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Chemical, Physical and Sensory Characteristics of Winter-Hardy Tart Cherry and Plum Jams

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Abstract

Plums are popular fruits for the fresh market but are often preserved as jams or dried fruits. In contrast, tart cherries are primarily grown for preserves. Both fruit types, however, are climacteric with high respiration rates, which decreases their shelf life. Our objective was to analyze jams made from winter-hardy plum and tart cherry fruits that survive in USDA Z3-Z4 for their sensory profiles and physicochemical properties. Fresh fruit from six tart cherry and 21 plum genotypes were made into jams and compared with three commercial products for soluble solids, pH, titratable acidity, L*a*b CIELAB chromaticity coordinates, hue angles, chrome values and sensorial profiles. Two sensory evaluation panels were convened to evaluate jam color, spreadability, texture, fruit pieces, flavor, off flavor, sweetness, bitterness, overall quality and desire to purchase. 'Suda' tart cherry had the lowest soluble solids (47.13°Brix) whereas 'Meteor' had the highest (65.5°Brix). 'Superior' (47.53°Brix) and 'Alderman' (48.73°Brix) plums had the lowest soluble solids but 'LaCrescent' and the plum control had the highest levels (65.83 and 66°Brix, respectively). The widest range in pH was among the plum jams (2.95, 'Underwood' to 3.56, 'Stanley') and the tart cherries fell within this range (3.08, 'Suda' to 3.19, 'Mesabi'). Both 'North Star' and 'Suda' tart cherries were the darkest in color (low L* values) along with eight plum genotypes and the plum control; 'Superior' plum and the apricot control had the highest L* values. Only spreadability, texture and bitterness varied significantly among the panels. 'Opal' and 'Superior' plums had significantly less fruit pieces than 'Bounty'. Sensory evaluation panelists determined that 'Underwood' plum jam had the highest off-flavor ratings. Jams were significantly different for red color rating with 'La Crescent' and 'Compass' plums being rated the least and most red in color, respectively. One hundred percent of the panelists said they would purchase 'North Star' tart cherry and 'Bounty' plum jams whereas 100% would not purchase 'Underwood' jam. Based on cultivar availability and the generated data, *Prunus cerasus* 'North Star' is the best winter-hardy tart cherry whereas *P. salicina* x *P. americana* 'Alderman' and 'Superior' plum hybrids rank highest for jam making.

Fleshy fruit crop species in the genus *Prunus* (Rosaceae) have multifunctional uses in fruit production, landscape services, timber production and medicines (Potter, 2012). In northern latitudes (USDA Z3-4), however, only a few *Prunus spp.* can be grown due to low winter temperatures and/or late spring frosts (Andersen and Weir, 1967). Northern fruit breeding programs developed and released winter-hardy cultivars with high fruit set and superior, non-astringent fruit quality (Andersen and Weir, 1967). Many such cultivars are the result of interspecific crosses with domesticated species, *P. domestica* L. and native but winter-hardy species such as *P. americana* Marsh.

Since the 1880s, the University of Minnesota's fruit breeding program has developed numerous winter-hardy *Prunus* cultivars including tart cherries (*P. cerasus* L.) and plums (*P. domestica* L.; *P. besseyi* Bailey x *P. salicina* L.; *P. salicina* x *P. americana*) (Hoover and Zins, 1998; Hoover, et al. 2015; West, 2014). Some of the University

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of Minnesota's hybrids are grown worldwide for production, e.g. *P. cerasus* 'North Star' (Budan, et al. 2013). World production of tart cherries was 1.36 M metric tonnes in 2014 with 207 K ha in production in areas with adequate chilling requirements (FAOSTAT 2014). In contrast, plums enjoy a greater market share with 11.28 M tons produced on 2.52 M ha (FAOSTAT 2014).

While a large portion of harvested nutritionally rich tart cherries and plums are sold in the fresh market, a significant percentage are dried or made into jams or jellies due to the climacteric nature of the fruit, soft textures limiting shelf life, and high respiration rates (Culetu et al., 2014; Touati et al., 2014). *Prunus domestica,* the European plum, is the most commonly grown plum type with >2,000 cultivars in production (Francis, 2000). In commercial plum jam manufacturing, high quality, ripe plum fruits from the Brumarie types (e.g. 'Stanley') are commonly used (Culetu et al., 2014). The skins are an important component for both plum and tart cherry jams, as they are higher in antioxidants and vitamins than the pulp and provide enhanced coloration (Vasantha Rupasinghe et al., 2006).

Jams and jellies are highly popular food products among consumers with consumption by 92% of all households in the U.S. (Agriculture and Agri-Food Canada, 2012). Such products allow for year-round consumption of processed fruit when the fresh market products may not be available (Touati et al., 2014). Jams are made by cooking fruits with sugars and acid to reach a spreadable consistency; if there is not sufficient natural pectin, then pectin can also be added (Kostick et al., 2017 Kurz et al., 2008; Vidhya and Narain, 2011; Wicklund et al., 2005). Sugar is the dehydrator for pectin molecules and gelling is the result of pectin and sucrose molecules forming a network that holds water. Proportions of ingredients are important to maximize color, flavor, consistency and other sensory characteristics (Grujić et al., 2007) since consumer acceptance and purchasing are influenced by these traits. In particular, one study showed that color is the most important sensory attribute for consumers to perceive jam quality, followed by taste, sweetness, sourness, spreadability and overall quality (Lawless and Heymann, 2010). In addition to studying these traits, previous jam research has also focused on physical and chemical characteristics (Culetu et al., 2014; Kostick et al., 2017; Sandulachi and Tatarov, 2012). Acidity, usually measured by pH in jams, affects flavor, shelf life and gelation whereas sugars impact gelation as well as jam stability (Culetu et al., 2014).

We previously reported on physicochemical properties and sensorial profiles of winter-hardy apricot jams (Kostick et al., 2017) and found that *P. armeniaca* L. 'Sungold' was the best apricot for jam. Winter-hardy tart cherries and plums have never been subjected to these types of analyses even though 'Meteor' and 'North Star' tart cherries were released in the 1950s and plum cultivars still on the market date as far back as 1920 ('Underwood') and 1923 ('La Crescent') (West, 2014). The objective of this research was to quantify attributes of jams made from selected USDA Zone 4 winter-hardy tart cherry and plum genotypes from the University of Minnesota breeding program as well as named comparisons. The two different fruit types were combined into one study since there were inadequate sour cherry cultivars available for analysis. Physiochemical properties and sensory profiles were evaluated to determine quantitative genotypic differences. The desire to purchase the jams (qualitative data) was also evaluated.

Materials and Methods

Genotypes and fruit harvest. Tart Cherries. In weeks 23 and 25 (2012), n=5 tart cherries *P. cerasus* 'Bali', 'Meteor', 'Mesabi', 'Suda' and unnamed MN Selection N87155 were harvested from mature trees at the University of Minnesota's Horticultural Research Center in Chanhassen, MN (44°52'06.5" N lat., -93°38'03.9" W long.) whereas 'North Star' was harvested from a tree in a private horticultural garden Saint Paul, MN (44°59'3.6744" N lat., -93°4'7.2546" W long.). All genotypes are self-compatible and at least 'North Star' is a natural, ungrafted dwarf tree. Week number is defined as the number of weeks from 1 Jan. 2012. All trees were managed for fruit production as previously reported (Kostick, et al., 2017). Approximately 4.5 kg of fruit was harvested/cultivar from a single tree for processing. Whole fruit was stored in plastic bags to minimize moisture loss at 3-5°C for 3-5 days until processing. The fruit of these tart cherry cultivars was pitted with a commercial, cast iron rotary pitter (Enterprise Cherry Stoner, No. 1308, Philadelphia, PA) prior to making jams.

Plums. During weeks 31-34 (2012), n=21 plum cultivars were harvested. European type plums, *Prunus domestica* 'Mount Royal', 'Opal'; cherry plums, *P. besseyi* x *P. salicina* 'Compass'; hybrid plums, *P. salicina* x *P. americana* 'Alderman', 'Bounty', 'Gracious', 'Hazel', 'Hennepin', 'La Crescent', 'Monitor', 'Pipestone', 'Red Coat', 'South Dakota', 'Superior', 'Todd', 'Toka', 'Underwood', unnamed selection MN598, 'Whittaker', and 'Winona' were all harvested from trees at the University of Minnesota Horticultural Research Center. Hybrid plum *P. salicina* x *P. americana* 'Stanley', a Brumarie type, was harvested from a tree in a private horticultural garden, Maplewood, MN (45°1'7.5786" N lat., -93°1'33.5712" W long.). Approximately 5-10 kg of fruit was harvest/cultivar from a single tree for processing. Fruit was stored in plastic bags to minimize moisture loss at 3-5°C for 3-5 days until processing. All plums were cut with a paring knife following the suture line around each fruit for pitting and subsequent jam preparation.

Jam Preparation. Jams were prepared in sterilized dishes using sterilized wooden, glass or non-reactive metal utensils in a semi-commercial, private kitchen (Kostick et al., 2017; Kurz et al., 2008). Sterilization of equipment was accomplished in a pressure canner (Presto® 01781 Aluminum Pressure Cooker/Canner, 23 Quart; National Presto Industries, Inc., Eau Claire, WI) at 116°C, 10 psi (6.894757 kPa) pressure for 15 minutes. Jam for each tart cherry and plum cultivar were made according to a standard recipe of 1.5 L (6.33 US cups) pitted fruit, 74 ml (5 US tablespoons) fresh-squeezed lemon juice (citric acid; Kostick, et al., 2017), 14.2 g (1 US tablespoon) unsalted butter, 56.8 g (4 US tablespoons) Ball® RealFruit® Classic Pectin (Newell Brands Co., Perimeter City, GA) and 1350 g (6 US cups) sugar or sucrose (Kostick, et al., 2017). Pitted fruit were macerated using a hand-held puree machine (KitchenAid® 2-Speed Immersion Hand Blender, #KHB1231) until fruit and skins were thoroughly pureed. Pectin, butter, lemon juice and pectin were combined in an uncovered, non-reactive Revere® copper-clad base stainless steel pot (4.26 L or 4.5 US quart), stirring constantly with a flat wooden spoon. The mixture was allowed to vigorously boil for 1 minute. Sugar was then added in, again stirring constantly until the jam began sheeting off from the flat, wide spoon, and then removed from the heat source. The jam surface was skimmed to remove any foam and immediately poured into sterilized 0.24 L (0.5 US pint) glass jars and metal lids/rings were attached to the jars. Jars were inverted for 5 minutes and then reverted to upright position and cooled under a towel for 24 hours until sealed (Kostick et al., 2017). To ensure jars remained sealed prior to sensory panel evaluations and free from spoilage, each lid had to have an indented lid as a sign of vacuum sealing. Visual inspections of jam surfaces were also done and any spoiled samples were discarded. Jars were labeled with the cultivar name and fruit type (plum, cherry) and stored at 12.8°C (55°F) in darkness for as long as 6 months to maximize color retention and stability (García-Viguera, et al., 1999). A minimum of three jars was made from each cultivar for sensory evaluations.

Chemical Analyses. Jam sugar content was measured in °Brix using an Atago Digital Hand-held "Pocket" Refractometer PAL-2 (Kostick, et al., 2017). All measurements were made in triplicate (n=3 replications) with new samples placed on the refractometer each time. The refractometer was washed in between each measurement with deionized water and dried with a Kimwipe (KIMWIPES™ Delicate Task Wipers, 11.2 cm x 21.3 cm or 4.4" x 8.4"). Between cultivars, the refractometer was washed with mild detergent and dried with a Kimwipe.

Titratable acidity (g/L citric acid equivalent), a measure of the total amount of protons available, was determined by titrating a solution containing 5 mL of jam and 50 mL of deionized water with 0.1 M NaOH (sodium hydroxide) to the endpoint of pH=8.20 using an Thermo Scientific Orion 950 ROSS® FAST QC™ Titrator with a Thermo Scientific Orion ROSS Sure-Flow pH electrode. Titrations were done in duplicate with all materials rinsed in between with deionized water. The pH of each undiluted sample (10-20 mL) was measured in triplicate using a Thermo Scientific Orion 950 ROSS® FAST QC™ Titrator with a Thermo Scientific Orion ROSS Sure-Flow pH electrode. The electrode was rinsed with deionized water between measurements of the same sample, between samples the junction was flushed and the electrode rinsed with deionized water.

Hue, lightness and color saturation angles for each sample were measured in triplicate for each jam sample using a Konica Minolta CR-400 chroma meter; data were expressed as L*a*b* color space or CIELAB where L* indicates lightness (higher values are lighter in color) and a* and b* are the chromaticity coordinates (Konica Minolta Sensing, Inc., 2003). Chromaticity coordinates a* and b* indicate the directions of color: +a* (red), -a* (green), +b* (yellow) and -b* (blue) with the center being "achromatic" (Konica Minolta Sensing, Inc., 2003). Color saturation increases as a* and b* values increase in size. Chroma or saturation (C_{ab}*) values were calculated using $\sqrt{a^2 + b^2}$ and are expressed as the distance between the center, the "achromatic point", and color (Gulrajani, 2010). Medium to high values of C_{ab}* are indicative of bright or saturated color whereas lower values denote duller or less saturated colors (Gulrajani, 2010; Kostick et al., 2017). Hue angle (H_{ab}) expressed the angle measured at the +a* axis (Konica Minolta Sensing, Inc., 2003) and calculated using $\text{Arctan}(\frac{b^*}{a^*})$ (Gulrajani, 2010).

Sensory Evaluations. Jams were evaluated in two different panels of sensory evaluations of primarily untrained evaluators (54% females, 46% males; aged 20- mid-60s years old). Panelists were recruited from the faculty, staff, and students of the University of Minnesota, College of Food, Agricultural, and Natural Resource Sciences. Among the panelists were participants with extensive trained sensory panel experience while others in each panel had little or no sensory panel experience. The first sensory panel consisted of n=45 panel members (58% females and 42% males) with ages ranging from low 20s to late 60s years old. This panel convened on the St. Paul, MN campus of the University of Minnesota in Room 310 Alderman Hall on 20 Feb., 2013 (44°59'17.8" N lat., -93°10'51.6" W long.). The second panel consisted of n=16 panelists (44% females and 56% males), with ages ranging from low 30s to low 60s years of age, and was conducted at the Horticultural Research Center Office Building, Chanhassen, MN (44°52'06.5" N lat., -93°38'03.9" W long.) on 28 March 2013.

For both sensory sessions, the jams from all 27 cultivars were randomized and then assigned an alphanumeric code. Four codes were then randomly assigned to each person's seat, while avoiding duplication. Each seat was also assigned each of three commercial jam standards for comparisons (Kostick, et al., 2017): Bonne Maman® apricot preserves (apricot control; http://www.bonnemaman.us/preserves-jellies/apricot-preserves/), Bonne Maman® cherry preserves (cherry control; http://www.bonnemaman.us/preserves-jellies/cherry-preserves/)

and Bonne Maman® plum preserves (plum control; http://www.bonnemaman.us/preserves-jellies/plum-preserves/) for a total of seven samples / evaluator. The apricot control was included to provide genetic diversity, particularly with flavor and color differing significantly from either tart cherry or plum jams. Seven samples is a standard sample size to avoid evaluator sensory exhaustion (Nikolaevich et al., 2015; D. Bedford, 2012, personal communication). For statistical purposes, sensory panels were complete blocks and individuals were incomplete blocks.

Both sensory panel setups were identical to that of Kostick, et al. (2017) with jam jars labeled with their fruit type- and cultivar-specific code, and then approximately 15 g of each sample was placed in a neutral colored (opaque), 29.6 mL plastic cup (disposable, odor-free; Culetu, et al., 2014) labeled with the jam code, along with a 7.62 cm (3") plastic taster spoon. These samples were placed at their corresponding seats along with one instruction (*cf.* Fig. 1, Kostick, et al., 2017) and seven evaluation sheets (*cf.* Fig. 2, Kostick, et al., 2017), one color reference card, one neutral white and unlined (7.62 x 12.7 cm; 3" x 5") card, water cup, spit cup, and unsalted crackers (*cf.* Fig. 3, Kostick, et al., 2017; Halat et al., 1997). All sensory evaluation panels were conducted at room temperature to match the predominant conditions for jam consumption and conditions for previous panels (Culetu, et al., 2014; Kostick, et al., 2017).

Each group was given a brief, oral introduction on how to taste jams, palette cleansing procedures, using the color chart (*cf.* Fig. 3, Kostick, et al., 2017) and a review of the instruction (*cf.* Fig. 1, Kostick, et al., 2017) and evaluation (*cf.* Fig. 2, Kostick, et al., 2017) sheets. A modification of the standard Hedonic 9-point (Lawless and Heymann, 2010) to 7-point scale (Grujić, et al., 2007) was implemented with an unnumbered scalar range of seven boxes for recording scores (*cf.* Fig. 2, Kostick, et al., 2017). All members of each group taste-tested the first sample (Apricot control) together using the instructions (Fig. 1) and, once they had recorded their evaluative assessments of the apricot control, discussed the potential data points for each of the ten factors for each jam (Fig. 2). Plum and cherry jams were evaluated separately. Sensory sessions took place in classroom settings with overhead cool white florescent lighting (538 Lux) and room temperature conditions (21°C). Panelists were provided with adequate space to evaluate their samples. However, physical barriers did not separate panelists.

Since evaluators marked the first nine sensory characteristics in the linear box plots (*cf.* Fig. 2, Kostick, et al., 2017), these were transformed into quantitative data points, based on measuring (mm) from the beginning (far left-hand side) of the scale to wherever the panelist made their mark. This value was then divided by the total length of the scale and then multiplied by ten to give data points on a ten-point scale.

Data Analyses. One-way Analysis of Variance (ANOVA) across genotypes (plums and cherries combined) as well as mean separations with Tukey's Honest Significant Difference (HSD) tests at α=0.05 were performed for all quantitative data using SPSS (Statistical Package for Social Sciences, University of Chicago, IL; v.22). To determine variant groups responsible in the chemical analyses and sensory panel traits, multivariate analyses were performed using principal component analyses (PCA) using the SPSS CATPCA procedure, similar to Holzwarth et al. (2013). Qualitative data, specifically the desire to purchase, was analyzed using a Chi-square test with equal distribution across the two classes (1:1 χ^2). Since there was only 1 degree of freedom for the Chi-square test, the Chi-square correction of $(\text{Observed-Expected-0.5})^2$ was used. Pearson's Rank Correlations were carried out between variables.

Results

Chemical Analyses. Mean soluble solids of the jams ranged from 47.13°Brix ('Suda') to 66.27°Brix (apricot control; Table 1).

Table 1. Mean soluble solids (S.S.; °Brix), pH, titratable acidity (g/L citric acid equivalent), L*a*b* color space or CIELAB (where L* indicates lightness; a* and b* are the chromaticity coordinates), hue angle ($H_{ab}^* = \arctan(b^*/a^*)$) and chrome ($C_{ab}^* = \text{sqrt}\ [a^{*2}+b^{*2}]$) for tart cherry and plum jams used in the sensory evaluation panels.

Genotype	S.S. (°Brix)	pH	Titratable Acidity (g/L citric acid equivalent)	L*a*b* color space: L*	a*	b*	H_{ab}*	C_{ab}*
'Bali'	55.57 j-k[z]	3.15 e-h[z]	10.26 b-e[z]	27.70 c-k[z]	19.49 g-i[z]	11.31 d-f[z]	0.53 e-g[z]	22.53 c-j[z]
'Mesabi'	51.87 f-h	3.19 h-k	13.65 g-i	27.36 c-j	27.17 j-k	12.72 d-g	0.44 c-e	30.00 j-l
'Meteor'	65.50 n	3.22 j-m	10.69 b-f	36.10 o-p	30.69 k	20.78 i-k	0.59 g-h	37.07 l-n
'North Star'	54.90 j	3.16 f-i	13.55 g-i	19.71 a	9.12 a-b	2.04 a	0.22 a	9.35 a
N81755	54.97 j	3.17 g-i	10.81 b-f	26.43 b-i	23.74 h-j	12.13 d-f	0.47 d-e	26.66 g-k
'Suda'	47.13 a	3.08 d	15.51 f-h	22.97 a-c	24.18 h-k	7.89 b-d	0.32 b	25.44 e-k
Cherry Control	54.30 i-j	3.14 e-g	13.23 f-i	24.06 a-e	18.95 e-i	6.12 a-c	0.31 b	19.91 b-h
'Alderman'	48.73 b-c	3.19 i-l	8.84 a-b	28.51 d-l	19.04 f-i	9.94 c-f	0.50 d-f	21.57 b-i
'Bounty'	63.60 m	3.19 h-k	14.96 i-k	34.18 m-o	13.12 a-g	19.63 i	0.98 m-n	23.61 d-l
'Compass'	58.97 l	3.36 o	6.52 a	21.30 a-b	8.21 a	3.68 a-b	0.42 c-d	8.99 a
'Gracious'	54.03 i-j	3.01 b-c	16.38 j	31.27 h-o	14.49 a-g	14.82 f-h	0.80 k	20.72 b-i
'Hazel'	52.77 h-i	3.22 k-n	12.03 e-h	31.71 j-o	13.92 a-g	11.75 d-f	0.70 i-j	18.21 b-e
'Hennepin'	50.80 e-g	3.17 g-i	11.59 e-g	29.22 e-m	14.46 a-g	9.83 c-e	0.60 g-h	17.48 b-e
'La Crescent'	65.83 n	3.03 c	6.90 a	32.55 k-o	10.84 a-c	12.54 d-g	0.86 k-l	16.57 a-d
MN 598	51.13 e-g	3.14 e-g	11.27 c-g	39.76 p-q	23.75 h-j	24.92 k	0.81 k	34.46 k-m
'Monitor'	50.00 c-e	2.98 a-b	19.49 k	35.93 o-p	12.28 a-e	20.14 i-k	1.02 n-o	23.59 d-j
'Mount Royal'	54.13 i-j	3.33 o	8.51 a-b	26.20 b-h	24.87 i-k	9.98 c-f	0.38 b-c	26.80 h-k
'Opal'	53.03 h-i	3.26 n	8.51 a-b	24.96 b-f	16.32 c-g	8.90 c-d	0.50 d-e	18.59 b-h
'Pipestone'	50.43 d-f	3.19 i-l	10.17 b-e	25.73 b-g	12.68 a-f	8.50 b-d	0.59 f-h	15.26 a-c
'Red Coat'	49.23 c-d	3.17 g-i	11.76 b-g	31.55 i-o	24.66 i-k	13.88 e-g	0.51 e-g	28.30 i-k
'South Dakota'	59.57 l	3.18 g-i	13.66 g-j	33.57 l-o	8.68 a-b	17.20 g-i	1.10 o-p	19.26 b-h
'Stanley'	56.77 k	3.56 p	7.43 a	23.09 a-c	17.89 d-h	5.44 a-c	0.29 a-b	18.71 b-g
'Superior'	47.53 a-b	3.12 d-e	11.35 d-g	43.00 q-r	23.59 h-j	30.05 l	0.91 l-m	38.21 m-n
'Todd'	54.97 j	3.03 c	13.22 f-i	23.98 a-d	12.57 a-f	5.60 a-c	0.41 c-d	13.77 a-b
'Toka'	52.03 g-h	3.12 d-f	13.64 g-i	29.31 f-m	15.21 b-g	11.11 d-f	0.63 h-i	18.83 b-h
'Underwood'	52.90 h-i	2.95 a	14.57 h-j	25.83 b-g	16.15 c-g	8.27 b-d	0.47 d-e	18.15 b-e
'Whittaker'	60.17 l	3.09 d	13.52 g-i	34.75 n-p	14.14 a-g	22.44 j-k	1.01 n	26.52 f-k
'Winona'	51.77 f-h	3.23 l-n	11.22 c-g	30.73 g-n	11.34 a-d	11.39 d-f	0.79 i-k	16.07 a-d
Plum Control	66.00 n	3.18 g-j	8.69 a-b	25.14 b-f	13.45 a-g	9.89 c-e	0.62 h-i	16.71 a-d
Apricot Control	66.27 n	3.26 m-n	13.05 f-i	44.97 r	13.41 a-g	42.96 m	1.27 p	45.01 n

[z]Mean separations within columns based on 5% Tukey's HSD test.

'Suda' had significantly lower levels of soluble solids (47.13°Brix) than all other tart cherries, followed by 'Mesabi' (51.87°Brix); a grouping of 'Bali', 'North Star', 'N87155' and the cherry control; 'Meteor' had the highest level (65.5°Brix; Table 1). Similarly, the plum jams 'Superior' (47.53°Brix) and 'Alderman' (48.73°Brix; Table 1) had the significantly lowest soluble solid levels, followed by a large grouping of 13 plum cultivars and then 'Stanley' (56.77°Brix); 'South Dakota', 'Whitaker' and 'Winona' (51.77-60.17°Brix); 'La Crescent' and the plum control (65.83-66°Brix; Table 1).

The mean pH for the plum cultivar jams tested ranged from pH=2.95 ('Underwood') to pH=3.56 ('Stanley'; Table 1). For tart cherry jams, the mean pH ranged from 3.08 ('Suda') to 3.19 ('Mesabi'; Table 1). Thus, the largest range in pH occurred in the plums. The tart cherry control had a mean pH=3.14 which differed significantly from the tart cherries 'Meteor', 'Mesabi' and 'Suda' and the majority of plum jams, except for 'Hennepin', M598, 'Red Coat', 'South Dakota', and 'Superior' (Table 1). The plum jam control had a mean pH of 3.18 and differed significantly from the tart cherry 'Suda' and the plums 'Compass', 'Gracious', 'Hazel', 'La Crescent', 'Monitor', 'Mount Royal', 'Opal', 'Stanley', 'Superior', 'Todd', 'Toka', 'Underwood', 'Whittaker', and 'Winona' (Table 1).

Titratable acidity means ranged from 6.52 g/L ('Compass' plum), to 19.49 g/L ('Monitor' plum; Table 1); again the largest range in values occurred in the plums rather than the tart cherries. Only 'Bali' (10.26 g/L) differed significantly for titratable acidity from other tart cherries; 'Meteor' (10.69 g/L) overlapped with both 'Bali' and the remaining tart cherry jams (Table 1). Plums 'Alderman', 'Compass', 'La Crescent', 'Mount Royal', 'Opal', 'Pipestone', 'Red Coat', 'Stanley' and the plum control had the significantly lowest levels of titratable acidity of all jams (Table 1). The significantly highest levels of titratable acidity were found in 'Bounty', 'Monitor', 'South Dakota', 'Todd', 'Toka', 'Underwood', 'Whitaker' plum jams and the apricot control (Table 1); this group also included tart cherry jams of 'Mesabi', 'North Star', 'Suda' and the cherry control.

Lightness of color ranged from the significantly darkest of L*=19.71 ('North Star' tart cherry) to the lightest with L*=44.97 (apricot control; Table 1). The 'North Star' L* value overlapped with tart cherry 'Suda', the cherry control, plums 'Compass', 'Hennepin', 'Mount Royal', 'Opal', 'Pipestone', 'Stanley', 'Todd', 'Underwood' and the plum control (Table 1). The light apricot control L* value was not significantly different from 'Superior' (Table 1).

Chromaticity coordinates for green-red ranged from low of a*=9.12 or the "greenest" color ('North Star' tart cherry), which overlapped with 14 other jam accessions, to an increased color saturation (the "reddest" color) of a*=30.69 ('Meteor' tart cherry; Table 1) which overlapped in significance with 'Mesabi' and 'Suda' tart cherries as well as plums MN 598, 'Mount Royal', 'Red Coat', and 'Superior'. Jams made from all other accessions had intermediate a* values. Blue to yellow chromaticity coordinates ranged from the lowest color saturation ("bluest") of b*=2.04 ('North Star' tart cherry) along with ten other cultivars (cherry control and 'Alderman' tart cherries; plums 'Compass', 'Hennepin', 'Mount Royal', 'Opal', 'Pipestone', 'Stanley', 'Todd' and the plum control; Table 1). The yellowest or least coloration saturation chromaticity coordinates occurred with the apricot control (b*=42.96) and 'Superior' plum (b*=40.05; Table 1).

Hue angles (H_{ab}*) ranged from 0.22 ('North Star' cherry) to 1.10 ('South Dakota' plum; Table 1). Within tart cherry jams, 'North Star' was significantly different than both 'Suda' and the Cherry Control whereas all others differed from these three. Among the plum jams, 'Stanley' and 'Mount Royal' H_{ab}* values were statistically similar, followed by 'Compass', 'Alderman', 'Todd', 'Opal', 'Underwood' and all of the others in varying classes of significance (Table 1).

The significantly lowest chrome (C_{ab}*) values occurred in 'North Star' cherry and 'Compass', 'Todd', 'Pipestone', and 'La Crescent' plums. Among the highest C_{ab}* were 'Meteor' cherry, MN598, and 'Superior' plums (Table 1).

Sensory Evaluations. There were no significant panel differences (P>0.05) for fruit pieces, flavor, off-flavor, sweetness, color and overall quality. Thus, for each of these factors, sensory evaluation panels 1-2 data were pooled. The remaining factors (spreadability, texture, bitterness) had significant panel effects (P≤0.001) and were not pooled but analyzed separately for panels 1 and 2. Mean separation tests were carried out for panel 1 means but not panel 2 due to the fact that some jams were only tasted once by panel 2. Jams (genotypes), however, were significantly different ($P \leq 0.001$) for all factors.

For fruit pieces, there was a significant panel x jam interaction (P=0.027). Mean ratings for the presence of fruit pieces in the jams ranged from 2.51-2.79 ('Opal' and 'Superior' plums, respectively) to 8.71 ('Bounty' plum; Table 2). 'Opal' and 'Superior' did not differ for fruit pieces whereas 'Bounty', 'Com-

Table 2. Mean tart cherry and plum jam ratings from two sensory evaluation panels (pooled) for fruit pieces, flavor, off-flavor, sweetness, color and overall quality (10-point scale).

Cultivar	Fruit Pieces	Flavor	Off Flavor	Sweetness	Color	Overall Quality
'Bali'	6.43 a-e[z]	5.96 a[z]	0.93 a[z]	6.46 b[z]	6.75 a-f[z]	6.19 a-e[z]
'Mesabi'	4.74 a-e	7.31 a	1.21 a-b	6.24 a-b	8.03 b-i	6.73 c-e
'Meteor'	6.63 a-e	7.46 a	1.80 a-d	6.94 b	7.31 a-i	6.41 b-e
N81755	6.09 a-e	6.52 a	1.29 a-c	6.93 b	7.37 a-i	5.18 a-e
'North Star'	5.22 a-e	7.49 a	1.31 a-c	6.09 a-b	8.21 e-i	8.06 e
'Suda'	4.81 a-e	7.14 a	1.67 a-d	5.70 a-b	8.94 g-i	4.87 a-e
Cherry Control	3.57 a-b	6.44 a	2.01 a-d	6.25 a-b	9.09 h-i	6.55 b-e
'Alderman'	3.62 a-b	6.28 a	1.35 a-c	6.44 b	7.31 a-i	6.54 b-e
'Bounty'	8.71 e	6.75 a	4.48 b-d	3.18 a	5.91 a	2.99 a
'Compass'	7.07 b-e	6.39 a	1.34 a-c	7.13 b	9.28 i	6.52 b-e
'Gracious'	4.16 a-d	6.96 a	1.29 a-c	6.17 a-b	6.22 a-e	5.97 a-e
'Hazel'	7.14 b-e	6.52 a	1.87 a-d	5.35 a-b	8.11 c-i	5.08 a-e
'Hennepin'	4.84 a-e	6.94 a	3.66 a-d	5.55 a-b	8.45 f-i	4.28 a-d
'La Crescent'	3.37 a-b	5.59 a	4.71 c-d	7.04 b	5.74 a	4.65 a-d
MN 598	3.26 a-b	7.26 a	2.28 a-d	5.59 a-b	8.18 d-i	6.12 a-e
'Monitor'	4.77 a-e	7.48 a	1.94 a-d	4.99 a-b	6.13 a-d	5.69 a-e
'Mount Royal'	5.86 a-e	6.14 a	1.67 a-d	6.46 b	9.06 h-i	6.60 b-e
'Opal'	2.51 a	5.52 a	2.71 a-d	6.61 b	8.14 c-i	4.56 a-d
'Pipestone'	3.71 a-c	6.65 a	2.66 a-d	6.32 a-b	7.18 a-h	5.77 a-e
'Red Coat'	3.83 a-c	6.95 a	2.48 a-d	4.49 a-b	8.93 g-i	5.48 a-e
'South Dakota'	8.11 d-e	6.86 a	3.49 a-d	5.40 a-b	5.94 a-b	3.76 a-c
'Stanley'	7.85 c-e	6.28 a	1.10 a-b	5.90 a-b	8.53 f-i	5.12 a-e
'Superior'	2.79 a	6.79 a	3.11 a-d	5.03 a-b	6.67 a-f	5.19 a-e
'Todd'	5.34 a-e	6.45 a	2.78 a-d	5.86 a-b	9.18 h-i	5.48 a-e
'Toka'	6.43 a-e	7.48 a	2.33 a-d	6.73 b	6.96 a-g	6.09 a-e
'Underwood'	4.23 a-d	7.62 a	5.01 d	5.60 a-b	8.03 c-i	3.38 a-b
'Whittaker'	7.40 b-e	7.12 a	1.90 a-d	4.53 a-b	5.94 a	5.47 a-e
'Winona'	6.56 a-e	7.72 a	3.12 a-d	5.64 a-b	6.10 a-c	3.97 a-c
Plum Control	5.42 a-e	5.98 a	1.71 a-d	6.73 b	8.23 e-i	6.62 b-e
Apricot Control	4.29 a-d	6.93 a	1.37 a-c	6.89 b	5.79 a	7.33 d-e

[z]Mean separations within columns based on 5% Tukey's HSD test.

pass', 'Hazel', 'South Dakota', 'Stanley', 'Whittaker' plums differed significantly. All other jams overlapped with one group and/or the other. None of the tart cherry cultivar jams differed significantly from each other or the control (Table 2). The mean rating for fruit pieces was slightly more variable for the plum cultivars (Table 2). However, none of the plum cultivars significantly differed from the controls (Table 2). The apricot control had statistically identical levels of fruit pieces as the cherry and plum controls.

There were no significant differences between jam types for flavor (P=0.17) or the flavor x panel interaction (P=0.432); the mean, pooled jam flavor =6.7. However, the means are displayed to show the minor but nonsignificant differences in flavor values. Mean flavor ratings ranged from 5.52 ('Opal' plum) to 7.72 ('Winona' plum; Table 2).

In contrast with the flavor ratings, off-flavor ratings were significantly different (P=0.001) although both panels and the off-flavor ratings x panel interaction were not. Mean off-flavor ratings ranged from 0.93 ('Bali' tart cherry) to 5.01 ('Underwood' plum; Table 2) – only these two jam differed significantly for this rating. All three controls had statistically similar off-flavor ratings and overlapped with all other jams. Similarly, the plum control did not significantly differ from any of the other jams for off-flavor (Table 2). There were very few significant differences between cultivars for off flavor. Jam made from 'Bali' tart cherry was significantly different than 'Bounty', 'La Crescent' and 'Underwood' plums (Table 2). In addition, 'Underwood' jam was significantly different than N87155, 'North Star', 'Alderman', and 'Stanley' for off-flavor (Table 2).

Sweetness ratings were significant (P=0.002) although panels and the interactions were not. Mean sweetness ratings ranged from 3.18 ('Bounty' plum) to 7.13 ('Compass' plum; Table 2) and jams from these two cultivars were significantly different. The majority of cultivar jams were not significantly different for sweetness (Table 2). However, 'Bounty' jam was significantly different from 'Bali', 'Meteor', N87155, 'Alderman', 'Compass', 'La Crescent', 'Mount Royal', 'Toka', and the plum control (Table 2).

Jam differed significantly for color ratings ($P \leq 0.001$) although the jam x panel interaction was not. Mean ratings for color ranged from 5.74 ('La Crescent' plum) to 9.28 ('Compass' plum; Table 2). The majority of cultivar jams were not significantly different for color (Table 2). However, 'Bounty, 'La Crescent', and 'Whittaker' plums were significantly different than tart cherries 'Mesabi', 'North Star', 'Suda', the cherry control; plums 'Compass', 'Hazel', 'Hennepin', MN598, 'Mount Royal', 'Opal', 'Red Coat', 'Stanley', 'Todd' and 'Underwood' (Table 2). In addition, 'Compass' plums also significantly differed from 'Bali' tart cherry, and plums 'Gracious', 'Monitor', 'Pipestone', 'South Dakota', 'Superior', 'Toka', and 'Winona' (Table 2).

Sensory evaluation ratings of overall quality for the jams were significantly different between types ($P \leq 0.001$), although panels and the interaction were not. Mean ratings for overall quality ranged from 2.99'(Bounty' plum) to 8.06 ('North Star' tart cherry; Table 2). Mean overall quality ratings for the majority of jams were not significantly different from each other (Table 2). 'North Star' jam was significantly different from 'Bounty', 'Hennepin', 'La Crescent', 'Opal', 'South Dakota', 'Underwood', and 'Winona' (Table 2). Similarly, 'Bounty' jam significantly differed for overall quality from 'North Star', 'Mesabi', 'Meteor', the cherry control, 'Alderman', 'Compass', 'Mount Royal' and the plum control (Table 2). Finally, 'Mesabi', 'South Dakota' and 'Winona' jams were significantly different than 'Underwood' (Table 2).

For panel 1, bitterness ratings ranged from 0.69, 'Toka', to 7.15, 'Bounty' (Table 3). For the most part, jam means for the bitterness rating in panel 1 did not significantly differ from each other (Table 3). However, 'Toka' jam mean rating for bitterness was significantly different than 'Bounty' and 'Under-

Table 3. Mean tart cherry and plum jam ratings for spreadability, texture and bitterness ratings on a 0 to 10 scale, separated by panel.

	Bitterness		Spreadability		Texture	
Cultivar	Panel 1	Panel 2	Panel 1	Panel 2	Panel 1	Panel 2
'Bali'	2.14 a-b[z]	0.94	3.63 a-f[z]	6.67	2.73 a-b[z]	4.92
'Mesabi'	2.61 a-b	1.99	4.37 a-f	7.25	3.54 a-c	7.78
'Meteor'	1.80 a-b	3.07	4.34 a-f	5.66	2.03 a-b	5.40
N87155	2.72 a-b	2.14	4.32 a-f	3.59	2.79 a-b	5.19
'North Star'	2.21 a-b	1.31	4.12 a-f	6.56	4.56 a-e	5.47
'Suda'	2.18 a-b	2.03	0.88 a	1.63	1.56 a	1.57
Cherry Control	2.39 a-b	1.76	5.63 d-f	8.07	3.32 a-c	6.21
'Alderman'	2.34 a-b	0.72	2.30 a-d	5.46	2.54 a-b	4.28
'Bounty'	7.15c	2.53	6.19 f	8.50	8.59 e	8.15
'Compass'	0.88 a-b	0.20	2.77 a-e	2.61	4.41 a-d	1.96
'Gracious'	2.11 a-b	0.26	6.38 e-f	7.84	5.11 a-e	7.97
'Hazel'	4.08 a-c	1.31	4.68 b-f	4.41	4.27 a-d	4.67
'Hennepin'	3.49 a-c	2.66	5.25 c-f	7.75	6.12 b-e	7.69
'La Crescent'	2.24 a-b	2.35	2.12 a-d	2.09	2.27 a-b	3.46
MN 598	2.68 a-b	1.80	4.64 b-f	7.42	4.06 a-d	8.01
'Monitor'	2.49 a-b	1.08	3.92 a-f	6.60	5.40 a-e	6.34
'Mount Royal'	2.66 a-b	0.87	5.63 d-f	6.27	4.10 a-d	6.56
'Opal'	2.24 a-b	1.39	4.05 a-f	4.14	2.69 a-b	3.57
'Pipestone'	2.78 a-c	1.18	1.91 a-c	4.75	3.23 a-c	5.21
'Red Coat'	4.10 a-c	1.85	3.78 a-f	4.64	3.66 a-c	4.62
'South Dakota'	3.60 a-c	1.47	6.52 f	6.83	8.14 d-e	7.42
'Stanley'	2.67 a-b	1.05	4.56 a-f	6.96	6.11 b-e	4.44
'Superior'	3.70 a-c	0.52	1.66 a-c	5.85	2.17 a-b	4.51
'Todd'	1.86 a-b	3.73	4.73 c-f	6.60	5.75 b-e	5.38
'Toka'	0.69 a	1.39	4.59 b-f	7.08	5.00 a-e	7.73
'Underwood'	5.37 b-c	1.76	1.04 a-b	2.03	2.38 a-b	1.76
'Whittaker'	2.50 a-b	5.20	4.64 b-f	6.63	6.98 c-e	5.78
'Winona'	1.89 a-b	3.14	3.70 a-f	6.76	7.88 d-e	5.23
Plum Control	1.79 a-b	1.36	5.19 c-f	7.16	3.69 a-c	6.47
Apricot Control	1.64 a-b	1.36	4.04 a-f	6.71	3.41 a-c	6.02

[z] Mean separations within columns based on 5% Tukey's HSD test.

wood' jam mean rating (Table 3). 'Bounty' jam rating differed significantly for bitterness from the majority of the other types except for 'Hazel', 'Hennepin', 'Pipestone', 'Red Coat', 'South Dakota', 'Superior', and 'Underwood' jams (Table 3). For panel 2, mean ratings for bitterness tended to be lower than ratings in panel 1 and ranged from 0.20, 'Compass', to 5.20, 'Whittaker' (Table 3).

Mean spreadability ratings in panel 1 ranged from 0.88 for 'Suda' to 6.52 for 'South Dakota' (Table 3). In contrast, mean spreadability ratings for panel 2 ranged from 1.63 for 'Suda' to 8.50 for 'Bounty' (Table

3). Mean separation tests were carried out for panel 1 but not for panel 2 due to too few replications in panel 2. 'Suda' jam's mean spreadability rating differed significantly from the cherry control, 'Bounty', 'Gracious', 'Hazel', 'Hennepin', MN598, 'Mount Royal', 'South Dakota', 'Todd', 'Toka', 'Whittaker' and the plum control (Table 3). In addition to 'Suda', 'Bounty' jam's mean spreadability rating was significantly different than 'Alderman', 'Compass', 'La Crescent', 'Pipestone', 'Superior' and 'Underwood' (Table 3). 'Alderman' jam also was significantly different from 'Gracious', 'Pipestone', 'Superior' and 'Underwood' (Table 3). The cherry control also was significantly different from 'Gracious', 'Pipestone', 'Superior' and 'Underwood' (Table 3). Besides differences already mentioned, 'Gracious' jam mean spreadability rating was significantly different from 'La Crescent', 'Pipestone', 'Superior', and 'Underwood' (Table 3). 'Underwood' mean spreadability rating also differed significantly from 'Hennepin', 'Todd', the plum control as well as those mentioned above (Table 3).

Mean texture ratings in panel 1 ranged from 1.56 for 'Suda' to 8.59 for 'Bounty' (Table 3). Similarly, in panel 2 mean ratings ranged from 1.57, 'Suda', to 8.15, 'Bounty' (Table 3). In panel 1, 'Suda' jam was significantly different for texture than 'Bounty', 'Hennepin', 'South Dakota', 'Stanley', 'Todd', 'Whittaker' and 'Winona' (Table 3). In panel 1, mean texture ratings for 'Bali', 'Meteor', N87155, 'Alderman', 'La Crescent', 'Superior' and 'Underwood' jams were all significantly different than 'Bounty', 'South Dakota', 'Whittaker' and 'Winona' (Table 3). In panel 1, 'Bounty' was significantly different for texture than the majority of other jams except for 'North Star', 'Gracious', 'Hennepin', 'Monitor', 'South Dakota', 'Stanley', 'Toka', 'Whittaker', 'Winona', and the plum control (Table 3). Finally, the plum control was also significantly different from 'South Dakota' and 'Winona' (Table 3). Correlations for rating factors color, fruit pieces, flavor, off-flavor, overall quality, and

Table 4. Plum and tart cherry jam correlations (pooled for panel; r values), between color, fruit pieces, flavor, off flavor, overall quality (quality), purchase, soluble solids (SS), titratable acid (TA), L*, a*, b*, H_{ab}, and C_{ab}.[z]

	Color	Fruit Pieces	Flavor	Off Flavor	Sweet.	Quality	Purchase	SS	pH	TA	L*	a*	b*	H_{ab}	C_{ab}
Color	1.00														
Fruit Pieces	-0.04	1.00													
Flavor	-0.04	0.01	1.00												
Off Flavor	-0.01	0.02	0.01	1.00											
Sweet.	-0.05	-0.02	0.10*	-0.06	1.00										
Quality	0.00	-0.10*	0.26*	-0.36*	0.33*	1.00									
Purchase	-0.02	-0.13*	0.18*	-0.25*	0.26*	0.74*	1.00								
SS	-0.23*	0.19	0.05	-0.05	0.18	0.10	0.04	1.00							
pH	0.09	0.21*	-0.09	-0.12	0.04	0.02	0.10	0.17	1.00						
TA	-0.24	-0.18	0.18	-0.20	-0.23	0.05	-0.10	-0.22	-0.62*	1.00					
L*	-0.33*	0.01	0.11	0.07	-0.14	-0.06	-0.05	0.18	-0.19	0.21	1.00				
a*	0.18	-0.15	-0.11	-0.09	-0.06	0.01	0.16	-0.25*	0.09	-0.05	0.16	1.00			
b*	-0.32*	-0.01	0.12	0.00	-0.10	0.03	0.06	0.26*	-0.11	0.25	0.94	0.18	1.00		
H_{ab}	-0.44*	0.14	0.18	0.08	-0.09	-0.08	-0.11	0.35*	-0.25*	0.31*	0.84*	-0.29*	0.81*	1.00	
C_{ab}	-0.13	-0.11	0.03	-0.07	-0.10	0.05	0.16	0.08	0.00	0.16	0.75*	0.67*	0.84	0.42*	1.00

[z]An asterisk next to correlation (r) values indicates a significant correlation ($p<0.05$).

purchase as well as chemical analysis factors soluble solids, pH, total acid, L*, a* and b* were mostly close to zero and not statistically significant ($p \geq 0.05$). The sweetness rating was significantly positively correlated with flavor (r=0.10, $p<0.05$) (Table 4). Overall quality was negatively correlated with fruit pieces (r=-0.10, p value <0.05) and off-flavor (r=-0.36, p value < 0.001) (Table 4). Overall quality was also positively correlated with flavor (r=0.26, p value < 0.001) and sweetness (r=0.32, p value < 0.001) (Table 4). Desire to purchase was negatively correlated with fruit pieces (r=-0.13, p value < 0.01) and off-flavor (r=-0.25, p value < 0.001) (Table 4). Desire to purchase was also positively correlated with flavor (r =0.18, p value <0.001), sweetness (r =0.26, p value < 0.001) and overall quality (r=0.74, p value < 0.001) (Table 4). Soluble solids were negatively correlated with color (r=-0.21, p value <0.05) and positively correlated with overall quality (r=0.11, p value <0.05) (Table 4). Total acid was negatively correlated with sweetness (r=-0.26, p value <0.05) and pH (r=-0.62, p value < 0.001) (Table 4). The hue variable L* was negatively correlated with color (r=-0.34, p value < 0.01) (Table 4). The hue variable a* was negatively correlated with soluble solids (r=-0.25, p value < 0.05) (Table 4). Finally, the hue variable b* was negatively correlated with color (r=-0.33, p value < 0.01) and purchase (r =-0.26, p value <0.05) while b* was positively correlated with L* (r=0.94, p value < 0.001) (Table 4).

Correlations between spreadability, bitterness and texture were performed separately due to the fact that panels were a significant factor in the ANOVA analysis. For panels 1 and 2, there were significant positive correlations between texture and spreadability: r =0.33, p value < 0.001, r =0.54, p value <0.001, respectively. Panel 1 also had significant positive correlations between texture and bitterness (r =0.25, p value < 0.001) (Table 5).

Chi-square. Chi-square tests for each jam type's purchase rating (1:1 expected ratio of purchase to not purchase) showed that for the majority of cultivars, the 1:1 χ^2 did not differ significantly from expected. Only 'North Star', 'Bounty', 'Underwood', plum and apricot controls differed significantly from the expected ratios. For 100% of individuals who tasted 'North Star' (χ^2=5, p value ≤ 0.05) and 'Bounty' (χ^2 =4.5, p value ≤ 0.05) jams, they stated that they would purchase these jams in a commercial setting. In contrast, 100% of individuals who tasted 'Underwood' jam (χ^2=4.5, p value ≤ 0.05) stated they would not purchase it. In contrast, 77% of individuals stated they would purchase the plum control (χ^2 =8.9, p value ≤ 0.01) while 93% said they would purchase the apricot control (χ^2=23.0, p value ≤0.001).

Chemical analysis PCA. The first two principal components for the chemical analysis data, PC1 and PC2, had eigenvalues ≥ 2.0 which summarily accounted for 70.1% of the variation. PC1 accounted for the majority

Table 5. Bitterness, spreadability and texture correlations (r values), separated for panels 1 and 2.[z]

	Spreadability		Bitterness		Texture	
	Panel 1	Panel 2	Panel 1	Panel 2	Panel 1	Panel 2
Spreadability	1.00	1.00				
Bitterness	0.10	0.10	1.00	1.00		
Texture	0.33*	0.54*	0.25*	0.07	1.00	1.00

[z]An asterisk indicates a significant correlation (p<0.05).

of the variation (44.1%) and was positively associated with all factors (a*, SS, C_{ab}*, B*, L*, H_{ab}*, titratable acid) except pH (Fig. 1A). PC2 accounted for 26.1% of the variation had negative association with pH, a*, SS, C_{ab}*, and B*, neutral for L* and positively associated with H_{ab}* and titratable acid (Fig. 1A). There was nearly equal dispersal among jam cultivars for positive and negative associations with PC1 and PC2, although 'Monitor' plum jam had the highest positive association with PC2 whereas 'Superior' plum and the Apricot Control were the highest for PC1.

Sensory Evaluation Ratings PCAs. For all traits analyzed, with the exception of bitterness, spreadability and texture (due to their significance; see ANOVAs), the first two principal components (PC1, PC2) had eigenvalues ≥ 1.0 which accounted for 73.6% of the variation among Panels 1 and 2. PC1 accounted for 41.5% of the variation and was positively associated with ratings for fruit pieces, color, sweetness, off flavor and overall quality but negatively associated with flavor (Fig. 1B). Fruit pieces and color as well as sweetness, flavor and overall quality vectors were closely clustered together, respectively, on the PCA biplot (Fig. 1B). Fruit pieces and color ratings were positively associated with PC2 whereas sweetness, overall quality, off flavor and flavor were negatively associated with PC2 (Fig. 1B). Approximately half of the tart cherry and plum jams were positively associated with PC1 (Fig. 1B). In particular, the Cherry Control and 'Compass' plum jams had the highest positive correlation with PC1. 'Opal' and 'La Crescent' plum jams had the greatest negative association with PC2 whereas 'Whittaker' plum jam had the highest positive association (Fig. 1B).

PCA analysis of the Panel 1 sensory evaluation for bitterness, spreadability and texture, resulted in the first two principal components (PC1, PC2) with eigenvalues ≥ ~1.0, which accounted for 80.9% of the variation. PC1 accounted for 48.5% of the variation and was positively associated with ratings for spreadability and texture but not bitterness (Fig. 1C). PC2 accounted for 32.5% of the variation with positive associations for bitterness and spreadability but not texture (Fig. 1C). All vectors were widely distributed with 'Compass' (PC2) and 'Monitor' (PC1) plum jams being the most positive outliers.

Panel 2 PCA sensory evaluation for bitterness, spreadability and texture, also resulted in the first two principal components (PC1, PC2) with eigenvalues ≥ ~1.0, accounting for 87.7% of the variation. PC1 accounted for 55.1% of the variation and was positively associated with ratings for spreadability, texture and bitterness (Fig. 1D); spreadability and texture were identical. PC2 accounted for 32.6% of the variation with positive associations for bitterness while barely negative associations occurred with spreadability and texture (Fig. 1D). All vectors were widely distributed as positive PC1 values with the notable exceptions of 'Hennepin', 'Whittaker', 'Compass', 'Toka' and 'Underwood' plum jams being the most negative PC1 outliers.

Discussion

There was a wide range of genetic variation within all chemical, physical and sensory characteristics evaluated in the tart cherry and plum jams made from the winter-hardy genotypes. The range in soluble solids (°Brix) or total carbohydrate content in jams due to fructose, glucose and sucrose for tart cherry and plum jams (47.13-66.37 °Brix; Table 1) are nearly identical to that reported for winter hardy apricots, *P. armeniaca* (48.87-68.47 °Brix; Kostick et al., 2017), but wider in range than thornless and Marion blackberries (65.4-66.4 °Brix; Halat et al., 1997). However, two Romanian tart cherry hybrids had lower soluble solids (18.7-19.5 °Brix; Budan et al., 2013) than our findings. Likewise, strawberry jams were reported to have 46 °Brix (Sandulachi and Tatarov, 2012), which is similar to the lower values of tart cherry 'Suda' (47.13 °Brix) and some additional plum jams reported herein (Table 1). Only 'La Crescent' plum jam, the plum and apricot controls had soluble solid levels

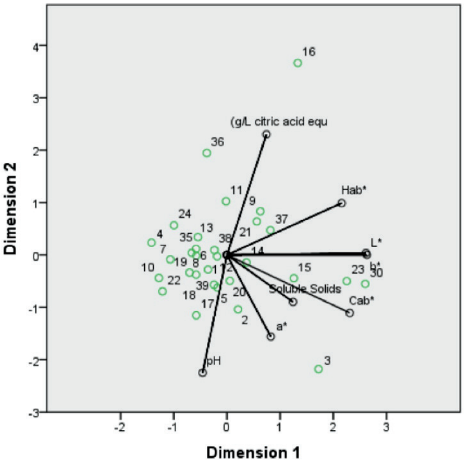

Fig. 1A

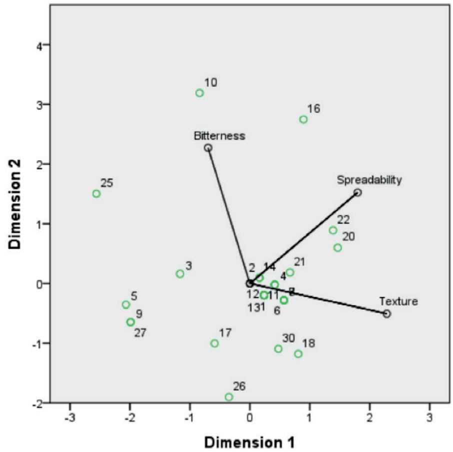

Fig. 1C

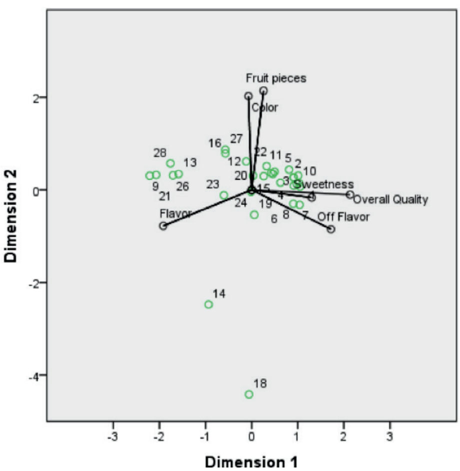

Fig.1B

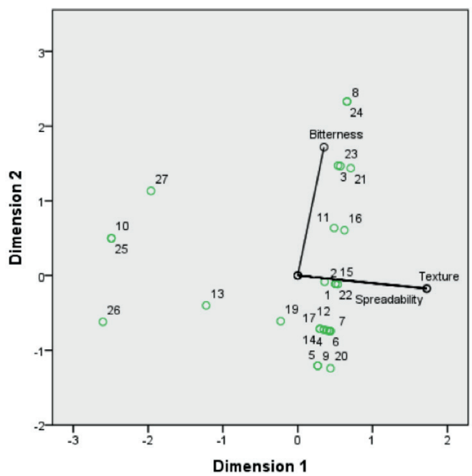

Fig. 1D

Fig. 1. Biplots from principal components analyses (PCA) measuring biochemical and sensory variables for 30 tart cherry and plum jams. The jams are represented by numbers (1-30), based on presentation in data tables (*cf.* Tables 1-3), e.g. 1='Bali', 2='Mesabi', 3='Meteor', 4=N87155, 5='North Star', 6='Suda', 7=Cherry Control, 8='Alderman', 9='Bounty', 10='Compass', 11='Gracious', 12='Hazel', 13='Hennepin', 14='La Crescent', 15=MN598, 16='Monitor', 17='Mt. Royal', 18='Opal', 19='Pipestone', 20='Red-Coat', 21='South Dakota', 22='Stanley', 23='Superior', 24='Todd', 25='Toka', 26='Underwood', 27='Whittaker', 28='Winona', 29=Plum Control, 30=Apricot Control. Component loadings are adjusted to the scale of the objects. The variables are: (A) mean soluble solids, pH, g/L citric acid equivalent (titratable acidity), L*a*b* color space or CIELAB (where L* indicates lightness; a* and b* are the chromaticity coordinates), hue angle ($H_{ab}^* = \mathrm{Arctan}(\frac{b^*}{a^*})$) and chrome ($C_{ab}^* = \sqrt{a^{*2} + b^{*2}}$); mean tart cherry and plum jam ratings from sensory evaluation panels (B) pooled for panels 1 and 2 for fruit pieces, flavor, off-flavor, sweetness, color and overall quality (10-point scale); spreadability, texture and bitterness ratings on a 0 to 10 scale, separated by panel: (C) Panel 1; (D) Panel 2.

as high as blackberries. Clearly the flesh of most winter-hardy Minnesota plums and tart cherries is either lower in soluble solids and/or it cooks down quicker than contrasting blackberry jam types. All remaining plum and tart cherry jams were much lower, particularly tart cherry 'Suda' (Table 1). The majority of tart cherry and plum jams had <60% soluble solids (°Brix), the minimal level required by Codex Alimentarious Standard (CODEXSTAN, 2009), similar to apricot (Kostick et al., 2017; Touati, et al., 2014) and quince jams (Ferreira et al., 2014). Since sucrose (sugars) in jams aids in increasing soluble solids as well as providing chemical, microbiological and physical stability and aids in pectin gelling (Culetu, et al., 2014), those jams with decreased levels of soluble solids might benefit from additional sucrose. With the use of citric acid, the usual range for pH of jams during manufacturing is 2.9 – 3.2 for the best gelling, shelf life and flavor (Herbstreith and Fox, 2011) and minimizing microorganism growth, particularly fungi (Gibson and Hocking, 1997), although Culetu et al. (2014) reported that pH=3.5 was where "gel formation by pectins takes place". This range of pH is more commonly used in pectin chemistry to achieve gelling and was similar to previous findings for blackberry (pH=3.09-3.22; Halat, et al., 1997) and low sucrose strawberry jams (pH=3.36; Sandulachi and Tatarov, 2012), but lower pH than that reported for sugar-free Romanian plum jams (pH=3.39 – 4.05; Culetu, et al., 2014). Our jam-making process lowered acidity by using freshly squeezed lemon juice, producing a range from pH=2.95 ('Underwood' plum) to pH=3.56 ('Stanley' plum; Table 1). Several plums produced jams with pH>3.2, i.e. 'Meteor' and 'Hazel' (pH=3.22), 'Winona' (pH=3.23), 'Opal' and the apricot control (pH=3.26), 'Mount Royal' (pH=3.33), 'Compass' (pH=3.36), and 'Stanley' (pH=3.56; Table 1). However, the spreadability values were not consistently low for these high pH jams, as would be expected with inadequate gelling, ranging from 2.61 ('Compass' plum, Panel 2) to 6.96 ('Stanley' plum, Panel 2; Table 3); the means were also statistically similar to those from lower pH jams (pH<3.2; 0.88, 'Suda' tart cherry, Panel 1 to 8.5, 'Bounty' plum, Panel 2; Table 3). Thus, crop and genotypic differences may influence the pH level for adequate gelling, confirming the recommended pH differences noted above.

Titratable acidity (g/L citric acid equivalent) levels in the tart cherry and plum jams matched those from previous studies for apricots (Aslanova et al., 2010; Kostick et al., 2017; Touati et al., 2014). Low pH levels in many of the tart cherry and plum jams might increase protection against microorganisms during storage (Touati et al., 2014).

As consumers use jam appearance and color to determine quality and, thus, purchase choice (Culetu, et al., 2014; Lawless and Heymann, 2010), our tested jams were stored appropriately to maximize color stability (García-Viguera et al., 1999; Kostick et al., 2017). 'Meteor' tart cherry jam had the highest values for all color parameters, L*, a*, b*, h_{ab}* and C_{ab}* (Table 1). High values of L* or the lightness index of jam color intensity also are involved in non-enzymatic browning and many of the jams with high L* values also had low pH levels, e.g. 'Meteor' tart cherry (L*=36.10, pH=3.22); MN598 (L*=39.76, pH=3.14), 'Monitor' (L*=35.93, pH=2.98), 'Superior' (L*=43.00, pH=3.12) plums and the apricot control (L*=44.97, pH=3.26; Table 1). However, there was a negative but non-significant correlation (r = -0.19) between L* and pH for all jams (Table 4). While L* is an important consumer purchasing criterion (Touati, et al., 2014), desired L* values vary depending on the fruit flesh coloration. Apricot jams, for example, are more desirable with a lighter color (higher L*; Kostick et al., 2017; Touati et al., 2014) while tart cherry jams are preferred with lower values (darker). For example, 'North Star', 'Suda' and the cherry control had the lowest L* values among the tart cherry jams (Table 1) and the sensory panels ranked these the highest for best color (Table 2), although they were not significantly different due to the high amount of variation. Future jam preparations involving winter-hardy tart cherries and plums would benefit from careful calibration of L* in jams for each crop, optimizing titratable acidity and pH levels for each fruit type as well as recipe modifications to improve jam storage and protection against the development of microorganisms and enzymatic browning from the Maillard reaction (Touati et al., 2014; Wicklund et al., 2005).

Conclusions

Panelists in the sensory evaluations could discern specific differences among the different jam types and then within cultivars for the various traits examined (Tables 2-3). Without exception for the tart cherry jam fruit types, the cultivars overlapped in distribution and significance for all traits evaluated. It should be noted, however, that 'North Star' had the highest score for overall quality and was equivalent to the cherry control for all traits (Tables 2-3). Since only winter-hardy 'Meteor' and 'North Star' are still available commercially in the US or world market (West, 2014), amongst these two cultivars the highest rankings are for 'North Star' jam where 100% of the consumers in both panels said they would purchase this jam (1:1χ^2). Thus, based on cultivar availability and the generated data, *Prunus cerasus* 'North Star' is the best winter-hardy tart cherry for jam making. Both sensory evaluation panels were more discerning among the plums than was evident among the tart cherry jams for differences in fruit pieces, flavor, color and, to a lesser degree, overall quality (Table 2). While 'Suda' had lower mean spreadability and texture values in sensory evaluation panel 1 (Table 3), they overlapped with 'La Crescent' and the apricot control but only for texture in the plum control. 'Underwood' had the highest off-flavor while 'Compass' had the highest sweetness as opposed to 'Bounty' with the lowest (Table 2). Overall, 'Alderman', 'Gracious', 'Hazel' and 'Hennepin' were equivalent to the plum control for most traits evaluated (Tables 2-3). 'Underwood' had the highest off-flavor and, correspondingly, 100% of the panelists (1:1χ^2) would not purchase it. In contrast, 77% of individuals would purchase the plum control. 'Alderman' and 'Superior' plum jams had the lowest °Brix; 'Alderman' was also among the lowest for pH and titratable acidity as well as being comparable to the plum control for the darkest color and statistically similar to tart cherry 'North Star' as well as plums 'Compass', 'Hennepin', 'Mount Royal', 'Opal', 'Pipestone, 'Stanley', and 'Todd' (Table 1). Since only winter-hardy 'Alderman', 'La Crescent', 'Pipestone', 'Superior' and 'Underwood' plums are still commercially available (West, 2014), the best of these plums for jam making would be 'Alderman' and 'Superior'. While both of these are clingstone types with good storage capability along with similar skin and flesh coloration, consumers preferred both equally well.

Acknowledgements

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