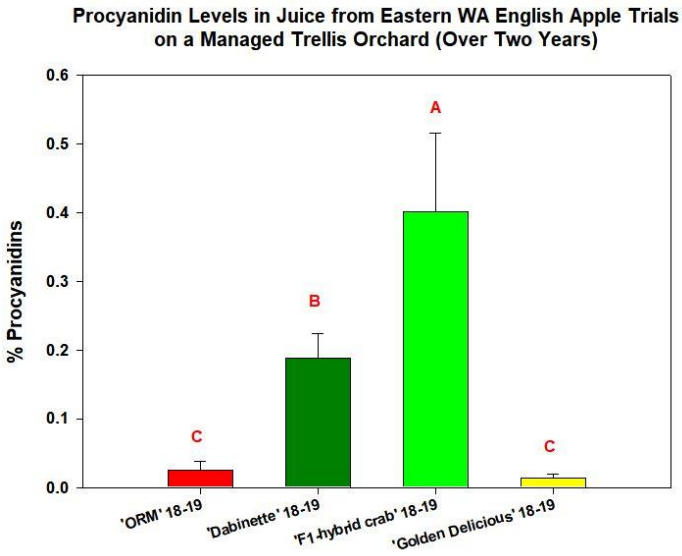

Figure 5. Data from the tannin analysis (represented as % procyanidins) assessed using the Porter assay on juice sampled after two years of study. Letters above each column indicate the statistically significant difference at the α = 0.05 level.

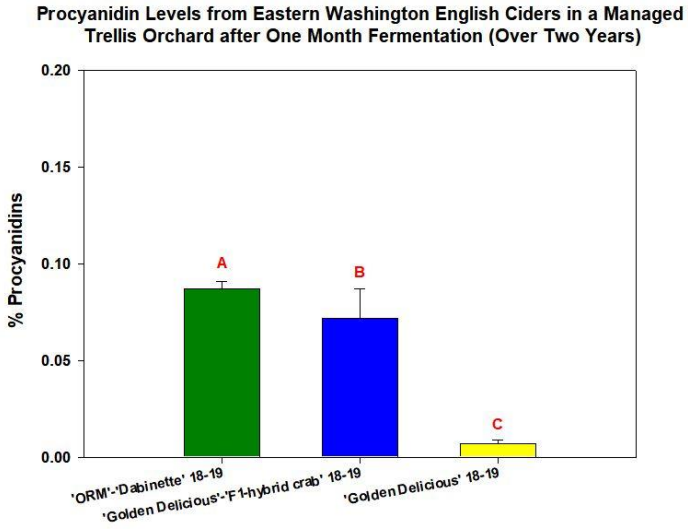

Figure 6. Data from the cider tannin analysis (represented as % procyanidins) assessed using the Porter assay after one month of fermentation, presented as the mean over two years of study. Letters above each column indicate the statistically significant difference at the α = 0.05 level.

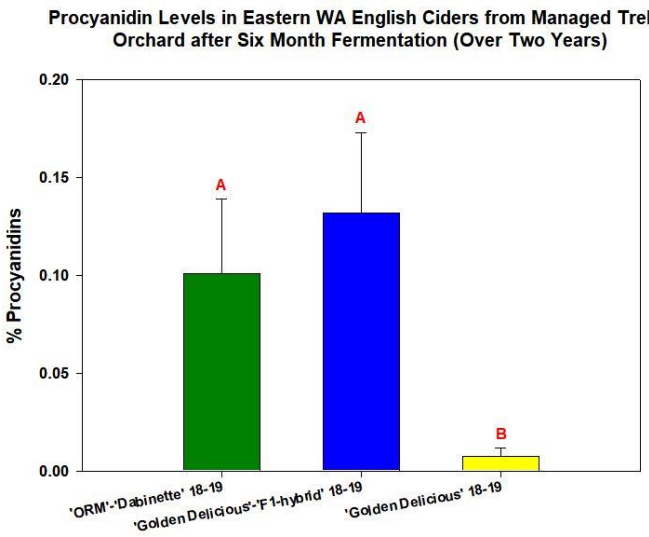

Figure 7. Data from the tannin analysis (represented as % procyanidins) assessed using the Porter assay on various cider blends after six months of bottle storage, presented as the mean over two years of study. Letters above each column indicate the statistically significant difference at the α = 0.05 level.

Final Comparison: Procyanidin Levels Compared between Cider Types

A final comparison was made between the 'IRM'-'Dabinette' cider blend and the 'ORM'-'Dabinette' blend after one month and six months of aging (Figure 8). Sampling results show the cider blends from conventionally produced apples had the highest percent procyanidins, 0.087% after one month and 0.102% after six months (Figure 8). The conventional cider had levels significantly higher than the organically produced cider at one month, but not significantly higher than the organically produced six-month-old cider (Figure 8). After six months, the conventionally produced cider had significantly higher tannin levels than both samples of organically produced cider at one month and six months (Figure 8). These samples, however, were not significantly different for the conventional treatment alone (Figure 8). The notable results are that the six-month-old, conventionally produced ciders had a higher tannin level (0.102%) compared to organically produced ciders (0.057%), a 1.78 factor difference.

As for hard cider apples, only Lea and Beech (1978) provide information on the percent procyanidin quantities detected in cider apple juices versus cultural practices performed in the orchard. Lea and Beech (1978) indicated that 33-year-old 'Dabinette' trees transplanted to 12-inch pots and either fertigated with a weekly NK drip or not fertigated had juice tannin of 0.30% for fed versus 0.35% for unfed trees. The leaf N was higher in fed trees (2.34%) versus unfed trees (2.00%). Ciders made from the 'Dabinette' juices also had lower tannin values after feeding compared to those that were unfed (Lea and Beech 1978).

Orchards growing hard cider apples in the Pacific Northwest, and especially those in central to eastern Washington, are not generally regulated with regard to cultural practice. In this study, the organic orchard is not certified; however, the orchard generally is fertilized by animal manure (Tim Steury, personal communication). Irrigation is comprised of annual precipitation and intermediate drip.

The conventional orchard used in this study was fully managed per conventional protocols, similar to that described in Moulton et al. (2010). The conventionally managed orchard applied zinc and boron via spray. $CaNO_3$ was applied in granular form. Occasionally, $(NH_4)_2SO_4$ was also applied. Irrigation was accomplished via drip and depended on seasonal precipitation patterns (Stephen Bishop, personal communication).

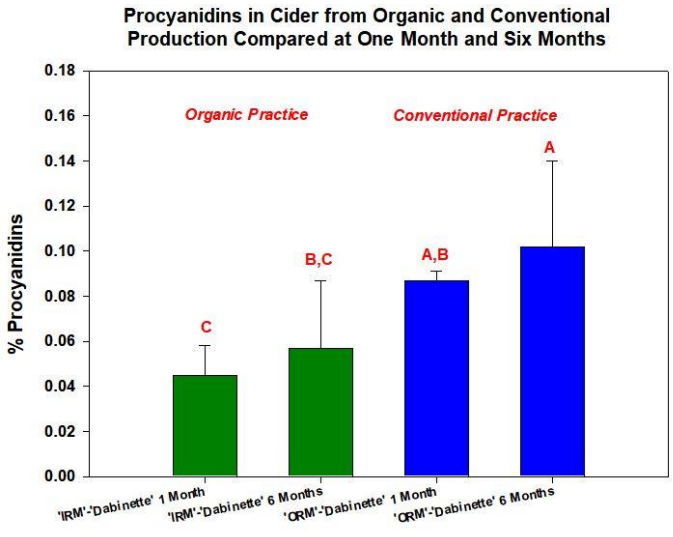

Figure 8. Data from the tannin analysis (represented as % procyanidins) assessed using the Porter assay on 'IRM'-'Dabinette' cider blends from the *organic* production trial after one month and six months of aging (green bars). The tannins were also directly compared to 'ORM'-'Dabinette' cider blends from the *conventional* trial after one month and six months of aging (blue bars). Letters above each column indicate statistically significant difference at an $\alpha = 0.05$ level based on ANOVA comparisons of all means.

Conclusions

The goal of this publication is to expand upon the information presented in *Condensed Tannin Measurements in Eastern WA Cider Juices and Hard Cider* (Mattinson 2018). This publication provides chemistry data for standard U.S. apple varieties, three English varieties, and one group of 'F1-hybrid crab' apples. Within this study, hard cider varieties were analyzed under an organic and conventional management system. The main goal was to analyze the percent TA, Brix values, and tannins within each apple variety's juice and to study the blends from the apple varieties at one month and six months of age. This study marks the first of its kind for eastern Washington hard cider apple growers and hard cider makers.

References

Alexander, T.R., T.S. Collins, and C.A. Miles. 2019. Comparison of the Phenolic Profiles of Juice and Cider Derived from Machine- and Hand-Harvested 'Brown Snout' Specialty Cider Apples in Northwest Washington. *HortTechnology* 29 (4): 423–433.

Alexander, T.R., J. King, E. Scheenstra, and C.A. Miles. 2016a. Yield, Fruit Damage, Yield Loss, and Juice Quality Characteristics of Machine- and Hand-Harvested 'Brown Snout' Specialty Cider Apples Stored at Ambient Conditions in Northwest Washington. *HortTechnology* 26 (5): 614–619.

Alexander, T.R., J. King, A. Zimmerman, and C.A. Miles. 2016b. Regional Variation in Juice Quality Characteristics of Four Cider Apple (*Malus ×domestica* Borkh.) Cultivars in Northwest and Central Washington. *HortScience* 51 (12): 1498–1502.

American Cider Association. 2021. Cider Culture.

Bishop, S. Personal communication. Bishop's Orchard, Garfield, Washington.

Fruit Growers News. 2020. Washington Apple Harvest Estimated to Hold Steady at 134M Boxes. Great American Media Services & Fruit Growers News.

Galinato, S.P., and C.A. Miles. 2017. Cost Estimates of Establishing and Producing Specialty Cider Apples in Central Washington. *Washington State University Extension Publication* TB35. Washington State University.

Lea, A.G.H. 1990. Bitterness and Astringency: The Procyanidins of Fermented Apple Ciders. In *Bitterness in Foods and Beverages*, edited by R.L. Rousseff, 123–143. Elsevier: Oxford, U.K.

Lea, A.G.H. 1996. Cider Apple Compositional Data. Under "Cider Apple Data." Data from Long Ashton Report 1905–1975. The Wittenham Hill Cider Pages.

Lea, A.G.H., ed. 2008. *Craft Cider Making*. The Good Life Press Ltd.

Lea, A.G.H. 2016. *Craft Cider Making*, 3rd edition. The Crowood Press Ltd.

Lea, A.G.H., and F.W. Beech. 1978. The Phenolics of Ciders: Effect of Cultural Conditions. *Journal of Science and Food Agriculture* 29: 493–496.

Lea, A.G.H., and J. Drilleau. 2003. Cidermaking. In *Fermented Beverage Production*, 2nd edition, edited by A.G.H. Lea and J.R. Piggot, 59–88. Kluwer Academic/Plenum Publishers.

Mattinson, D.S. 2018. Condensed Tannin Measurements in Eastern WA Cider Juices and Hard Cider. *Washington State University Extension Publication* TB52E. Washington State University.

Miles, C.A., J. King, T.R. Alexander, and E. Scheenstra. 2017. Evaluation of Flower, Fruit, and Juice Characteristics of a Multinational Collection of the Cider Apple Cultivars Grown in the U.S. Pacific Northwest. *HortTechnology* 27 (3): 431–439.

Miles, C.A., J. King, and G. Peck. 2015. Commonly Grown Cider Apple Cultivars in the U.S. CIDER Report 202. Washington State University Northwest Research Extension Center: Mount Vernon, WA.

Moulton, G., C. Miles, J. King, and A. Zimmerman. 2010. Hard Cider Production and Orchard Management in the Pacific Northwest. Pacific Northwest Extension Publication PNW621. Washington State University.

Porter, L.J., L.N. Hrstich, and B.G. Chan. 1986. The Conversion of Procyanidins and Prodelphinidins to Cyanidin and Delphinidin. *Phytochemistry* 25: 223–230.

Statista. 2019. Alcoholic Drinks, Revenue Growth—Worldwide.

Steury, T. Personal communication. Steury Orchards, Potlatch, Idaho.

U.S. Apple Association. 2021. 2016 Production and Utilization Analysis.

Watson, B. 2013. *Cider, Hard and Sweet: History, Traditions, and Making Your Own*, 3rd edition. The Countryman Press.

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