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Research Article

Consumer Hedonic Testing and Chemical Analysis of Iowa Wines Made from Five Cold-hardy Interspecific Grape Varieties (*Vitis spp*)

Erin L. Norton,[1,2]* Joey N. Talbert,[1] and Gavin L. Sacks[3]

Author affiliation(s): [1]Department of Food Science and Human Nutrition, Iowa State University, 536 Farm House Lane, Ames, IA, 50011; [2]Midwest Grape and Wine Industry Institute, Iowa State University, 536 Farm House Lane, Ames, IA, 50011; [3]Department of Food Science, Cornell University, 411 Tower Road, Ithaca, NY, 14853.

*Corresponding author (elnorton@iastate.edu; tel: 1-515-294-1555)

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Key words: consumer behavior, chemical composition, cluster analysis, interspecific hybrids

Background and goals. Research into wines made from cold-hardy interspecific hybrids, which have been integral for the establishment of a grape and wine industry through the Upper Midwest, has produced few reports investigating chemical composition and consumer perception. The goals of this project were to i) survey Iowa wine industry members on varieties

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they thought were best suited for premium wine production and ii) measure consumer hedonic scores and chemical composition of 20 commercial Midwest wines made from five varieties, selected based on the initial survey. Cluster analysis was performed on the sensory data, and correlation of consumer segments with wine composition evaluated.

Methods and key findings. A survey of Iowa industry members identified five cold-hardy interspecific cultivars as growing best in the state: Brianna, Edelweiss, La Crescent, Marquette, and Frontenac. Chemical analyses of 20 commercial wines revealed that titratable acidity weas generally higher than *Vitis vinifera* wines. The highest protein concentrations were observed in La Crescent and Frontenac wines. Consumers were clustered into five groups based on liking scores and the two largest segments showed a preference for wines with higher residual sugar.

Conclusions and significance. This is the first survey of chemical composition and consumer liking for Midwestern wines produced from cold-hardy interspecific hybrids. The high protein concentrations observed in red and white wines are notable as these may affect tannin extraction and haze formation, respectively. Although average Iowa consumers prefer wines with substantial residual sugar (>20g/L), there is evidence of multiple consumer segments with different residual sugar and varietal preferences.

Introduction

Due to their cold winters, Iowa and other Upper Midwest states (MN, ND, NE, SD, WI) have no commercial plantings of *V. vinifera* cultivars. Commercial grape production in these and other cold climates, relies on interspecific cultivars (*Vitis spp.) including V. labruscana* (also called “native”, e.g., Concord), French-American hybrids (e.g. Maréchal Foch) and newer cold-hardy cultivars (e.g. Marquette).(Atucha et al. 2018, Pedneault et al. 2013) Although reports

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exist on the composition of commercial wines produced from *V. vinifera* grapes (and to a lesser extent, French-American hybrids) there are no surveys on the composition of commercial varietal wines produced from cold-hardy cultivars. Several authors have reported on basic wine chemistry as well as phenolic and volatile content of cold-hardy varietal wines (Nicolle et al. 2019, Norton et al. 2020, Rice et al. 2017, Slegers et al. 2015) but these previous studies have relied on wines produced in research settings rather commercial wines. Furthermore, there are few studies of consumer preference utilizing interspecific hybrid wines and no published research of consumer liking of Midwestern US produced wines. Reports in the literature concerning consumer preferences/attitudes to interspecific hybrid wines include one of consumer preference for New York State Seyval blanc (Berkey et al. 2011), one of consumer stigma towards Colorado produced Chambourcin wine (Costanigro et al. 2021) and one from Brazil investigating consumer acceptability of wines made from several Brazilian bred interspecific hybrid cultivars.(Biasoto et al. 2014)

There have also been no reports of correlating interspecific hybrid wine chemical composition with consumer hedonic scores, as has been reported for *vinifera* wines.(Lund et al. 2009, Sáenz-Navajas et al. 2015, Wang et al. 2016) For example, a recent study on Australian wines produced from non-traditional varieties found that consumers could be clustered into three segments with distinct preferences for wine.(Mezei et al. 2021) Overall preference and segment preferences were then correlated with wine chemistry. The existence of consumer segments for wines produced from cold-hardy interspecific hybrids and/or commercial Midwestern US wineries has not been explored.

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In this research, Iowa grape and wine industry members were surveyed to determine the cultivars that grew best and were best representative of the state. Based on these results, a representative sample of 20 commercial wines made from the five interspecific grape varieties were selected for chemical analysis and hedonic sensory evaluations. Consumers were then clustered to evaluate if variety or composition were correlated with hedonic scores for different consumer segments.

Materials and Methods

Industry Survey. A survey was sent by email to Iowa grape and wine industry members in September 2019, to gather information about cultivar plantings, wine production and general comments about the idea of an Iowa Signature wine. The survey was open for two months, with several reminder emails sent to ask for participation. Questions and results are provided in Table 1 and Table S1. This survey was approved for human subjects participation by the Institutional Review Board at Iowa State University.

Wine Selection. Based on the industry survey results, five wine varieties (white: Brianna, Edelweiss, La Crescent; red: Marquette, Frontenac) were selected as representative of the grapes and wines grown and produced by the Iowa grape and wine industry. Fifteen commercially available wines of each variety were purchased and tasted blindly by five wine professionals that have previously experience tasting these hybrid varieties. These wines were narrowed to four wines of each variety (for a total of twenty wines) that would be chemically analyzed and used for the consumer sensory evaluation portion of the study. A variety of styles (e.g., dry vs. sweet, sparkling vs. still) were chosen to expose consumers to a broad selection of Iowa wines. Wines

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were stored at room temperature in the dark for approximately 2 months until the consumer sensory evaluation was performed.

Chemical Analysis. Chemical analysis was performed on all 20 wines that were used in the consumer sensory evaluation. All measurements were performed in duplicate. Residual sugar (RS) and acetic acid (AA) were measured using enzymatic assays (Megazyme, Ireland). Percent alcohol (% alc.) was measured by near infrared spectroscopy on an Alex-500 (Anton-Paar, Graz, Austria). pH was measured using an Orion 2-Star benchtop pH meter (ThermoFisher Scientific, Waltham, MA) and titratable acidity (TA) was measured using a Titrino plus automatic titrator (Metrohm, Riverview, FL). Glycerol was measured by an HPLC-RID method previously documented.(Savits 2014) Tannin and total Iron-Reactive Phenolics (IRP) were measured by the Adams-Harbertson Assay previously published.(Heredia et al. 2006) Protein was measured using an ethanol precipitation, acid hydrolysis, amino acid quantification method modified from a recent report.(Kassara et al. 2022) Following hydrolysis, the resulting amino acids were derivatized using the EZFaast kit (Phenomenex, Torrance, CA) according to manufacturers instructions, and validated to the manufacturer's standards.

Sugar-related wine styles were assigned to the wines based on their residual sugar in the following way: dry (<10g/L), off-dry (10-19.9g/L), semi-sweet (20-75 g/L), sweet (>75 g/L).

Consumer Sensory Evaluation. Untrained consumer participants were recruited through Iowa State University email lists by the Sensory Evaluation Center (Iowa State University, Department of Food Science & Human Nutrition). Inclusion criteria required that participants (1) were 21 years old or older, (2) consumed wine 3-5 times/month, (3) had no known allergies to sulfur dioxide or asthma, and (4) were not knowingly pregnant, or planned to

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become pregnant during the study. All willing participants that met the inclusion criteria were selected. The consumer sensory evaluation occurred over 5 weeks in February/March 2021, with one varietal (four wines) presented each week. Number of participants and demographic information is presented in Table S2. Each participant was assigned a 4-digit code to anonymize subject data and allow researchers to link an individual's responses during the multiple weeks of the study. There were 46 participants that completed all five sessions. The sensory evaluations were approved for human subjects participation by the Iowa State University Institutional Review Board. Study participants gave written informed consent and were compensated for their participation ($5 per week and an extra $25 for participating in all 5 weeks).

During the tasting session, participants were seated in individual sensory booths and presented with all four wines in plastic tumblers (30 mL each wine) coded with 3-digit numbers along with napkin, consent form, pen, water and spit cup with lid. All wines were presented in the booth at the beginning of the session due to COVID-19 pandemic protocols to avoid interaction between staff and participants during the session. Thirty milliliters of each wine was served at room temperature, except for sparkling wines, which were refrigerated overnight before each tasting, and bottles removed from the refrigerator immediately before the tasting session. Wines were presented in ascending residual sugar, except for rosé wines which were presented at the beginning of the red wine sessions (Marquette and Frontenac). This ordering was done to prevent sweetness carry-over.(Jackson 2008) Participants were instructed to evaluate each wine independently and were asked to rate their liking on a 7-point hedonic scale (extremely dislike to extremely like). Participants also ranked the four wines at the end of the session (data not

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shown). An additional preference question was asked during the final session to determine whether participants preferred the white or red wines in the study.

Statistics. Statistical analyses were conducted using JMP Pro version 15.0.0 (SAS Institute Inc., Cary, NC) and GraphPad Prism version 9.2.0 (GraphPad Software, San Diego, CA). A one-way analysis of variance (ANOVA) was conducted to determine if grape variety was a significant predictor of protein concentration ($p<0.05$). A one-way analysis of variance (ANOVA) was also performed to determine if grape variety or wine style was a significant predictor of liking scores.

Linear correlation statistics between hedonic liking and chemical analyses were calculated as Spearman's r ($p<0.05$) using GraphPad Prism.

Participants' hedonic scores were used to rank the 20 wines for each participant, and hierarchical clustering (Ward's method) on rankings was used to cluster participants. Rankings were not standardized, and duplicate hedonic scores were assigned the same rank with lower rankings taking into account the duplicate rankings above. For example, if a participant scored three wines as "Extremely Like" and two wines as "Like," the "Extremely Like" wines were all given Rank 1, and the "Like" wines were both given Rank 4. The wine rankings for each of the 46 participants is available in Table S3.

Results and Discussion

Industry Survey and Wine Selection. Results from a survey sent to Iowa grape and wine industry members are shown in Table 1. The survey polled industry members on the grape(s) they thought grew best in Iowa, and the varietal wine(s) and style(s) that best represented Iowa. Respondents represented a range of vineyard/winery occupations and

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vineyard/winery sizes (Supplementary Info). There were 51 unique participants, however, the total number of responses for some questions was greater than 51 due to the "Check All That Apply" nature of some questions.

Industry members reported that the five cultivars that grow best in Iowa were all newer cold-hardy interspecific hybrids: Brianna (69%), Frontenac (65%), Marquette (49%), La Crescent (49%), and Edelweiss (39%). The top four of these cultivars were reported by industry members to also produce varietal wines that best represent Iowa, although Petite Pearl replaced Edelweiss for the fifth position, possibly due to the former more recently being released (2009) (Table 1). The cultivars of Brianna, Frontenac, Marquette, La Crescent and Edelweiss also were identified as having significant plantings from an industry survey conducted for a previous project.(Tuck et al. 2014) These five cultivars were selected to be used in the rest of the study based on the aforementioned importance, but also because all five cultivars can be grown throughout the entire state (based on cold-hardiness) and varietal examples of each are produced by several commercial wineries. Respondents gave mixed answers, with respect to sweetness, for the best Iowa wine style, with semi-sweet white as the top answer (67%) followed by dry red (35%), semi-sweet red (35%) and dry white (29%) (Table 1). Therefore, the aim for the wine selection was to procure a large array of styles ranging in sweetness levels, including specialty styles like rosé, sparkling, and fortified.

Fifteen Iowa wines made from each of the 5 cultivars were purchased and tasted blindly by wine professionals with good knowledge of hybrid cultivars. Wines were individually scored (20-point scale) followed by discussion to identify a set of four wines that were perceived as fault free and covered a range of styles for each cultivar (total = 20 wines). Compositional and

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hedonic data on the wines are presented in Table 2. Initial chemical testing revealed one wine had a chemical parameter higher than US regulatory limits and was exchanged for a similar wine (variety and style) from a neighboring state (Nebraska).

Chemical Analyses. Chemical composition of the 20 commercial wines used in this study are shown in Table 2.

Typical values for pH and TA range from 3.0-3.7 and 5-8g/L tartaric acid equivalents for dry wines of *V. vinifera*.(Waterhouse et al. 2016) The pH values for cold-hardy interspecific hybrid varietal wines are within this range, but the upper end of the TA range is higher (5 - 15 g/L as tartaric acid equivalents).(Watrelot et al. 2020) The wines used in this study all fell within these expected pH and high TA ranges.

TA and pH were, as expected, inversely correlated (r = -0.543, Figure 1) across all wines. However, we did observe both higher pH and higher TA in La Crescent wines as compared to the other white varietals. This may be due to 'La Crescent' grapes having substantially more malic acid than 'Brianna' or 'Edelweiss' (0.075 molar equiv. vs. 0.044 and 0.050 molar equiv. respectively; molar equiv. is assumed from the sum of malic acid and lactic acid molar equivalents as determined by HPLC-DAD-results not shown), and presumably also more minerals like potassium. Glycerol, a fermentation by-product from yeast metabolism and measured by HPLC-RID, ranged from 3.5 to 10.7 g/L among the varieties, compared to 7-10 g/L reported in *V. vinifera*.(Waterhouse et al. 2016) In the hybrid wines of this study, however, it is unclear what impact glycerol may have on consumer sensory perception. A positive correlation was observed between glycerol and acetic acid (r = 0.650, Figure 1). Higher concentrations of both compounds are typically observed in higher gravity fermentations due to a yeast osmotic

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stress response(Waterhouse et al. 2016), although high concentrations of acetic acid may also be produced by lactic or acetic acid bacteria. Glycerol and % alcohol were also positively correlated (r = 0.520, Figure 1), presumably because higher alcohol wines were more likely to start with higher gravity must with more osmotic stress.

Red wines in the study were analyzed for their phenolic content with the premise that these commercial wines would be low tannin as previously reported.(Nicolle et al. 2019, Norton et al. 2020, Watrelot 2021) Total iron reactive phenolics (IRP) in the red wines were generally lower than values reported for vinifera (median 723.7 mg/L catechin equiv. vs. a *V. vinifera* range of 872-3005 mg/L catechin equiv. .(Heredia et al. 2006) Tannin concentrations measured by the Adams-Harbertson assay were below the limit of quantification and therefore much lower than reports of *V. vinifera wines*.(Heredia et al. 2006) The one exception to this was Marquette 2, which had IRP (1380 g/L) comparable to some vinifera wines, however, the tannin concentration (150 g/L) is considerably lower than vinifera wines.(Heredia et al. 2006) As a caveat, the winemaking protocols for these commercial wines were unknown.

The protein concentration of each wine (Table 2) was determined by a recently developed method (Kassara et al. 2022) involving ethanol precipitation, dialysis, protein hydrolysis and amino acid quantification by GC/MS. Protein concentrations for Marquette and Frontenac wines have been reported previously (Nicolle et al. 2019, Norton et al. 2020) using other methods. This is the first report of protein concentrations for the white cultivars, Brianna, Edelweiss and La Crescent. The highest protein concentrations were observed in Frontenac and La Crescent wines (avg =113 mg/L ± 46 and 101 mg/L ± 37, respectively). A one-way ANOVA analysis revealed that variety is a significant effect for protein concentration; a post-hoc Tukey's analysis was

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performed with results shown in Table 2. The higher protein and lower tannin of red wines produced from interspecific hybrids as compared to *V. vinifera* has been previously reported.(Springer et al. 2014, Springer et al. 2016) These observations may result from low initial tannin and high protein in the original hybrid grapes and may be further exaggerated by poor extraction of tannin during the fermentation due to potential interactions between the two macromolecular classes, i.e., the high protein content of hybrids results in lower tannin extractability.(Springer et al. 2016)

Wine of the other cultivars of Brianna, Edelweiss and Marquette all had significantly lower protein concentrations than the Frontenac and La Crescent wines (34 mg/L ± 6, 38 mg/L ± 20 and 46 mg/L ± 16, respectively). In white wines made from interspecific hybrid cultivar, the impact of high protein is unreported. Anecdotal reports suggest that wines made from hybrid varieties require higher than anticipated bentonite rates for protein stabilization.

Consumer Acceptability & Cluster Analysis. The consumer hedonic data were collected over 5 weeks (one session per week) with varying numbers of participants each week (60-75 participants; demographic data in Supplementary Information). Of the original panelists, 46 participants completed all five sessions. ALL DATA refers to the complete data set of all participants over the 5 weeks (1392 data points), ALL 46 refers to the data set of the 46 participants that completed all 5 sessions (920 data points).

Using ALL DATA, we observed that both varietal and sugar level (dry, off-dry, semi-sweet or sweet; ranges defined in the Experimental Details) were significant factors in the consumer scores (ANOVA, $p<0.0001$ for both factors, Tables 3 and 4). Mean hedonic scores for the semi-sweet and sweet Brianna and Edelweiss wines were higher than others (Tables 3 and 4).

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Since Brianna and Edelweiss are described as having "grapey, foxy" aroma/flavor (University of Minnesota 2022, Maniscalco 2012), the findings suggest that Midwest consumers prefer "grapey, foxy" wines made from grapes with significant *Vitis labrusca* heritage. This grapey/foxy attribute is associated with several compounds, and especially methyl anthranilate and 2-aminoacetophenone.(Acree et al. 1990) Neither the foxy sensory characteristic nor associated odorants were quantified in this current study, but previous research has demonstrated that consumers from California and Pennsylvania had different preferences for these specific aroma/flavor compounds (Perry et al. 2019), emphasizing the appropriateness of performing wine preference studies at regional levels.

Correlations between overall consumer preferences (ALL DATA) and individual chemical components are presented in Figure 1. A positive correlation was observed between hedonic scores and residual sugar ($r = 0.292$), and negative correlations were observed between hedonic scores and alcohol, acetic acid, glycerol, and IRP ($r = -0.144$, $r = -0.181$, $r = -0.254$, $r = -0.270$ respectively). However, while all aforementioned correlations were weak ($r < |0.3|$) they were all statistically significant ($p<0.05$).

A subset of consumers was created using the 46 participants that completed all five sessions, thereby giving a complete data set for all wines. Using this data set (ALL 46) and the rank sums of hedonic scores for each wine it was observed that two wines were favored overall, and one was least favored. The sum of rankings (Table S3) for Edelweiss 4 (sweet sparkling) and Frontenac 1 (sweet rosé) were considerably lower (151 and 226 respectively) than all other ranking sums (overall range 151-680) indicating a higher liking across many participants.

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Marquette 2 (dry) had the highest sum of rankings (680) indicating a lower liking across many participants.

To identify consumer preference segments, a hierarchical clustering analysis (Ward's type) was performed on the ALL 46 data, resulting in five clusters. There was no correlation between clusters and participant demographics: age and gender (results not shown).

Mean hedonic scores for each varietal and sweetness style were determined within each participant cluster (Tables 3 and 4). The ALL 46 data were compared to the ALL DATA using a χ^2 test, which indicated that the ALL 46 data sufficiently represented the overall data set. Cluster hedonic means for each variety or sweetness style are reported in Table 3 and 4. Cluster 2 possessed the same order of mean hedonic scores as the ALL DATA (and ALL 46), however with a larger overall range (for variety 3.38-5.49 vs. 4.06-5.02 respectively).

To facilitate interpretation of participant cluster data, average concentrations of all chemical parameters were determined for the upper and lower quintiles of wines (based on hedonic scores) for each cluster (Table 5). For all clusters (representing 89% of participants) except Cluster 4 the top quintile wines had high average residual sugar (>40 g/L) and low alcohol (<12.5%). Labrusca wines made up all four of Cluster 2 top wines and none in the bottom wines. The other clusters showed less evidence for preference for labrusca-type wines. Cluster 4 participants (11%) preferred wines with lower sugar. Aside from residual sugar (Cluster 2), glycerol (Cluster 2) and titratable acidity (Cluster 5), no other chemical parameter was significantly different between the top 20% and bottom 20% of wines within a cluster.

Results of the cluster analysis indicate the average consumer liked wines with substantial residual sugar and made from labrusca-based varieties (Cluster 1, 2 and 3), however, some

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consumers preferred lower sugar or wines not made from labrusca varieties (Cluster 4 and 5 respectively). Our observation that some wine consumer segments prefer sweeter wines is both widely accepted in non-technical wine literature (Thach 2021), and not well-substantiated in the literature. Studies of other fruits or fruit-derived products, however, have clearly shown the importance of sweetness perception in consumer liking.(Crisosto et al. 2005, Shewfelt et al. 2000) This perception is based on both the sugar content and the acidity of the product. Several studies have shown that the highest sugar concentrations are not always the most accepted or preferred by consumers when there is a correspondingly high acidity. Instead, there is an optimal sugar concentration that is in balance with other chemical parameters, particularly acidity, within the fruit or fruit-derived product. While there are some wine groups that promote the use of a sweetness scale (using a sugar to acid ratio), it is not widely applied throughout the wine industry. For the wines in this study, the sugar to acid ratio (Table S4) had a low correlation ($r = 0.260$, result not shown) to hedonic scores and was lower than the correlation of hedonic scores with RS ($r = 0.292$). Therefore, the sugar to acid ratio parameter was assumed to not be a driver of consumer liking for these wines.

The current study considered only major chemical components associated with mouthfeel and taste and did not measure other important contributors to overall perception including visual aspects of color hue and intensity, and flavor odorants. Several reports of volatile compounds present in grapes and wine made from these varieties are available, however there are no reports linking to consumer sensory evaluation.(Mansfield et al. 2009, Rice et al. 2018, Rice et al. 2019, Savits 2014) Future studies could include both color analyses, volatile analyses and descriptive sensory analyses, as has been reported for vinifera wines.(Lund et al. 2009, Mezei et al. 2021)

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Conclusions

Although the Midwestern US wine industry has grown rapidly in recent years, and most sales occur through the tasting room to local consumers, little is known about these consumers and their preferences. The combination of consumer preference clustering and chemical analyses helps understanding consumer segments in Iowa for Iowa wines, and potentially more broadly the Midwest. Over half of the participants fell into two clusters (1 and 2) who preferred semi-sweet and sweet styles of white varietals (Brianna and Edelweiss). This observation clearly supports the popular stereotype of Midwest consumers preferring sweet wines(Hammon 2021) and is corroborated with the current Industry Survey results where the majority of the top selling wines were sweet (54%, Table S3). However, there is also evidence that other consumers (Cluster 4, 11%) preferred less sweet wines and gave low scores to the sweetest wines. This knowledge helps grape growers and winemakers understand that a range of consumer preferences exist, which may be helpful for marketing initiatives and wine portfolio planning.

The chemical analysis performed for the study contributed to new knowledge for commercial versions of these five cold-hardy, interspecific wine cultivars. Notably, some wines have remarkably high protein concentrations, and the red varieties have low tannin concentrations as compared to *V. vinifera* wines. These results lead to additional questions regarding protein stability in white wines, and mouthfeel perceptions in red wines. Anecdotally, winemakers have commented on the increased rates of bentonite necessary for stabilizing wines made from interspecific hybrids. Future research considerations should consider cultivar effect on protein concentrations, and what other winemaking protocols could be employed to mitigate high protein.(Nicolle et al. 2019, Norton et al. 2020, Springer et al. 2016) In terms of red wine,

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the high protein concentration is currently being considered as a factor in low tannin concentrations which were again observed in this study. Further investigations into protein removal or disruption to increase tannin extraction/retention from these grapes is ongoing. The overall goal in increasing tannin concentration is to improve mouthfeel of red wines through enhanced astringency perception.

Overall, this study aimed to increase knowledge about wines produced from interspecific hybrid cultivars through chemical testing and consumer sensory information. This information is useful for both researchers and grape and wine industry members in the design of future research experiments for grape-growing and production protocols.

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Table 1 Selected survey results for Iowa grape and wine industry members. Fifty-one unique individuals responded.

Cultivar/Style	Percentage of Respondents
Which cultivar(s) do you believe grow best in Iowa? (check all that apply) (n=179)	
Brianna	69%
Frontenac	65%
Marquette	49%
La Crescent	49%
Edelweiss	39%
Petite Pearl	25%
Concord	22%
other	33%
Which cultivar(s) do you believe could best represent Iowa? (check all that apply) (n=127)	
Brianna	57%
La Crescent	55%
Marquette	37%
Frontenac	33%
Petite Pearl	18%
Edelweiss	16%
Concord	6%
other	27%
What wine style(s) do you believe could best represent Iowa? (check all that apply) (n=134)	
Semi-Sweet White	67%
Dry Red	35%
Semi-Sweet Red	35%
Dry White	29%
Sparkling	24%
Sweet Red	24%
Sweet White	18%
Dessert	18%

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Rose	14%

Table 2 Summary of consumer sensory data and chemical analyses for all wines used for the sensory evaluation. Wines' data are presented in the order they were presented to consumer participants. Significantly different values (one-way ANOVA $p<0.05$) for the variety means are italicized with the proceeding letters indicating the result of the Tukey's post-hoc test. IRP and Protein are presented as mean concentration ± standard deviation. RS=residual sugar, % abv=% alcohol by volume, TA=titratable acidity, IRP=iron-reactive phenolics, nd=below limit of detection. The number of wines in each category of sweetness level is listed in parentheses.

Wine	Style	Hedonic Mean (1 to 7)	Median	Mode	RS (g/L)	%abv	pH	TA (g/L tartaric acid)	Acetic Acid (g/L)	Glycerol (g/L)	IRP (mg/L cat. equiv.)	Tannin (mg/L cat. equiv.)	Protein (mg/L)
Brianna	*Variety mean*	4.9	5.25	5.25	64	12.5	3.37	7.73	*0.25* ab	*5.75* bc			*33.5* c
1	Dry	4.58	5	5	5	12.74	3.27	7.32	0.27	6.16			42 ± 0.3
2	Semi-Sweet	5.52	6	6	59	11.8	3.43	8.19	0.22	4.88			31 ± 0.4
3	Sweet	4.80	5	5	110	12.99	3.36	7.13	0.22	6.54			30 ± 5
4	Sweet	5.20	5	5	82	12.31	3.41	8.29	0.29	5.43			32 ± 8
Edelweiss	*Variety mean*	4.8	5.25	6	58	10.5	3.44	8.06	*0.21* b	*4.86* c			*37* c
1	Semi-Sweet	5.14	5	6	25	11.07	3.21	8.49	0.24	4.98			37 ± 3
2	Semi-sweet	4.50	5	6	53	9.64	3.55	5.8	0.16	3.5			20 ± 0.2
3	Semi-Sweet	4.24	5	5	75	13.65	3.43	8.41	0.32	6.61			28 ± 0.3
4	Sweet Sparkling	5.88	6	7	79	7.65	3.55	9.52	0.12	4.36			66 ± 4
La Crescent	*Variety mean*	4.5	4.24	4.75	24	12.99	3.56	8.90	*0.24* ab	*7.32* abc			*101* ab
1	Dry	3.90	3	3	4	13.78	3.17	9.79	0.2	7.14			51 ± 4
2	Off-dry	4.16	4	5	15	12.66	3.76	6.62	0.26	7.41			118 ± 0.2
3	Off-dry	4.51	5	5	16	13.4	3.73	9.04	0.36	7.69			100 ± 24
4	Semi-sweet	5.41	5	6	64	12.12	3.56	10.14	0.16	7.03			136 ± 0.3
Marquette	*Variety mean*	4.1	4.5	4.25	28	13.85	3.66	6.56	*0.64* a	*7.98* ab	*759*		*68.5* bc
1	Dry Rose Sparkling	4.34	5	5	7	14.77	3.64	6.73	0.39	9.55	231 ± 7	nd	41 ± 4
2	Dry	3.12	3	1	0.1	10.12	3.49	7.25	0.61	7.6	1380 ± 126	150 ± 7	41 ± 0.1
3	Dry	4.12	5	5	0.2	12.46	3.67	7.78	1.06	8.5	764 ± 112	nd	33 ± 2
4	Sweet Fortified	4.68	5	6	104	18.05	3.82	4.49	0.48	6.29	661 ± 21	nd	68 ± 11
Frontenac	*Variety mean*	4.5	4.74	5.25	25	12.73	3.46	9.58	*0.57* ab	*8.67* a	*679.5*	nd	*113* a
1	Semi-sweet Rose	5.48	6	6	40	12.16	3.17	11.71	0.47	5.73	166 ± 2	nd	54 ± 0.1
2	Dry	4.05	4	6	0.04	13.34	3.71	8.28	0.95	10.68	925 ± 0.4	nd	132 ± 14
3	Dry	3.57	3	3	1.5	12.7	3.27	11.07	0.34	8.77	770 ±16	nd	104 ± 0.2
4	Semi-Sweet	4.92	6	6	58	12.72	3.67	7.24	0.51	9.49	858 ± 128	nd	162 ± 5
Average by Sweetness Level													
<9.9g/L	Dry (7)	3.95			2.6	12.84	3.46	8.32	0.55	8.34			63
10-19.9g/L	Off-dry (2)	4.33			15.3	13.03	3.74	7.83	0.31	7.55			109
20-75g/L	Semi-Sweet (7)	5.03			53.4	11.88	3.43	8.57	0.30	6.03			67
75+	Sweet (4)	5.14			93.8	12.75	3.54	7.36	0.28	5.66			49

Table 3 Mean hedonic scores by variety for: all participant scores (ALL DATA), the 46 participants who completed all weeks (ALL 46) and the clusters identified through Ward's Hierarchical cluster analysis. One-way ANOVA ($p < 0.05$) performed on the ALL DATA to determine if variety is a factor. Mean comparisons for the ALL DATA performed using Steel-Dwass method.

Group	n	Brianna	Edelweiss	La Crescent	Marquette	Frontenac
ALL DATA		5.02 a	4.94 a	4.50 b	4.06 c	4.51 b
ALL 46	46	5.03	4.82	4.33	3.98	4.50
Cluster 1	17 (37%)	5.35	5.04	3.98	4.47	4.83
Cluster 2	8 (17%)	5.47	5.09	4.03	3.38	4.56
Cluster 3	12 (26%)	4.85	4.50	4.73	3.25	3.71
Cluster 4	5 (11%)	3.55	4.55	4.65	4.30	4.55
Cluster 5	4 (9%)	5.12	4.62	4.75	4.88	5.31

Table 4 Mean hedonic scores by style for: all participant scores (ALL DATA), the 46 participants who completed all weeks (ALL 46) and the clusters identified through Ward's Hierarchical cluster analysis. One-way ANOVA ($p < 0.05$) performed on the ALL DATA to determine if variety is a factor. Mean comparisons for the ALL DATA performed using Steel-Dwass method.

Group	n	Dry	Off-dry	Semi-sweet	Sweet
ALL DATA		3.94 a	4.34 a	5.04 b	5.13 b
ALL 46	46	3.87	4.20	4.91	5.19
Cluster 1	17 (37%)	4.06	3.68	5.24	5.57
Cluster 2	8 (17%)	2.98	4.06	5.25	6.09
Cluster 3	12 (26%)	3.55	4.88	4.42	4.67
Cluster 4	5 (11%)	4.43	5.30	4.11	4.00
Cluster5	4 (9%)	5.11	3.25	5.32	4.81

Table 5 Description of the five clusters from Hierarchical Clustering Analysis. Average chemical parameters from the top 20% and bottom 20% of wines are shown with standard deviations. Significantly different values from the top 20% to bottom 20% within the same cluster are shown in italics and underlined.

	Cluster 1		**Cluster 2**		**Cluster 3**		**Cluster 4**		**Cluster 5**	
	Top 20%	**Bottom 20%**	**Top 20%**	**Bottom 20%**	**Top 20%**	**Bottom 20%**	**Top 20%**	**Bottom 20%**	**Top 20%**	**Bottom 20%**
# People/% Participants	17/37%		8/17%		12/26%		5/11%		4/9%	
% White	50%	50%	100%	25%	100%	25%	50%	75%	75%	100%
% Labrusca	50%	25%	100%	0%	50%	25%	25%	75%	25%	50%
Residual Sugar (g/L)	59 ± 16	20 ± 36	*82 ± 20*	*3 ± 3*	60 ± 31	39 ± 50	10 ± 12	67 ± 46	42 ± 27	48 ± 45
% Alc. (v/v)	11.08 ± 2.32	12.56 ± 1.70	11.19 ± 2.41	12.78 ± 2.01	11.18 ± 2.37	12.79 ± 3.87	12.57 ± 1.09	12.91 ± 0.57	12.46 ± 0.89	12.17 ± 1.72
pH	3.46 ± 0.21	3.34 ± 0.15	3.44 ± 0.08	3.49 ± 0.23	3.57 ± 0.14	3.64 ± 0.15	3.58 ± 0.25	3.37 ± 0.07	3.33 ± 0.20	3.60 ± 0.18
Titratable Acidity (g/L)	9.16 ± 1.94	9.13 ± 1.66	8.28 ± 0.98	7.89 ± 1.34	8.64 ± 1.55	6.46 ± 1.66	8.40 ± 0.52	8.73 ± 1.67	*9.96 ± 1.44*	*7.15 ± 1.38*
Acetic Acid (g/L)	0.33 ± 0.19	0.37 ± 0.17	0.21 ± 0.07	0.57 ± 0.37	0.21 ± 0.08	0.55 ± 0.33	0.65 ± 0.41	0.29 ± 0.05	0.26 ± 0.14	0.25 ± 0.08
Glycerol (g/L)	6.12 ± 2.32	7.53 ± 0.92	*5.30 ± 0.93*	*8.20 ± 1.06*	6.06 ± 1.42	7.02 ± 2.98	7.96 ± 2.36	6.84 ± 1.40	6.20 ± 1.08	6.29 ± 1.92
Total Iron-Reactive Phenolics (mg/L epicat. equiv.)	511.72 ± 489.07	1075.02 ± 431.65		791.83 ± 575.17		988.68 ± 363.84	844.55 ± 113.42	769.80	165.9	
Protein (mg/L)	78 ± 57	56 ± 33	40 ± 17	42 ± 7	88 ± 48	66 ± 49	76 ± 49	48 ± 37	68 ± 46	67 ± 49

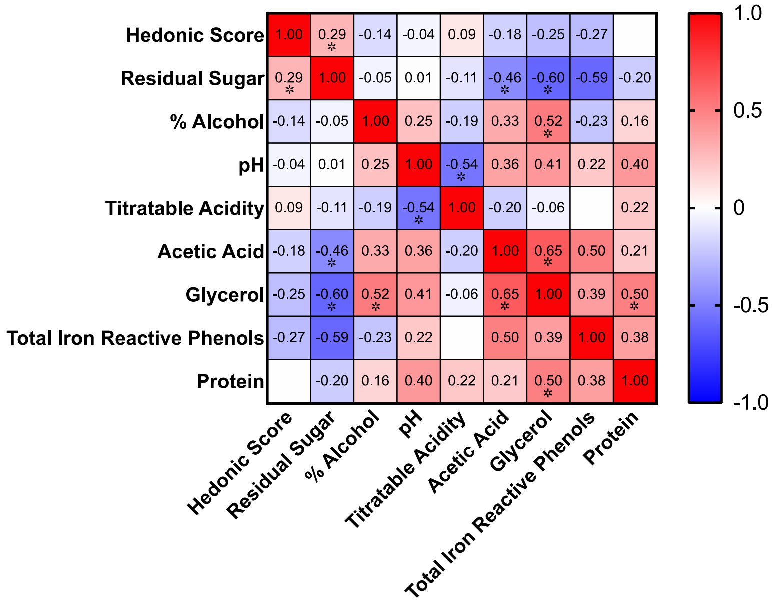

Figure 1. Heat map for linear correlations, showing Spearman's r (* denotes significance at $p<0.05$), between chemical parameters and hedonic liking scores for ALL DATA.

Supplementary Table 1 Ranking of ALL 46 data for clustering analysis. Rank sums and averages are presented for each wine. The cluster assigned each panelist after the Ward's cluster analysis was performed is also presented.

Panelist/Wines	B1	B2	B3	B4	E1	E2	E3	E4	L1	L2	L3	L4	M1	M2	M3	M4	F1	F2	F3	F4	Cluster
5001	6	6	1	13	6	17	13	6	17	20	13	6	1	6	6	17	1	13	1	1	1
5005	4	1	4	2	4	16	4	4	16	4	15	4	13	13	4	16	16	2	16	4	3
5006	3	3	3	1	3	3	14	3	14	3	19	3	1	19	14	14	3	3	18	3	1
5008	9	2	1	2	9	9	19	2	9	17	9	2	9	20	9	2	2	2	17	9	1
5009	1	7	1	7	19	7	17	1	19	17	7	1	7	13	13	1	1	7	13	13	1
5010	12	7	2	1	12	11	15	2	15	7	7	7	15	20	12	2	2	15	15	2	2
5011	16	11	3	11	11	3	16	3	16	1	20	1	3	11	3	3	3	16	11	3	1
5013	12	12	16	16	2	12	16	12	2	2	6	6	6	16	5	16	6	1	6	6	4
5014	7	1	4	1	11	11	4	1	17	14	14	4	11	17	14	7	7	17	17	7	2
5015	12	4	12	4	1	12	12	1	12	12	12	4	10	12	4	4	4	10	12	1	1
5016	11	1	1	11	1	1	18	1	11	1	18	11	1	20	11	11	1	11	1	1	1
5017	5	5	12	1	1	5	12	1	19	12	17	12	5	12	5	1	5	17	19	5	1
5018	7	1	1	10	17	1	17	1	17	10	10	7	10	10	9	1	10	10	17	1	1
5019	5	7	11	11	7	11	7	1	1	11	5	7	1	11	11	19	1	19	11	11	3
5020	2	2	15	8	8	2	16	2	16	16	16	8	8	14	8	1	8	2	16	2	1
5021	5	3	11	5	1	13	11	1	13	5	13	5	19	19	13	13	3	13	5	5	3
5022	5	2	5	2	12	12	11	5	12	5	5	5	17	19	17	19	1	2	12	12	3
5023	7	1	7	7	1	7	16	1	7	1	7	1	7	16	7	6	16	16	16	7	3
5024	13	1	1	5	11	5	13	3	16	11	16	5	20	16	16	5	5	5	13	3	2
5025	11	4	11	4	4	16	4	1	11	4	11	1	4	19	11	19	1	16	10	16	3
5026	8	2	8	1	2	17	14	2	8	2	2	2	17	14	8	19	8	19	8	14	3
5027	10	15	5	15	2	15	10	1	15	10	5	10	5	20	5	10	2	2	15	5	4
5028	14	8	2	1	2	14	14	2	14	2	14	2	8	11	8	2	11	14	20	11	3
5029	11	4	1	1	11	4	14	1	19	14	14	4	4	19	14	14	4	4	11	4	1
5031	15	3	15	3	3	1	15	3	15	3	3	1	3	15	3	3	3	3	15	3	1

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5032	16	5	12	1	12	16	5	1	16	16	5	1	16	12	12	5	1	5	5	5	2
5034	13	5	13	13	5	5	1	1	18	13	5	5	1	18	13	1	5	5	20	5	1
5035	2	2	18	10	2	19	10	15	2	19	10	2	2	15	10	1	2	10	2	15	5
5036	4	4	16	4	11	12	4	12	1	16	16	1	4	16	20	9	1	12	9	12	5
5037	11	13	6	1	6	13	6	1	13	6	6	4	4	19	19	12	13	13	13	1	3
5038	5	1	5	5	10	5	15	5	15	15	10	1	10	15	20	10	1	10	15	1	1
5039	5	5	5	13	5	13	13	5	1	13	20	13	5	13	5	1	1	1	13	5	5
5040	13	2	2	7	13	7	2	1	16	12	7	2	20	16	16	7	2	16	13	7	2
5041	12	5	1	1	12	5	5	1	17	12	5	5	12	17	5	1	12	17	17	5	2
5042	3	3	10	16	1	16	10	3	10	3	1	16	10	3	3	10	10	3	16	16	4
5043	8	1	15	8	1	15	8	8	1	15	15	1	8	8	15	8	1	1	15	1	5
5046	11	5	5	5	11	1	13	1	13	18	18	5	5	18	13	3	5	13	13	3	1
5049	14	8	3	1	14	3	3	8	19	14	8	3	18	19	14	8	8	8	3	1	2
5050	15	12	19	6	6	12	19	1	6	10	1	15	12	15	1	1	1	6	15	10	4
5051	6	11	14	1	1	14	11	6	11	6	1	14	20	14	6	14	1	6	1	14	3
5053	2	9	9	2	9	16	16	1	2	2	2	2	19	9	9	2	19	9	16	9	3
5054	2	9	9	9	15	2	2	2	17	9	9	2	17	15	2	9	1	2	17	17	1
5055	11	3	7	1	3	7	11	1	15	13	15	10	7	15	15	13	3	15	15	3	1
5056	16	2	2	2	2	2	2	1	12	12	16	11	16	19	20	2	2	12	12	2	2
5057	12	4	16	18	4	4	12	1	4	4	1	18	12	4	1	16	4	4	12	18	4
5058	1	12	12	9	1	15	1	15	1	1	1	1	1	18	18	9	9	17	14	18	3
sum	393	234	352	276	305	427	491	151	541	433	450	251	424	680	467	367	226	424	571	317	
average	8.54	5.09	7.65	6	6.63	9.28	10.67	3.28	11.76	9.41	9.78	5.46	9.22	14.78	10.15	7.98	4.91	9.22	12.41	6.89	
mode	11	1	1	1	1	16	16	1	16	12	5	1	1	19	5	1	1	2	15	1	
rank overall	10	3	8	5	6	13	17	1	18	14	15	4	11	20	16	9	2	11	19	7	

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Supplementary Table 2 Sugar to acid ratios (RS divided by TA) for all wines. RS=residual sugar, TA=titratable acidity; B=Brianna, E=Edelweiss, L=La Crescent, M=Marquette, F=Frontenac.

Wine	RS (g/L)	TA (g/L tartaric acid equiv.)	Sugar to Acid Ratio
B1	5	7.32	0.66
B2	59	8.19	7.22
B3	110	7.13	15.40
B4	82	8.29	9.94
E1	25	8.49	2.98
E2	53	5.8	9.16
E3	75	8.41	8.88
E4	79	9.52	8.28
L1	4	9.79	0.44
L2	15	6.62	2.24
L3	16	9.04	1.75
L4	64	10.14	6.30
M1	7	6.73	1.06
M2	0.1	7.25	0.01
M3	0.2	7.78	0.02
M4	104	4.49	23.17
F1	40	11.71	3.41
F2	0.04	8.28	0.005
F3	1.5	11.07	0.13
F4	58	7.24	7.99

Supplementary Table 3 Demographic and additional survey results from Iowa grape and wine industry members.

Category	Percentage of Responses
Affiliation (check all that apply) (n=93)	
Winery Owner	55%
Winery Employee	29%
Vineyard Owner	55%
Vineyard Employee	16%
Sales/Marketing/Retail	25%
Other	2%
Winery Size (gallons/year) (n=35)	
10 000+	28%
5000-9999	23%
1000-4999	31%
100-999	14%
<100	3%
Top Selling Wine Varieties (n=53)	
Brianna	28%
Concord/Catawba	15%
Edelweiss	13%
Marechal Foch	8%
Frontenac	8%
Marquette	6%
Other	23%
Top Selling Wine Styles (n=52)	
Sweet White	31%
Sweet Red	23%
Semi sweet white	21%
Dry Red	10%
Semi sweet red	6%
Rose	6%
Dry White	4%

Supplementary Table 4 Demographic data by week for the consumer sensory evaluation. (*Demographics of participants that completed all 5 sessions). Demographics for participants that completed all five sessions (46 participants) is also presented.

Week	Variety	n	Gender		Age				
			Female	Male	21-30	31-40	41-50	51-60	>60
1	Brianna	60	75%	25%	58%	15%	8%	10%	8%
2	Edelweiss	66	71%	29%	68%	11%	6%	9%	6%
3	La Crescent	73	68%	32%	63%	12%	8%	8%	8%
4	Marquette	74	70%	30%	62%	12%	9%	8%	8%
5	Frontenac	75	69%	31%	63%	11%	11%	8%	8%
	*All 5 Weeks	46	80%	20%	54%	15%	9%	13%	9%